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MARYLAND DEPARTMENT OF TRANSPORTATION
STATE HIGHWAY ADMINISTRATION

RESEARCH REPORT

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

KATHARINA A. M. ENGELHARDT
KARA HAWKINS

UNIVERSITY OF MARYLAND CENTER FOR ENVIRONMENTAL SCIENCE
APPALACHIAN LABORATORY

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16. Abstract

Roadsides are managed as mowed turfgrass to prevent erosion, maintain visibility, provide a safety zone for stopped vehicles, and improve aesthetics. Roadside vegetation often needs to be mowed several times each growing season, and in addition to its cost mowing exposes workers to traffic and other hazards, discharges tailpipe gases, and disturbs soil. This study explored the efficacy of using commercially-available grass species that may reduce maintenance costs, yet still provide economic and ecological services such as fast establishment, erosion control, ecosystem benefits, and resilience. A literature review of over 500 journal articles, white papers, reports, and fact sheets and discussions with turfgrass experts produced a list of over 100 graminoid species. A trait-based approach was then used to select a subset of species for evaluation. The final selection included 21 species and cultivars. Each species was given an overall grade (A=Excellent, B=Good, C=Fair, D=Poor, and F=Very poor) reflecting six economic and ecological services. Maryland's standard roadside seed tall fescue received a grade below the median grade. Fine fescues ranked higher than tall fescue owing to lower stature and generally higher resilience. The native grass species Sporobolus, side-oats grama, and purple lovegrass received excellent grades (A or A-) and should be further studied as alternatives to tall fescue. Species that are not recommended for roadsides include Kentucky bluegrass, perennial ryegrass, prairie junegrass, alkaligrass, and zoysia.

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Executive Summary

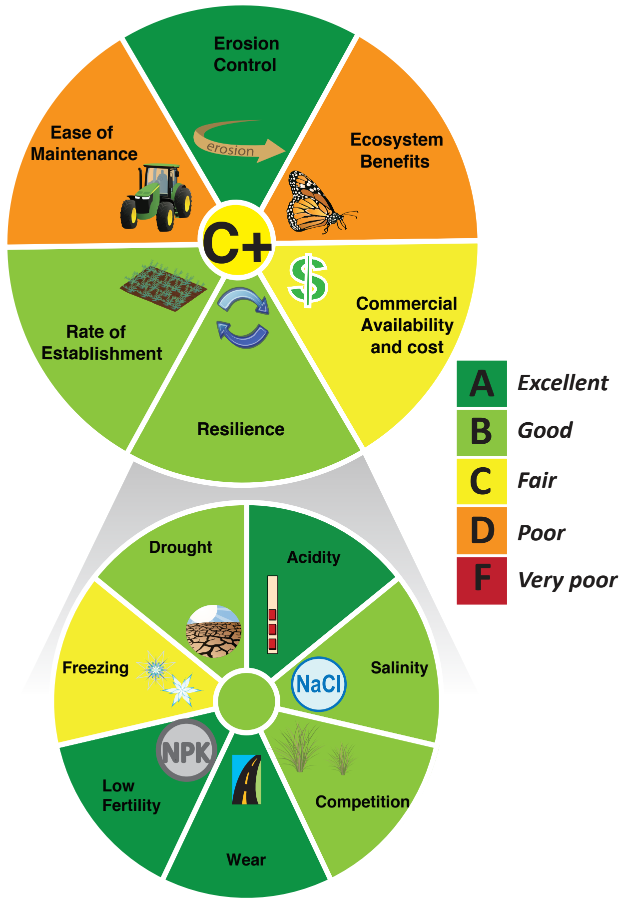
Roadsides are managed as mowed turfgrass to prevent erosion, maintain visibility, provide a safety zone for stopped vehicles, and improve aesthetics. However, roadside vegetation often needs to be mowed several times each growing season, which is expensive and puts equipment operators in danger. Here, we explore grass species that are commercially available and may reduce maintenance costs, yet still provide economic and ecological services such as fast establishment, erosion control, ecosystem benefits, and resilience.

A	*Excellent*
B	*Good*
C	*Fair*
D	*Poor*
F	*Very poor*

Through a literature review of over 500 journal articles, white papers, reports, and fact sheets and detailed discussions with turfgrass experts, we first considered 104 commercially available graminoid species and then used a trait-based approach to select a subset of species for evaluation. We assessed our final selection of 25 species for commercial availability and cost, rate of establishment, ease of maintenance, potential for erosion control, ecosystem benefits, and resilience. Most of the reviewed species are cultivated turfgrasses with known cultivars or ecotypes. Some species are nursery-grown native species that are not developed as turfgrass but are used in native landscaping, grassland restoration, or mine reclamation. We focus solely on graminoids although forbs, such as clovers, may also be used with success along roadsides. Each species was reviewed for six economic and ecological services and then given an overall grade (A=Excellent, B=Good, C=Fair, D=Poor, and F=Very poor). Four grading scenarios were applied to reflect different management priorities: 1. All six services weighted equally; 2. Establishment and maintenance weighted twice as high as the other services; 3. Equal weighting with ecosystem benefits not included in grading; 4. Equal weighting with ecosystem benefits and erosion not included in grading.

We recommend that grass species consistently receiving a B grade or higher with no lower grade in any of the 4 scenarios be tested for suitability along Maryland roadsides. We hypothesize that 9 species are suitable as long as management challenges, which will vary among species and site conditions, are carefully considered.

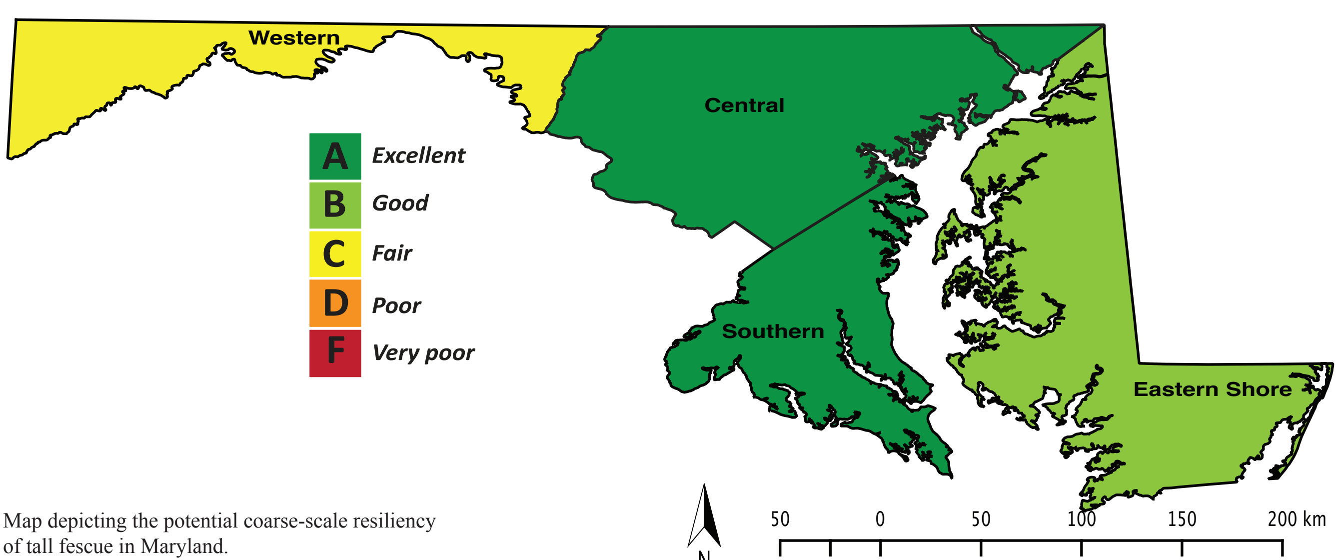
			Equally weighted services				
Species	Cost	Establishment	Maintenance	Erosion	Ecosystem	Resilience	Overall Grade
Sporobolus	100	90	90	100	100	97	96.2 A
Side-oats grama	86	90	90	100	100	91	92.8 A-
Purple lovegrass	55	95	100	100	100	99	91.4 A-
Little bluestem	80	65	100	100	100	93	89.6 B+
Weeping lovegrass	98	95	85	100	65	93	89.3 B+
Blue Grama	66	80	90	100	100	91	87.8 B+
Tufted hairgrass	96	85	82	82	92	84	86.8 B
Hard fescue	63	75	100	88	89	92	84.5 B
Upland bentgrass	67	65	100	95	100	73	83.3 B
Red fescue	75	80	100	85	65	88	82.2 B-
Sheep fescue	61	65	100	88	89	89	82.0 B-
Buffalograss	45	75	80	100	100	89	81.5 B-
Chewings fescue	69	80	100	83	60	86	79.7 C+
Poverty oatgrass	20	95	100	80	85	93	78.8 C+
Tall fescue	72	85	60	100	60	89	77.6 C+
Bermudagrass	60	100	70	100	50	82	77.0 C
Prairie junegrass	87	50	100	60	85	76	76.3 C
Alkaligrass	92	95	20	85	90	71	75.5 C
Zoysia	35	60	100	80	50	90	69.2 D+
Kentucky bluegrass	77	70	65	85	40	69	67.7 D+
Perennial ryegrass	78	100	20	90	30	71	64.8 D



Ecosystem services (above) and Resiliency (below) grading wheels for tall fescue.

Tall fescue is SHA's standard roadside grass owing to its vigorous growth and resilience, yet tall fescue received a grade below the median grade in all four grading scenarios. Fine fescues all ranked higher than tall fescue owing to lower stature and, better ecosystem services, and/or higher resilience. Of the fine fescues, hard fescue ranked highest, receiving a solid B grade across all scenarios. The native grass species Sporobolus, side-oats grama, and purple lovegrass received excellent grades (A or A-) for at least 3 out of the 4 grading scenarios. They are therefore excellent alternative species to the commonly used non-native species. Fine fescues are recommended. Little bluestem, weeping lovegrass, blue grama, tufted hairgrass, and upland bentgrass may be suitable undersome environmental conditions but not under others. Species that are not recommended for roadsides but are currently used in Maryland seed mixes include Kentucky bluegrass and perennial ryegrass in addition to tall fescue. Other assessed grass species not recommended for roadsides because they receive a C or D grade in at least 2 of the 4 scenarios include alkaligrass, buffalograss, prairie junegrass, and zoysia.

We have identified a diversity of native and non-native grass species that are suitable for seeding along Maryland roadsides. Although the assessment and grading of the species was based on a careful literature review that was followed up by extensive discussions with experts, our gradings and rankings of species are effectively hypotheses that need to be tested through field and greenhouse experimentation. Maryland is a diverse state that varies considerably in climate and soil conditions, which will impact establishment, survival, and long-term persistence. The next step therefore is to plant the recommended species in various climatic zones and site conditions to test resilience to a variety of environmental conditions as well as the rankings of ecological services. A further step is to assess some of the grass species that were filtered out owing to their height or lack of information, as well as to consider promising forb species for use along roadsides.



Map depicting the potential coarse-scale resiliency of tall fescue in Maryland.

Symbols courtesy of Integration and Application Network, University of Maryland Center for Environmental Science (ian.umces.edu/symbols/).

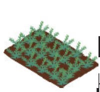
INTRODUCTION and PURPOSE

Turfgrasses are widely used as vegetative ground cover to reduce soil erosion, filter runoff, improve air quality, provide food resources and habitat to native fauna, and to provide surfaces for recreation and aesthetic appeal (Brown and Gorres 2011, Brown et al. 2011, Friell et al. 2012, Uddin and Juraimi 2013). They are therefore used for sports recreation surfaces and lawns as well as in parks, cemeteries, airports, roadsides, and mine reclamation. In the Chesapeake Bay watershed, turfgrass covers over 3,800,000 acres with 23% (1,300,000 acres) located in Maryland (Schueler 2010). In 2005, over 4% (52,000 acres) of the turfgrass acreage in Maryland was distributed on roadside right-of-ways (Schueler 2010).

The State Highway Administration (SHA) of Maryland maintains turfgrasses along highway right-of-ways to provide a clear zone / recover zone as well as an aesthetic landscape to motorists. Mowing also reduces wildlife use of areas near roadsides to decrease risk of vehicle impacts, and reduces fire hazards from roadside vegetation catching on fire. However, the turfgrass seed mixtures currently used in Maryland require frequent mowing in often narrow and congested areas. Thus, maintenance of roadsides remains costly and often places maintenance staff in danger, highlighting the need to identify turfgrasses and seed mixtures that require less maintenance but that will establish rapidly, be resilient in the harsh roadside environment, have neutral or positive effects on ecosystems and watersheds, and are available and affordable through commercial growers.

Using a broad literature review, we evaluated grass species for use along roadsides in Maryland, paying particular attention to commercial cost, rate of establishment, ease of maintenance, potential for erosion control, ecosystem benefits, and resilience. Resilience is multi-faceted and includes tolerance to drought, low fertility, freezing, salinity, acidity, wear, and competition. The literature summarized observational and experimental studies throughout the world; thus, not all studies were relevant to the varied climates found in Maryland. Studies from Maryland and surrounding states were therefore weighted more heavily. Most of the reviewed species are cultivated turfgrasses with known cultivars or ecotypes. Some species are nursery-grown native species that are not developed as turfgrass but are used in native landscaping, grassland restoration, or mine reclamation. We focus solely on graminoids although forbs, such as clovers, may also be used with success along roadsides (Andres and Jorba 2000, Karim and Mallek 2008, Strelkute and Braduliene 2014).

Commercial availability and cost: Seed that is used for roadside turfgrass establishment needs to be commercially available and be affordable. We consider grass species and cultivars as viable candidates for roadside planting if they are currently commercially available, although promising but undeveloped species or cultivars are noted. Ratings are based on cost per acre, which reflects not only the quantity available for purchase but also seed size and recommended seeding rate. We received this information from Chesapeake Valley Seed.



Rate of establishment: Contractors with SHA will get paid only when 95% grass cover has been established. Thus, rapid establishment of turfgrasses is desired for pure economic reasons, as well as for reducing erosion on new cut slopes and roadside fills (Andres and Jorba 2000). We assessed rate of establishment by reviewing germination rate of grass species under laboratory, greenhouse, and field conditions. We also reviewed the literature that monitored percent cover and/or quality through time, including the establishment year.

Ease of maintenance: Vertical growth rate and overall short stature are important traits in roadside vegetation owing to budget constraints that limit the frequency with which the grass is mowed (Brown and Gorres 2011). In addition, turfgrasses that require no fertilization will decrease the need for continued maintenance past establishment therefore reducing long-term maintenance costs. We therefore determined the stature of each species through information provided by nurseries and species fact sheets, and reviewed scientific papers that focused on the performance of species under low-maintenance conditions (Dernoeden et al. 1994, Mintenko and Smith 1999, Brede 2002, Johnson 2000, 2003, Bunderson et al. 2009, Watkins et al. 2011, 2014.

Erosion control: Turfgrasses that produce deep roots and dense sod, and that can increase infiltration capacity will stabilize soils, draw water away from road sides, and decrease run-off, providing erosion control and local nutrient retention. We determined the potential of each species to provide erosion control by reviewing papers that studied rooting depth and sod density under greenhouse and natural conditions (Weaver 1958, Simon and Collison 2002, Bonos et al. 2004, Brown et al. 2010).

Ecosystem benefits: As living organisms, grasses contribute to the functioning of ecosystems. Benefits to ecosystems include erosion control, nutrient retention, plant and animal biodiversity, and habitat for pollinators and wildlife. Wildlife, however, may be a hazard near roadsides and could therefore be viewed as a risk rather than a benefit adjacent to roads. Further from the road, benefits to wildlife could be valued more highly. Many turfgrasses are non-native and were specifically selected for their growth habit. Thus, turfgrasses may be invasive to native habitats and be reducers of native biodiversity. We review these potential positive and negative ecosystem effects paying particular attention to whether species are native or considered to be potentially invasive or weedy.

Resilience: The roadside environment in Maryland is an extreme environment that is dry and hot in the summer and cold in the winter with soils that are compacted, low in fertility, generally acidic, and sodic due to road deicers. As highly disturbed ecosystems, roadside environments receive propagule pressure from surrounding ecosystems such that desirable species have to compete with volunteers, many of which are weedy and invasive. Thus, species require a combination of traits for optimal survival. We rate each turfgrass for 7 traits that together provide an overall resilience rating as well as information that determines which climatic zones in Maryland may be the most suitable for the species or cultivars of a species. For example the climate in Western Maryland is very different from the climate on the Eastern Shore and, hence, species may be resilient in one loacation in Maryland but not in another.

Drought and heat tolerance: Heat reflected from the pavement and the constant wind from passing vehicles results in a microclimate along roadsides that is droughty. In addition, roadsides are engineered to rapidly drain water away from the roadside into swales, storm drains or storm water retention ponds (Brown and Gorres 2011), decreasing the availability of water to roadside vegetation. Providing supplemental irrigation for roadside vegetation is cost-prohibitive such that turfgrass species selected for roadsides need to be drought tolerant to survive. Drought tolerance is conferred through a range of morphological and physiological mechanisms (Beard

1973, Carrow 1995, McCann and Huang 2008), the most common of which are deep root systems that allow plants to avoid drought by accessing water resources deep in the soil column; low evapotranspiration rates that conserves water within leaves; and dormancy during the hottest and driest times of the summer.

Tolerance to low fertility soils: Soils after construction are generally poor, low in organic matter, microbial activity, and cation exchange capacity (Booze-Daniels et al. 2000, Brown and Gorres 2011). Brown and Gorres (2011) even recommend amending roadside soils with compost after showing that the soil amendments were able to enhance persistence. Low soil fertility, however, may be offset with high nitrogen deposition near roadsides owing to vehicle exhaust (Brown and Gorres 2011), which can interact with salt to increase plant uptake of nitrogen.

Cold and freezing tolerance: Maryland is located in the transition zone between warm climates of the southern United States that are suitable for warm season grasses with the C4 photosynthetic pathway, and cool climates in the northern U.S. that are more suitable for cool-season grasses with the C3 photosynthetic pathway. The transition zone provides opportunities for using a diversity of turfgrass species in roadside plantings but also places many species at the edge of their range. Maryland, for example, delineates the northern edge of the bermudagrass range and may be close the southern edge for red fescue. Furthermore, Maryland spans a wide elevation range from sea level to over 3000 feet (=1000 m) on the Appalachian Plateau and thus offering a range of climates. Cold temperatures and freezing soils and sod are therefore important considerations for assessing the suitability and potential for success of turfgrasses along roadsides in Maryland.

Salinity tolerance: Deicers are used in winters to keep roads free of ice. These salts leach into the soils along roadsides (Butler et al. 1971, Hughes et al. 1975) and leave residues on above-ground plant parts that can negatively impact germination, growth, and survival (Harivandi et al. 1992, Biesboer et al. 1998, Marcum 2008). In contrast, Brown and Gorres (2011) and Brown et al. (2011) found that salt was the primary cause of turfgrass failure along roadsides but that persistence could be significantly improved by amending soils. Both sodium and chloride are toxic to plants and can interfere with a plants' water holding capacity (Brown et al. 2011), but tolerance to high salt levels vary among species and cultivars (Marcum 2009) and with plant developmental stage (Friell et al. 2012). Friell et al. (2013) observed that foliar exposure was most likely an important aspect of relative salinity tolerance assessments and argue that under prolonged exposure to salinity, cultivar selection is of little importance relative to species selection.

Tolerance to acid soils: Most soils in Maryland (without addition of agricultural lime) tend to be acidic and buffered by the Al system. Thus, native soils are generally between pH of 4.0 to 5.5. Some surface horizons enriched in organic materials may have even lower pH values. Exceptions to these would be particular types of geological parent materials that are less extensive, and which are more base-rich; limestone and dolomite (for sedimentary rocks) and mafic igneous and metamorphic rocks (such as in the Baltimore gabbro complex, the Boyds diabase sill in Montgomery county, and various diabase dikes associated with the triassic rocks of the piedmont.) These exceptional cases could have subsoil pH values that range into the mid-6s, although surface horizons may be more weathered, organic rich, and thus, have lower pHs than the subsoils. The soils along highways are challenging, because the earth has been disturbed during construction. Thus, it is often unclear what soil horizons might be exposed at the surface and therefore hard to predict what soil pH would be. Topsoils that are tested along MD roadsides immediately after road construction can have high pH (Robert LaRoche personal communication) but it is unclear how long this condition lasts. We rated species more highly if they could tolerate a wide range of pH's, including acid soils (Booze-Daniels 2000) and high aluminum tolerance (Liu et al. 2008).

Wear tolerance: Roadside environments need to be mowed regularly to maintain aesthetic appeal, provide sight distance, and minimize fire hazards. Roadsides also see some traffic from cars that pull over during emergencies. Even if low statured turfgrasses are planted along roadsides, persistence will be enhanced if they can withstand at least some mowing and traffic from vehicles.

Tolerance to competition: To survive in a community with other plant species, a grass species needs be competitive enough to withstand competition pressure for light, nutrients, and water from other species. This includes resisting the invasion of weeds, which are successful when resident species do not provide adequate ground cover and hence offer niche opportunities for new colonizers.

METHODS

Through an extensive literature review of over 500 journal articles, white papers, reports, and fact sheets and detailed discussions with turfgrass experts, we graded 21 turfgrass species and species groups for their ability to provide six services to roadside management and to be resilient towards the stressful conditions that are frequently encountered along roadsides. Because the geography of Maryland is diverse ranging from coastal to mountain habitats, we assessed the suitability of turfgrasses to grow in four regions of Maryland – Southern Maryland, Eastern Shore, Central Maryland, and Western Maryland.

We first developed a list of potential grass species that are currently commercially available. Commercial availability is important to ensure that seed would be available in a high enough quantity to be used for roadside planting. To develop this initial list of species, we consulted nurseries and seed suppliers within the region, including Chesapeake Valley Seed, Ernst Conservation Seed, and Newsome Seed, as well as companies with an internet presence. In all, we identified 32 companies and reviewed species catalogues from 28. We also consulted published seed mixes of state transportation agencies within the mid-Atlantic area to identify which species have been used along roadsides within the region.

After developing a list of grass species that are commercially available, we selected species from the list that were low growing and will grow on dry land. Wetland species were therefore immediately excluded. Another consideration included whether the species has a presence within the region and therefore has a proven track record to persist within the mid-Atlantic climate. We consulted the Maryland Biodiversity Project and the USDA NRCS Plants Database to identify those species that already have known occurrences in Maryland. Because roadsides bisect a variety of habitats such that they are corridors for species movements, we also considered weediness or invasiveness.

In the end, we constrained our final list of species to 25 grass species that have either been planted in the past along mid-Atlantic roadsides or have promise for the future. Our list could be expanded. However, our approach provides a thorough sampling of grass species that are currently available commercially and for which literature exists.

After selecting a focused list of species, we consulted Chesapeake Valley Seed to assess cost of planting each species. The company provided us with information on number of seeds per pound, cost per pound, and cost per acre. These data were then used to rank the species by their cost of establishing an even monoculture.

We then conducted an in-depth literature search of turfgrass species to assess establishment rate, maintenance requirements, ability to stabilize soil and provide ecosystem benefits, and traits that confer resilience to a variety of roadside conditions such as acid and infertile soils, drought, freezing, salt, traffic and competition. Searches were conducted on Web of Science and Google Scholar with the terms in many combinations. General search terms included:

- Roadside
- Restoration
- Turf
- Road

Species were searched using common and scientific names:

- Tall fescue, *Schedonorus arundinaceus, Festuca arundinacea*
- Hard fescue, *Festuca trachyphylla, Festuca ovina var. duriuscula*
- Sheep fescue, *Festuca ovina*
- Blue fescue, *Festuca glauca, Festuca ovina var. glauca*
- Chewings fescue, *Festuca rubra ssp. commutata*
- Creeping red fescue, *Festuca rubra ssp. rubra L.*
- Fine fescue as a more general term
- Zoysiagrass, *Zoysia*
- Bermudagrass, *Cynodon dactylon*
- Kentucky bluegrass, *Poa pratensis*
- White clover, *Trifolium repens*
- Micro clover
- Purple prairie clover, *Dalea purpurea*
- White prairie clover, *Dalea candida*
- Annual ryegrass, *Lolium multiflorum*
- Perennial ryegrass, *Lolium perenne*
- Seashore paspalum, *Paspalum vaginatum*
- Buffalograss, *Buchloe dactyloides*
- Blue grama, *Bouteloua gracilis*
- Alkaligrass, *Puccinellia distans*
- Switchgrass, *Panicum virgatum*
- Prairie junegrass, *Koeleria macrantha*
- Poverty oat grass, *Danthonia spicata*
- Poverty dropseed, *Sporobolus vaginiflorus*
- Weeping lovegrass, Lehmann's lovegrass, *Eragrostis curvula*
- Purple lovegrass, *Eragrostis spectabilis*
- St. Augustine, *Stenotaphrum secundatum*
- Deertongue, *Dichanthelium clandestine*

- Tufted hairgrass, *Deschampia cespitosa*
- Kalm's brome, Prairie brome, Arctic brome, *Bromus kalmii*
- Side-oats grama, *Bouteloua curtipendula*
- Little bluestem, *Schizachyrium scoparium, Andropogon scoparium*

The literature search yielded over 300 journal papers and book chapters from different states and countries and therefore many different climates. All information was considered useful but research from within Maryland and surrounding sates was given greater weight. ISI sometimes did not yield many results. In those cases we consulted literature citations, agency reports, and fact sheets. Of particular help were the Forest Service Fire Effects Information System (http://www.feis-crs.org/feis/) and USDA Plant Fact Sheets and Plant Guides.

We consulted with turfgrass experts that have had experience with roadside grasses or growing grasses under low-maintenance conditions. Experts included:

Ms. Jody Booze-Daniels – Virginia Tech University
Dr. Rebecca Brown – University of Rhode Island
Mr. Mark Fiely – Ernst Conservation Seeds
Dr. Mike Goatley – Virginia Tech University
Mr. Gordon Kretser – Chesapeake Valley Seed
Dr. Pete Landschoot – Pennsylvania State University
Dr. Bill Meyer – Rutgers University
Dr. Kevin Morris – National Turfgrass Evaluation Program
Mr. Jon Straughn – Chesapeake Valley Seed
Dr. Tom Turner – University of Maryland College Park
Dr. Eric Watkins – University of Minnesota

After compiling a literature database, we summarized information for six economic and ecological services summarized above by reviewing, categorizing, and synthesizing the literature for the 25 species. In lieu of a statistical meta-analysis, we focused particularly on literature that compared different species such that we could score species relative to each other. For example, Beard's (1973) book on turfgrasses assessed and compared many of the turfgrasses we synthesize. Although over 40 years old, it provides information for relative differences among species, realizing that cultivars within a species can vary widely in traits. Much research has gone into cultivars over the last decades and some ratings have changed as denoted by an * (Turner, *pers. communication*).

		Hardiness				Tolerance		
Turfgrass	**Temperatures**	**Heat**	**Low temperature**	**Drought resistance**	**Optimum pH**	**Salinity**	**Wear**	**N requirement**
Bermudagrass	Warm	Excellent	Poor-Fair	Excellent	7.0-6.0	Good	Excellent	High
Creeping bentgrass	Cool	Medium	Excellent	Poor	6.5-5.5	Good	Poor	High
Kentucky bluegrass	Cool	Medium	Good	Medium	7.0-6.0	Poor	Medium	High
Perennial ryegrass	Cool	Fair	Poor	Fair	7.0-6.0	Medium	Medium	Medium
Red fescue	Cool	Fair	Medium	Good	6.5-5.5	Poor	Poor	Low
Sheep fescue	Cool			Good	5.5-4.5			
Tall fescue	Cool	Good	Medium	Good	6.5-5.5	Medium	Good	Medium
Zoysiagrass	Warm	Excellent	Medium	Excellent	7.0-6.0	Good	Excellent	Low
Buffalograss	Warm	Excellent		Excellent				Very Low
Chewings fescue	Cool	Fair			6.5-5.5			Low

After writing a synthesis for each species or species group, we gave each species an overall grade (A=Excellent, B=Good, C=Fair, D=Poor, and F=Very poor). This report card approach has been used effectively in Maryland and the Chesapeake Bay (CB) region to evaluate and communicate the health of CB tributaries (Williams et al. 2009).

Priorities for managing roadsides will differ depending on proximity to the road surface and roadside conditions. For example, ecosystem benefits may not be a management priority near the road but can be a management priority elsewhere. Erosion control is an important consideration for sloped roadsides but management may be less concerned with erosion of flat roadsides. Further, establishment and maintenance may be ranked as the top two management priorities with the other four services secondary. For these reasons we developed 4 grading scenarios:

1. All six services weighted equally
2. Establishment and maintenance weighted twice as important as the other 4 services
3. All services weighted equally with ecosystem benefits removed from grading
4. All services weighted equally with ecosystem benefits and erosion control removed from grading.

RESULTS

Species identification. We initially identified 88 grass species, two rushes and 14 sedges for a total of 103 commercially available graminoid species. Of these, 53 species were immediately rejected for one or more reasons:

- Prohibited weed - annual bluegrass (*Poa annua*);
- Potentially weedy - orchardgrass (*Dactylis glomerata*); path rush (*Juncus tenuis*); bottlebrush squirreltail (*Elymus elymoides*); smooth brome (*Bromus inermis*); smut grass (*Sporobolus indicus*); chess (*Bromus secalinus*); Canada bluegrass (*Poa compressa*);
- Obligate or facultative wetland species, or upland species that require moist soils – 35 species including, e.g., Virginia wild rye (*Elymus virginicus*);
- Shade loving species - 8 species including, e.g., Pennsylvania sedge (*Carex pensylvania*); and
- Southern species not suited for Maryland climates - St. Augustine grass (*Stenotaphrum secundatum*), seashore paspalum (*Paspalum vaginatum*);

Fifty-one species were considered potentially suitable after the initial filtering of candidate species. Of these, 26 were not assessed owing to:

- Tall stature - 16 species have a tall stature but would otherwise be suitable for roadsides if they can be maintained as tall grasslands. Species include indiangrass (*Sorghastrum nutans*), switchgrass (*Panicum virgatum*), and big bluestem (*Andropogon gerardii*).
- Limited commercial supply - 2 species are suitable but commercial supply is extremely limited. These species include puffsheath dropseed (*Sporobolus neglectus*) and poverty dropseed (*Sporobolus vaginiflorus*). A third species – hairy lens grass (*Paspalum setaceum*) – was used in Jenkins et al. 2004 and recommended in Brown et al. (2011) as a drought hardy species that requires little management. However, its seed availability is limited as well as unreliably among years.

- Nurse grasses - 4 species are used as nurse grasses including foxtail barley (*Hordeum jubatum*), common oat (*Avena sativa*), common barley (*Hordeum vulgare*), and common wheat (*Triticum aestivum*). Although they may be used in mixes to facilitate establishment, they were not considered as primary turfgrass species.
- Limited information - 4 species were not assessed because information on the species was extremely limited. These species included hairawn muhly (*Muhlenbergia capillaris*), Leavenworth's sedge (*Carex leavenworthii*), green needlegrass (*Stipa viridula*), and sweet vernalgrass (*Anthoxanthum odoratum*).

In the end, 25 species were assessed and graded. Three Sporobolus species were grouped into one assessment, as were annual and perennial ryegrass, and two Puccinellia (alkaligrass) species. Thus, 21 summaries were developed to represent 25 commercially available species.

Economic and ecological services

Commercial availability and cost: Cost of grass seed per pound is misleading because the end-result of establishing an even monoculture (used as a measure to standardize across species) may require different amounts of seed. We therefore assessed cost of planting as the cost of planting an acre of each species. This information was provided by Chesapeake Valley Seed, Ernst Conservation Seed, and T. Turner (*pers. communication*). Although the fescues have low seed costs per pound, their seeding rate is relatively high, which substantially increases their cost per acre. In contrast, small seeded species, such as Sporobolus, require a lower seeding rate such that even though the cost per pound may be relatively high, the cost of seeding an acre is not. The cost of planting zoysia and bermudagrass is high because both species are best sodded rather than seeded, which increases cost.

	Price per LB	Seeds per LB	Seeding Rate LB per Acre	Price per Acre
Sand dropseed	$ 10.00	5,600,000	1	$ 10.00
Weeping lovegrass	$ 8.00	1,482,000	3	$ 24.00
Tufted Hairgrass	$ 17.64	1,308,000	2	$ 35.28
Alkaligrass	$ 4.23	1,200,000	20	$ 84.60
Prairie Junegrass	$ 65.55	2,315,000	2	$ 131.10
Side-oats grama	$ 12.00	159,000	12	$ 144.00
Little bluestem	$ 16.00	225,000	12	$ 192.00
Perennial Ryegrass	$ 1.85	230,000	130	$ 240.50
Kentucky Bluegrass	$ 2.95	2,200,000	87	$ 256.65
Red fescue	$ 1.80	615,000	175	$ 315.00
Tall Fescue	$ 1.60	227,000	200	$ 320.00
Chewings fescue	$ 2.38	500,000	175	$ 416.50
Upland bentgrass	$ 14.65	8,000,000	30	$ 439.50
Blue grama	$ 15.00	710,000	35	$ 525.00
Hard fescue	$ 3.45	592,000	175	$ 603.75
Sheep fescue	$ 3.75	700,000	175	$ 656.25
Bermudagrass	$ 15.00	725,000	45	$ 675.00
Purple lovegrass	$ 180.00	4,480,000	5	$ 900.00
Buffalograss	$ 16.00	335,000	125	$ 2,000.00
Zoysia	$ 75.00	1,000,000	45	$ 3,375.00
Poverty Oatgrass	$ 480.00	400,000	10	$ 4,800.00

Rate of establishment: Rate of establishment varied across species. Perennial ryegrass is the best example of a fast establishing species and for that reason is used as a nurse grass in many projects. Other species, however, can establish just as rapidly including seeded bermudagrass, followed closely in rank by alkaligrass, poverty oatgrass, lovegrass (purple and weeping), and then by side-oats grama, and Sporobolus. Most fescues establish at an intermediate rate with tall fescue establishing faster on average than the fine fescues. Some grasses that are slow in establishing include little bluestem, upland bentgrass, prairie junegrass, buffalograss, Kentucky bluegrass and zoysia, suggesting that when fast establishment is a management priority, these species should not be selected.

Ease of maintenance: Maintenance is a major management concern for state highways. Because we selected species to represent a low-statured growth habit, maintenance generally ranked highly among species. Therefore, the only species that received a low rank for maintenance because it requires a high mowing frequency was tall fescue, which we included in our list to serve as a reference species. All other species that ranked low for maintenance (bermudagrass, alkaligrass, Kentucky bluegrass, perennial ryegrass) require high inputs of fertilizer, liming, or herbicides.

Erosion control: Erosion control ranked high for most species because many of the species are commercially selected owing to their ability to produce a dense sod through their extensive root system. The one exception is prairie junegrass, which has a shallow and sparse root system.

Ecosystem benefits: Ecosystem benefits tended to be ranked lower for non-native species and higher for native species. However, other considerations included information on leaching losses, soil stabilization, food web support, and invasiveness. Therefore, bermudagrass, Kentucky bluegrass, zoysia, and perennial ryegrass ranked as ‘very poor’ followed by weeping lovegrass, red fescue, chewings fescue and tall fescue, which ranked ‘poor’.

Resilience: Each grass species has traits that allow the species to be resilient to environmental stress or disturbance. Many species were remarkably resilient when averaged across six traits although even very resilient species may be particularly vulnerable to one environmental stressor. The most resilient species across all resilience parameters is purple lovegrass, followed closely by Sporobolus. The least resilient species (with an average resilience score of Fair or Poor) are prairie junegrass, upland bentgrass, alkaligrass, perennial ryegrass, and Kentucky bluegrass. Upland bentgrass, however, included several unknowns and we are therefore less confident with its resilience score.

	Resilience Parameters							**Grade**
Species	*Drought*	*Fertility*	*Freezing*	*Salinity*	*Acidity*	*Wear*	*Competition*	Resilience
Purple lovegrass	100	100	100	100	100	100	90	99
Sporobolus	100	100	100	95	100	100	85	97
Little bluestem	90	100	100	75	100	85	100	93
Weeping lovegrass	100	100	60	100	100	100	90	93
Poverty oatgrass	100	100	100	unknown	100	100	55	93
Hard fescue	100	95	85	80	100	85	100	92
Blue Grama	100	90	100	85	82	100	80	91
Side-oats grama	100	100	100	80	100	85	70	91
Zoysia	85	90	75	97	100	95	90	90
Sheep fescue	100	95	80	80	95	80	95	89
Buffalograss	100	90	100	90	85	100	60	89
Tall fescue	85	95	75	88	100	95	83	89
Red fescue	85	87	85	90	95	80	95	88
Chewings fescue	85	87	78	75	100	85	95	86
Tufted hairgrass	35	97	95	85	100	90	85	84
Bermudagrass	100	65	20	100	100	89	100	82
Prairie junegrass	40	90	95	70	100	95	40	76
Upland bentgrass	60	unknown	100	30	100	unknown	unknown	73
Alkaligrass	65	50	100	100	50	50	80	71
Perennial ryegrass	40	50	20	85	100	100	100	71
Kentucky bluegrass	40	30	100	45	85	85	100	69

After averaging across six services scores and seven resilience scores, the majority of species received a score of "Good" (B +/-). However, grades ranged from A to D. Species with grades lower than D were not identified owing to the initial filtering of species and because each species has at least one trait that allows it to excel in at least one service. Overall, the grade report (equal weighting of all 6 services) includes:

A	Sporobolus
A-	Side-oats grama and Purple lovegrass
B+	Little bluestem, Weeping lovegrass, and Blue grama
B	Tufted hairgrass, Hard fescue, Upland bentgrass
B-	Red fescue, Sheep fescue, and Buffalograss
C+	Chewings fescue, Povery oatgrass, and Tall fescue
C	Bermudagrass, Prairie junegrass, Alkaligrass
D+	Zoysia and Kentucky bluegrass
D	Perennial ryegrass

Equally weighted services

Species	Cost	Establishment	Maintenance	Erosion	Ecosystem	Resilience	Overall Grade
Sporobolus	100	90	90	100	100	97	96.2 A
Side-oats grama	86	90	90	100	100	91	92.8 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+
Blue Grama	66	80	90	100	100	91	87.8 B+
Tufted hairgrass	96	85	82	82	92	84	86.8 B
Hard fescue	63	75	100	88	89	92	84.5 B
Upland bentgrass	67	65	100	95	100	73	83.3 B
Red fescue	75	80	100	85	65	88	82.2 B-
Sheep fescue	61	65	100	88	89	89	82.0 B-
Buffalograss	45	75	80	100	100	89	81.5 B-
Chewings fescue	69	80	100	83	60	86	79.7 C+
Poverty oatgrass	20	95	100	80	85	93	78.8 C+
Tall fescue	72	85	60	100	60	89	77.6 C+
Bermudagrass	60	100	70	100	50	82	77.0 C
Prairie junegrass	87	50	100	60	85	76	76.3 C
Alkaligrass	92	95	20	85	90	71	75.5 C
Zoysia	35	60	100	80	50	90	69.2 D+
Kentucky bluegrass	77	70	65	85	40	69	67.7 D+
Perennial ryegrass	78	100	20	90	30	71	64.8 D

Weighting services or omitting some services altogether only slightly changed some grades and the rankings of species. Weighting establishment and maintenance or removing ecosystem benefits from the grading tended to enhance grades for some species, whereas removing both ecosystem benefits and erosion control tended to decrease the grades of the better performing species and increase the grades for the worse performing species.

Four species received an excellent grade for 1 or more of the grading scenarios. These species include Sporobolus (3 out of 4), side-oats grama (3/4), purple lovegrass (3/4), and weeping lovegrass (2/4). An additional five species consistently received a B or B+ grade with no lower grade in any of the 4 scenarios. These species include little bluestem, blue grama, tufted hairgrass, hard fescue, and red fescue.

Owing to their consistent high performance across the 4 grading scenarios, we recommend the above 10 grasses for their ability to provide a variety of services. However, even though we are recommending these species, they may not be suitable for all situations along roadsides. For example, tufted hairgrass ranks high enough to be included in the recommended list; however, it has poor resilience under drought conditions and may therefore not be a good choice for many, if not all, roadside settings. Red fescue is also recommended; yet, it has shown poor summer-time performance in trials in Maryland and should therefore be used only in cooler climates of Western Maryland.

The selection criteria here are stringent. If they are relaxed to include all species that received a B in at least one of the 4 scenarios, seven additional species can be recommended including upland bentgrass, sheep fescue, buffalograss, chewings fescue, poverty oatgrass, tall fescue, and bermudagrass. The turfgrasses that are not recommended for widespread use include prairie junegrass, alkaligrass, zoysia, Kentucky bluegrass, and perennial ryegrass.

Species	Equal weighting		Weighted establishment & maintenance		Without ecosystem benefits		Without ecosystem benefits and erosion control	
Sporobolus	96.2	A	95	A	95	A	94	A
Side-oats grama	92.8	A-	92	A-	91	A-	89	B+
Purple lovegrass	91.4	A-	93	A	90	A-	87	B
Little bluestem	89.6	B+	88	B+	88	B+	84	B
Weeping lovegrass	89.3	B+	89	B+	94	A	93	A
Blue Grama	87.8	B+	87	B	85	B	82	B-
Tufted hairgrass	86.8	B	86	B	86	B	87	B
Hard fescue	84.5	B	85	B	84	B	83	B
Upland bentgrass	83.3	B	83	B	80	B	76	B
Red fescue	82.2	B-	84	B	86	B	86	B
Sheep fescue	82.0	B-	82	B-	81	B-	79	C+
Buffalograss	81.5	B-	81	B-	78	C+	72	C-
Chewings fescue	79.7	C+	82	B	84	B	84	B
Poverty oatgrass	78.8	C+	83	B	78	C+	77	C
Tall fescue	77.6	C+	76	C	81	B-	76	C
Bermudagrass	77.0	C	79	C+	82	B-	78	C+
Prairie junegrass	76.3	C	76	C	75	C	78	C+
Alkaligrass	75.5	C	71	C-	73	C	69	D+
Zoysia	69.2	D+	72	C-	73	C	71	C-
Kentucky bluegrass	67.7	D+	68	D+	73	C	70	C-
Perennial ryegrass	64.8	D	64	D	72	C-	67	D

CONCLUSIONS and RECOMMENDATIONS

Roadsides are planted to be managed as mowed turfgrass that improves aesthetics, prevents erosion, maintains visibility and provides a safety zone for stopped vehicles (Brown et al. 2011). As such, roadside vegetation is often managed as a high maintenance front yard using mostly non-native turfgrass species (Harper 1988) that need to be mowed several times each growing season to look manicured. However, managing the roadside as a lawn is expensive and often results in problems with invasive species and failed plantings. Here, we explore grass species that are commercially available but may reduce maintenance costs while providing economic and ecological services such as fast establishment, erosion control, ecosystem benefits, and resilience.

We recommend that grass species consistently receiving an average grade of good (B) or higher across the 4 management scenarios should be considered for planting along Maryland roadsides. We therefore recommend 5 species as highly suitable under a variety of management situations and climates and an additional 4 species under more restricted conditions where quick establishment is not a concern (little bluestem and blue grama), the roadside is wet (tufted hairgrass), or the climate is cool (red fescue).

Recommended	Species
1	Sporobolus
2	Side-oats grama
3	Purple lovegrass
4	Little bluestem
5	Weeping lovegrass
6	Blue Grama
7	Tufted hairgrass
8	Hard fescue
9	Red fescue

We further recommend that some species that are currently planted frequently along roadside be used in limited quantities. For example, although frequently seeded along Maryland roadsides owing to its vigorous growth and resilience, tall fescue received a rating that was below the median grade. Although seed cost per pound is low, the recommended seeding rate is high, resulting in a cost per acre that is higher than 50% of the assessed species. In addition, this species has high maintenance costs and has poor ecosystem benefits yet, tall fescue has excellent mowning tolerance and can therefore withstand the stringent mowing regime applied by highway management. Similarly, Kentucky bluegrass and perennial ryegrass are not recommended to be planted in high quantities owing to maintenance costs, low ecosystem benefits, and, for Kentucky bluegrass, high seed cost.

Several native grass species received high grades and are therefore excellent alternative species to the commonly used non-native species that are produced and used widely. National highway policy strongly encourages the use of native vegetation in highway right-of-ways (Clinton 1999), and Harper (1988) argues that the use of native plants can help in reducing costs while providing ecosystem functions and services. Similarly, Brown and Sawyer (2012) argue that roadsides along Rhode Island highways are not wastelands but can be habitat for a diversity of species, some even rare and endangered. They further found that many of the grasses that were seeded did not survive but were replaced by native species that had dispersed into the roadside environment from elsewhere (Brown et al. 2011). Thus, Brown et al. (2011) recommend using standard seed mixes as temporary vegetation for the first 5 years with a plan for succession by slower-growing native species. Johnson 2008 also argues for use of native species in turf lawn to decrease maintenance, which also decreases the risk of non-native species becoming problem invaders (Jenkins et al. 2004) into neighboring agricultural areas or native habitats.

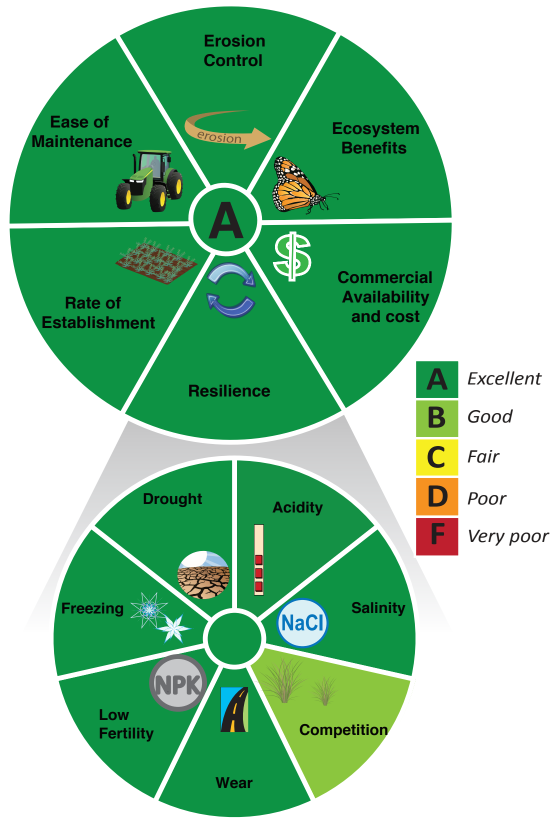
NEXT STEPS

We have identified a diversity of native and non-native grass species that are suitable for seeding along Maryland roadsides. Although the assessment and grading of the species was based on a careful literature review that was followed up by extensive discussions with experts, our grading and ranking of species is effectively still a hypothesis that needs to be tested. Maryland is a diverse state that varies considerably in climate and soil conditions, which will impact establishment, survival and long-term persistence. The next step therefore is to plant the recommended species in various climatic zones and site conditions to test resilience to a variety of environmental conditions and the rankings of economic and ecological services. A further step is to consider some of the grass species that were filtered out owing to their height or lack of information, as well as consider promising forb species such as microclover, *Trifolium repens, Dalea purpureum, Asclepias tuberosa, Coreopsis palmate, Allium stellatum, Ratibida columnifera, Anaphalis margaritacea, Thermopsis caroliniana, Polemonium reptans, and Medicago lupulina.*

Sand, Prairie and Rough dropseed

Sporobolus cryptandrus, S. heterolepis, and S. asper = S. compositus

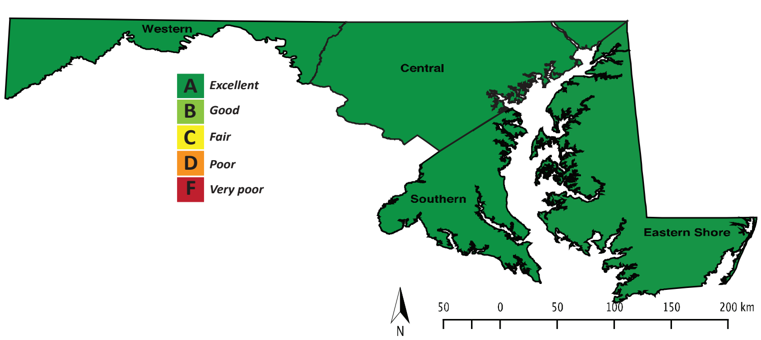
Dropseeds are native grass species that provide excellent services for roadside management including high erosion control benefits, excellent resilience to roadside conditions, and superior ecosystem benefits. Dropseeds are best used in combination with other species to enhance biodiversity. As the top recommended group of species, dropseeds are rated as Excellent (grade = A) with a few minor management concerns:



Although the seed cost per pound for dropseeds is high, the seeding rate is low such that the cost per acre is excellent.

 Dropseeds attain moderate plant height such that mowing may be required to maintain sight distance.

 Germination and establishment rates are good but variable, requiring extra attention to seed pre-treatment.



Dropseeds are adapted to environmental conditions throughout Maryland.

If seed costs can be improved, dropseeds could be more widely used in roadside management. Commercial growers should also consider growing two additional dropseed species that are common along roadsides but are currently not available commercially – poverty grass (*S. vaginiflorus*) and small dropseed (*S. neglectus*).

Biology: One hundred and eighty-nine species within the genus Sporobolus are recognized worldwide. Most Sporobolus species that occur within the United States are adapted to southern climates (Leithead 1973) but ten species are present in the mid-Atlantic region (Rhoads and Klein 1993, USDA Plants Database). Of these, three species (*S. compositus*, *S. cryptandrus*, and *S. heterolepis*) are commercially available. Some species within the genus are desiccation tolerant ('resurrection species'; Wood and Gaff 1989). Others are drought resistant due to drought avoidance mechanisms such as deep roots (Hameed et al. 2008). Some have salt glands and are therefore salinity tolerant (Wood and Gaff 1989).

Sand dropseed (*Sporobolus cryptandrus*) is a native perennial warm-season bunch type grass that is widespread throughout the United States and southern Canada and occurs in many different habitats, including roadsides, rocky to sandy shores, slopes, scrub, and woodlands (Jepson Manual 1993), and at elevations from 0 to 2900m (Peterson et al 2002; http://herbarium.usu.edu/webmanual). Despite its widespread habit, it is most common on the North American Great Plains and intermountain region (Leithead 1973, Johnson 2008). It is listed as rare in Pennsylvania (Rhoads and Klein 1993) and has not been documented by the Maryland Biodiversity Project. The species produces abundant seeds and can therefore be of value commercially as well as for wildlife. It is tolerant of heavy grazing and mowing (Johnson 2008) and is drought hardy (USDA plant guide). It is used for rehabilitating disturbed sites (USDA Forest Service).

Prairie dropseed (*Sporobolus heterolepis*) is a perennial grass species that occurs on serpentine barrens of the mid-Atlantic region. Prairie dropseed is state rare in both Pennsylvania (Rhoads and Klein 1993) and Maryland (S1; Maryland Biodiversity Project) where it occurs only on serpentine barrens. Prairie dropseed is used widely for roadside revegetation, grassland rehabilitation, and residential landscapes (USDA Forest Service).

Rough dropseed or tall dropseed (*Sporobolus compositus = S. asper*) is a long-lived perennial species that is most widespread in the Great Plains and the Midwest but occurs almost throughout the United States except California, Nevada, Florida, South Carolina, New Hampshire, Alaska, and Hawaii. It occurs patchily in Pennsylvania (Rhoads and Klein 193) and is considered state rare (S1 rank) in Maryland where it has been documented to occur in Montgomery, Anne Arundel, Queen Anne's and Talbot counties (Maryland Biodiversity Project). Tall dropseed occurs on dry sites in the eastern United States and is often associated with disturbed lands such as roadsides and railroad banks. It does not produce rhizomes but has a persistent seed bank (USDA Forest Service).

Seeds per pound:

Sand dropseed:	5,600,000 (Ernst Conservation Seed); 5,300,000 (Stock Seed Farms); 3,200,000 (Prairie Moon Nursery); 1,760,000 (Agrecol)
Prairie dropseed:	240,000 (Stock Seed Farms); 256,000 (Prairie Moon Nursery and Agrecol)
Composite dropseed:	760,000 (Ernst Conservation Seed); 750,000 (Roundstone Native Seed); 450,000 (Prairie Moon Nursery), 480,000 (Agrecol)

Cost per pound:

Sand dropseed:	$10 from Ernst Conservation Seed and Chesapeake Valley Seed

Prairie dropseed: $120 from Ernst Conservation Seed
Composite dropseed: $ 24 from Ernst Conservation Seed

Suggested sowing rate:
Sand dropseed: 1 pound per acre (Chesapeake Valley Seed and Ernst Conservation Seed)
Prairie dropseed: Drilled 6 lbs/acre (Stock Seed Farms); does not establish well when direct seeded
Composite dropseed: Unknown

Cost per acre:
Sand dropseed: $10.00 per acre
Prairie dropseed: $720.00 per acre
Composite dropseed: unknown

Sowing depth: 1/8 inch (USDA Plant Guide)
Germination time: 7-10 days
Seeding timing: Fall or early spring; cold stratification is necessary for good germination.
Seed viability: Low
Length of growing season: Late winter or early spring (USDA Plant Fact Sheet)

Leaf length:
Sand dropseed: 3-10 inches (USDA Forest Service)
Prairie dropseed: 6-18 inches (USDA Forest Service)
Composite dropseed: 20 inches (USDA Plant Fact Sheet), 2-28 inches USDA Forest Service)

Height at seed head stage:
Sand dropseed: 12-40 inches (USDA Forest Service)
Prairie dropseed: 1-3 ft (USDA Forest Service)
Composite dropseed: 2-4 feet (USDA Plant Fact Sheet), 8-51 inches (USDA Forest Service)

Shade tolerance: intolerant of shade (USDA Forest Service)
Suggested mowing height: Unknown; do not mow in July and August
Tolerance of wet conditions: Sand dropseed is an upland species and will not tolerate wet conditions for prolonged periods of time.
Humidity tolerance: Adequate for those Sporobolus species adapted to the mid-Atlantic region.
Disease resistance: Unknown

Services:

Commercial availability and cost: Sand dropseed, prairie dropseed, and composite dropseed are available commercially from several native plant nurseries. Prairie dropseed is significantly more expensive and yet contains the least amount of seeds per pound than the other two species. Sand dropseed is the least expensive, has the most seeds per pound and the lowest sowing rate.

Rate of establishment: Establishment of dropseed is variable and depends on whether seed has been pre-treated. Sand and composite dropseed require overwintering and scarification for germination because new seed is very hard and impermeable (USDA Plant Guide, USDA Forest Service). Germination was only 6% after 6 weeks of cold and moist conditions, 44% after 9 weeks of stratification, and 96% after 15 weeks (USDA Forest Service). Seeds stay viable in the soil for a long time with germination increasing as seeds age. Ten to twenty-five percent of sand dropseed germinated in lab and field experiments (Biesboer 1994, 1998) but pretreatment with potassium nitrate resulted in 39% germination of composite dropseed. Fedawa and Stewart (2009) found very high viability of seeds for prairie dropseed but low germination percentage. Only ~1-5% of prairie dropseed germinated in Minnesota (Biesboer 1994). Germination of prairie dropseed in petri dishes was 5-13% after cold stratification and only 2% in NE Illinois field plots (Gibson and Carrington 2008). Ninety-one percent of composite dropseed seeds germinated when planted in April, but the previous year none of the seeds germinated when planted in April (USDA Forest Service). In a drought experiment of 15 grass species, composite dropseed showed excellent establishment (Mueller and Weaver 1942). Composite dropseed was used to seed reclaimed Appalachian surface mines (Thorne et al. 2011) where it established a good population density after 30 days (33% viable seeds sown) that was maintained at 24-29% across two years. At the end of the 2-year study, composite dropseed began to spread into adjacent plots.

Seedlings may have low vigor and will therefore be susceptible to drought and grazing before becoming fully established (USDA Plant Guide). The USDA Forest Service suggests that composite dropseed establishes and spreads quickly on open sites owing to high seed production and good viability.

Ease of maintenance: Sand dropseed, prairie dropseed, and composite dropseed are all tall perennial plants that will grow ca. 1 m tall (Brown et al. 2010, USDA Plant Guide). Some mowing will therefore be required to be acceptable for roadsides.

Erosion control: Sand dropseed is considered an excellent species for erosion control because it produces dense mat-forming rhizomes (USDA Forest Service). In a roadside experiment along Rhode Island right-of-ways, Brown et al. (2010) showed that sand dropseed had an even root distribution that reached the bottom of rooting columns at 76 cm depth. Similarly, prairie dropseed produces an extensive root system that spreads horizontally in the upper soil by 1-2 ft and extends down vertically by 4-5 ft (Weaver 1958). Composite dropseed roots may extend to 18 inches (45 cm) soil depth (USDA Forest Service) but the species does not produce rhizomes.

Ecosystem benefits: Sand dropseed, prairie dropseed, and composite dropseed are native species. Their seeds provide food for birds and small mammals and their foliage provide forage for wildlife and cover for small animals (USDA Plant Fact Sheet). Sand dropseed has been used by Native American tribes to make bread and porridge and was used to create a cold infusion to aid in the healing of horse legs (USDA Plant Guide). Sand dropseed may become weedy and invasive in grazed environments because herbivores prefer more palatable grasses than sand dropseed (USDA Plant Guide).

<u>Resilience</u>:

Drought: Sand dropseed is considered to be a very drought tolerant warm season bunchgrass that produces a deep root system (Brown et al. 2010) and therefore has access to water resources within the soil column. Composite dropseed is considered drought tolerant but less so than sand dropseed (USDA Plant Guide). In a drought experiment of 15 grass species, composite dropseed showed excellent establishment and drought tolerance compared to most species (Mueller and Weaver 1942). Only buffalograss and blue grama were more drought tolerant but composite dropseed was more tolerant than side-oats grama and prairie junegrass. Sand dropseed planted along a Rhode Island roadside was one of 8 species (out of 14) that did not survive a drought. New transplants failed to survive as well

(Brown et al. 2010). This poor survival is likely due to low adaptation to the New England environment (R. Brown *pers. communication*) rather than poor tolerance to drought.

Low fertility: Sand dropseed increases on poor condition sites (USDA Plant Guide). Composite dropseed can occur on sites with little organic matter (USDA Forest Service).

Freezing*:* Sand dropseed grows at elevations up to 8,000 feet (USDA Plant Fact Sheet) and composite dropseed up to 6,500 feet (USDA Forest Service).

Salinity: The genus *Sporobolus* is generally well adapted to soils that are saline. In a study of seven grasses evaluated for salinity tolerance (Marcum 1999), salt grass > alkali sacaton (*Sporobolus airoides*) > bermudagrass = Zoysia > sand dropseed > buffalograss > side-oats grama. Prairie dropseed was more tolerant of salinity than sand dropseed (Biesboer 1994), and germination percent increased from 5% to 13% when salinity was increased in petri dishes (Gibson and Carrington 2008). Sand dropseed, however, did not survive salinity treatments in Biesboer (1998). The biomass yield and foliage injury in the predominantly western species *S. airoides* was not affected by salinity treatments (Greub et al. 1985), but seedling survival of the species was completely inhibited by salinity treatments (Hughes et al. 1975).

Acidity: Dropseeds have a wide pH range that varies by species. Composite dropseed can occur on soils ranging from 5.5 to 7 (Thorne and Cardina 2011).

Wear tolerance: Sand dropseed can withstand heavy use owing to a protected root crown; however plants will be killed by overgrazing (USDA Plant Guide). *Sporobolus elongates*, a species in Australia, showed high flexibility and resistance to trampling suggesting that it is wear tolerant (Sun and Liddle 1993). Prairie dropseed will decrease in response to heavy grazing (USDA Forest Service). Composite dropseed may increase following mowing (USDA Forest Service) but mowing in July and August may result in declines.

Competition: Composite dropseed was able to withstand the reinvasion of Kentucky bluegrass better than many other species seeded on reclaimed surface mines (Thorne et al. 2011).

<u>Mixes</u>: Prairie dropseed co-occurs with little bluestem (Weaver 1958), big bluestem, indiangrass, side-oats grama, and switchgrass (USDA Forest Service). It can also occur with buffalograss and blue grama in shortgrass prairie (USDA Forest Service).

<u>Other Species</u>: Two dropseed species are annual (*S. vaginiflorus* and *S. neglectus*) and are common on dry thin soils such as roadsides (Fernald 1933) but are not available commercially. Poverty grass (*Sporobolus vaginiflorus*) is a native annual grass species that occurs in the Eastern United States and eastern Ontario (Catling 2013). The species occurs as an early successional species on disturbed sites (Simmons et al. 2011). Thus, it is observed frequently along roadsides (Catling 2013). The species is low growing and inconspicuous. In Central Europe, poverty grass is considered an invading grass species along roadsides although conservation threats have not been reported (Kiraly and Hohla 2015).
Seashore dropseed *(Sporobolus virginicus*) is a halophyte that occurs in tropical and subtropical

coastal zones world-wide and is considered a low-maintenance turfgrass. In the United States, it occurs in southern states (Leithead 1973) and along the eastern coast up to Maryland. Seashore dropseed will continue to thrive under full strength sea water (Marcum 2008a,b). Seeds have low viability. Thus, seashore dropseed needs to be planted by sodding.

Side-oats grama

Bouteloua curtipendula

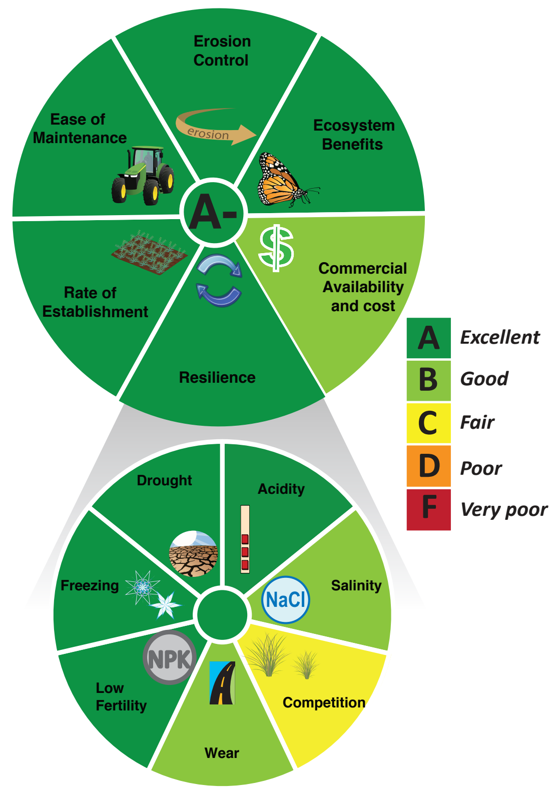
Side-oats grama is native to the Great Plains of North America but occurs in the mid-Atlantic region in areas that are dry and hot. As such, side-oats grama has excellent resilience to drought, freezing, low soil fertility, and high soil pH. Further, side-oats grama germinates well and has excellent seedling vigor; produces medium height plants that thrive under low-maintenance; is an excellent species to use in bank stabilization when mixed with other species; and has excellent ecosystem benefits. Among the 20 assessed species, side-oats grama is ranked within the top three roadside species for use along roadsides with a rating of Excellent to Good (grade = A-) with a few management challenges:

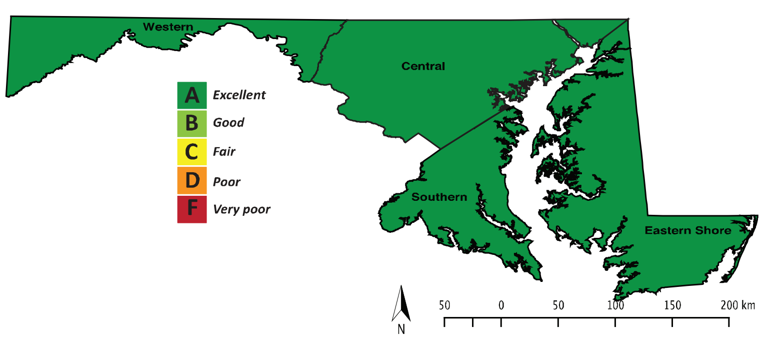
Side-oats grama is commercially available. Seed costs are high but seeding rate is low to decrease cost per acre.

Side-oats grama germinates rapidly but establishment of adequate cover is slow owing to slow lateral spread. This species is therefore best mixed with other native species.

Side-oats grama has poor mowing tolerance and therefore should be used only in areas where low-intensity culture is desired.

Side-oats grama is not a good competitor and should only be used in areas where propagule pressure from other species is low.





Side-oats grama is a suitable grass species for planting along roadsides throughout Maryland, especially on dry south facing slopes that are mowed infrequently.

Cultivars suitable in Maryland include Butte, El Reno, Killdeer, and Trailway. Development of ecotypes for the mid-Atlantic region is recommended. Seed costs need to be reduced to increase use over larger areas.

Biology: Side-oats grama is a perennial warm season species that is native to the Great Plains of North America (Johnson 2000) but is more wide-spread than blue grama and buffalograss (Beard 1973). It grows from southern Canada to northern Mexico but also outside the Great Plains eastward to Virginia (Leithead et al. 1971, Johnson 2008). Side-oats grama was important in the recovery of grasslands after the 1930's drought (Weaver and Albertson 1944). Side-oats grama is mostly observed growing on poorly developed shallow soils, steep slopes, and ridgetops (Sedivec et al. 2001). Side-oats grama is considered to be state-rare (S2) in Maryland, but is documented to occur on the Eastern shore, Montgomery County, and Allegany and Washington County of western Maryland (Maryland Biodiversity Project). In Pennsylvania, side-oats grama is state listed (Rhoads and Klein 1993) and is the characteristic and dominant graminoid species of xeric limestone prairies (Laughlin and Uhl 2003), restricted to dry, south-southwest facing slopes within the Ridge and Valley region.

Seeds per pound: 159,000 seeds per pound (Ernst Conservation Seed)
Cost per pound: $12 per pound from Chesapeake Valley Seed and Ernst Conservation Seed
Cost per acre: $144.00 per acre
Suggested sowing rate: 12 pounds per acre (Cheaspeake Valley Seed)
Sowing depth: ¼ inch on fine textured soils and ¾ inch on coarse textured soil (USDA Plant Guide)
Germination time: 7 days when moisture is adequate (USDA Plant Guide)
Seeding timing: May 1 to July 20 (Meyer and Gaynor 2002)
Length of growing season: early spring to fall (Leithead et al. 1971)
Leaf height: 4-8 inches (Leithead et al. 1971)
Height at seed head stage: up to 30 inches but low growing growth forms up to 14 inches (Leithead et al. 1971), 15-30 inches (USDA Plant Fact Sheet)
Shade tolerance: Moderately tolerant (USDA Plant Guide)
Suggested mowing height: side-oats grama is best managed as a now-mow grass
Tolerance of wet conditions: tolerant of spring flooding (USDA Plant Guide)
Humidity tolerance: prefers xeric landscapes but can tolerate humid climates
Disease resistance: Grasshoppers can destroy seedlings. Stem and leaf ruse may occur during wet years. Side-oats grama is susceptible to several leaf spot and root rot fungi (USDA Plant Guide).

Services:

Commercial availability and cost: Side-oats grama is commercially available with seed costing less than buffalograss and blue grama. Seeding side-oats grama over a large area is affordable because seeding rate per acre is relatively low.

Rate of establishment: Side-oats grama can be propagated vegetatively and through seeding (Beard 1973). Fifty percent germination was observed in side-oats grama whereas 80% germination was observed for buffalograss (Harrington and Meikle 1992). Likewise, Tinsley et al. 2006 report a germination rate of 73% for side-oats grama, 93% for buffalograss, and 66% for little bluestem. Once germinated, excellent seedling vigor results in rapid establishment of side-oats grama (Sedivec et al. 2001). Rhizomes spread slowly such that lateral spread of plants is slow (Beard 1973). Side-oats grama was used in roadside trial in Virginia (Doak et al. 2004) but establishment was poorest for side-oats grama grown alone or with little bluestem (35% cover in both cases). Cover across 6 years never exceeded 53%. Side-oats grama, similar to blue grama, did not survive past the establishment year on reclaimed mine soil in southeast Ohio (Thorne and Cardina 2011) whereas eastern gamagrass and western wheatgrass established well. Native grass mixtures containing 32-35% side-oats grama by weight were slow to establish in Minnesota low-input trials (Miller et al. 2013).

Ease of maintenance: Side-oats grama is taller than blue grama and buffalograss. Yet, it thrives under low-intensity culture where mowing is minimal (Beard 1973). Under no-mow conditions in Minnesota, two native grass mixtures containing side-oats grama produced the best quality and had low weed cover compared to 6 other turfgrass mixtures (Miller et al. 2013).

Erosion control: Side-oats grama produces short rhizomes that form a weak sod compared to blue grama (Beard 1973). However, the root system is moderately deep, fibrous, branching, and spreading (Beard 1973, USDA Plant Guide). It is therefore used for bank stabilization in species mixes.

Ecosystem benefits: Side-oats grama provides high quality forage to livestock and wildlife (Willard and Schuster 1971, Sedivec et al. 2001) and remains palatable even into winter (USDA Plant Guide). Wild turkey eat its seed (Leithead et al. 1971). It is used widely for reseeding disturbed lands and croplands (Leithead et al. 1971) and is especially successful in rocky and shallow soils such as stony hillsides and breaks (USDA Plant Guide).

Resilience:

Drought: Side-oats grama is very drought tolerant (Sedivec et al. 2001, Johnson 2008) but inferior in drought tolerance to blue grama (Beard 1973). Similarly, Mueller and Weaver (1942) observed side- oats grama seedlings to be less tolerant than blue grama and dropseed but more drought tolerant than prairie junegrass.

Low fertility: Side-oats grama is adapted to shallow ridges and rocky slopes but responds well to fertilizer (Leithead et al. 1971). In low-input trials in Minnesota (Miller et al. 2013), two native grass mixtures containing 32-35% side-oats grama by weight performed well after the initial establishment year.

Freezing: Side-oats grama has excellent freezing tolerance. It can grow well in northern environments and has been observed at elevations of 7,000 feet (USDA Plant Fact Sheet). Side-oats grama had 84% winter mortality between the first and second growing season (Meyer and Gaynor 2002).

Salinity: Side-oats grama is moderately salt sensitive (Marcum 2002, 2008a). Side-oats grama was more salt sensitive than buffalograss and 5 other grasses (Marcum 1999). In a salinity experiment, Biesboer and Jacobson (1994) observed side-oats grama to be more salt sensitive than buffalograss and blue grama but, more salt tolerant than little bluestem, prairie dropseed, and sand dropseed. Similarly, Harrington and Meikle (1992) observed lower tolerance than buffalograss but higher tolerance than little bluestem. In contrast, Roberts and Zybura (1967) observed side-oats grama to be more tolerant of salt than buffalograss and blue grama but less tolerant than sand lovegrass and tall fescue.

Acidity: Side-oats grama is better adapted to calcareous and moderately alkaline soils than to neutral and acid soils (Leithead et al. 1971). However, it can grow on soils with pH ranging from 5.5 to 8.5 (Thorne and Cardina 2011).

Wear tolerance: Side-oats grama has poor mowing tolerance (Johnson 2008) and therefore requires a low-intensity culture (Beard 1973), if mowed at all (Johnson 2000). A southern Canada study that compared the responses of 24 native species and cultivars to three mowing heights (Mintenko et al. 2002) found that side-oats grama performed poorly compared to buffalograss and especially blue grama. However, side-oats grama is adapted to grazing suggesting that it can withstand infrequent mowing.

Competition: Side-oats grama rarely forms monospecific stands (Johnson 2008). Root and shoot biomass of side-oats grama were reduced in the presence of indiangrass (Weatherford and Myster 2011).

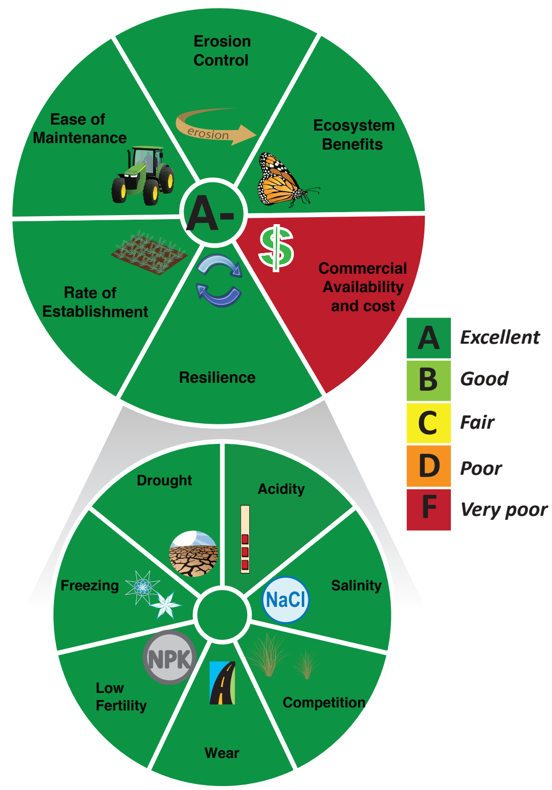
<u>Mixes</u>: Side-oats grama frequently occurs in native communities with blue grama and buffalograss (Beard 1973, Johnson et al. 2000, Tinsley et al. 2006). It is rarely planted alone but planted with other species, such as blue grama and little bluestem, to add diversity and visual interest (Johnson 2008). In a Minnesota low-input study of 8 seed mixtures, Miller et al. (2013) included side-oats grama at 32-35% by weight in two native seed mixtures. Both mixtures were the slowest to establish and had low quality and high weed cover in the establishment year. However in the second and third year of the study, turfgrass quality ratings were second and third only to a tall fescue blend. Weed cover sowed in native grass mixtures was higher or equal to plots seeded with tall fescue and fine fescues but lower than plots containing Kentucky bluegrass. A mix of little bluestem and side-oats grama used in a Virginia roadside trial established poorly and never exceeded 53% cover (Doak et al. 2004). Side-oats grama failed to become established in a stand of buffalograss (Willard and Schuster 1971).

<u>Cultivars</u>: Released varieties include ‘Butte’ from Nebraska, ‘El Reno’ from Oklahoma, ‘Haskell’ from Texas, ‘Niner’ from New Mexico, ‘Premier’ from Mexico, ‘Killdeer’ from North Dakota, and ‘Pierre’ from South Dakota (Johnson 2008). Cultivar ‘Trailway’ from Nebraska is winter hardy, long-lived, and late maturing and cultivar ‘Vaughn’ from New Mexico is easy to establish with good seedling vigor (USDA Plant Guide).

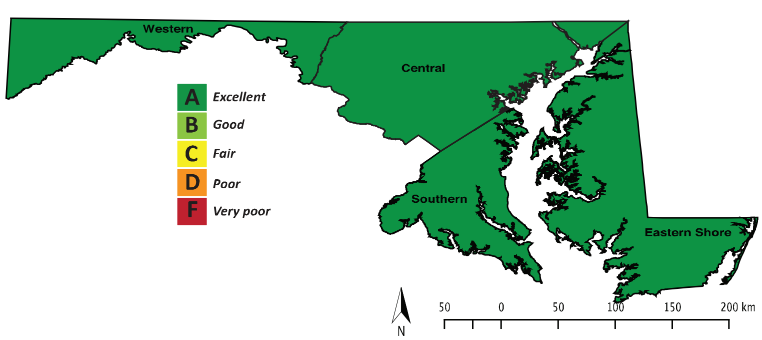
Purple lovegrass

Eragrostis spectabilis = Eragrostis spectabilis var. sparsihirsuta = Poa spectabilis

Purple lovegrass is native to the United States and has species traits that allow it to be resilient to roadside conditions, and provide services to roadside management including superior establishment, low stature to reduce maintenance, superior rooting for erosion control and excellent ecosystem benefits. It is rated as Excellent to Good (grade = A-) owing to only one major concern:



$ Purple lovegrass is commercially available only in limited quantities and seed is therefore very expensive.



Purple lovegrass is suitable for all regions of Maryland.

Purple lovegrass is an excellent species for roadside vegetation. Thus, this species should be developed further, including the development of regional ecotypes. Tiny lovegrass (*Eragrostis capillaris*) is another species that is currently not commercially available but suitable for roadsides.

Biology: Purple lovegrass is a perennial warm season grass that is native to eastern and central United States. Plants produce short and slender rhizomes that connect individual bunches into colonies (USDA plant fact sheet). As a C_4 plant, purple lovegrass actively grows in the summer months. Due to its aesthetic appeal in the landscape, it is considered in China to be cultivated as a non-native ornamental plant (Qing et al. 2013). Purple lovegrass has been observed at sites in 15 counties of central and southern Maryland, including the Eastern Shore (Maryland Biodiversity Project).

Seeds per pound: 4,480,000 seeds per pound
Cost per pound: $180 per pound from Ernst Conservation Seed and Cheaspeake Valley Seed
Cost per acre: $900.00
Suggested sowing rate: 5 pounds per acre (Chesapeake Valley Seed; USDA Plant Fact Sheet)
Sowing depth: Seeds should not be covered; germination percentage decreases with soil depth between 0.4-1.6 inches (Qing et al. 2013).
Germination time: 14-21 days, depends on temperature (Baskin and Baskin 1967, Qing et al. 2013)
Seeding timing: Seed in mid- to late spring
Length of growing season: spring to fall
Leaf height: 8-18 inches (USDA plant fact sheet)
Height at seed head stage: 12-36 inches (USDA Plant Fact Sheet)
Shade tolerance: prefers full sun but can tolerate partial shade
Suggested mowing height: best for no-mow conditions
Tolerance of wet conditions: requires well drained soils
Humidity tolerance: adapted to the humid climate of eastern United States
Disease resistance: no serious disease or insect problems

Services:

Commercial availability and cost: Purple lovegrass is available in limited quantities through native plant nurseries. While the sowing rate per acre for purple lovegrass is low, the cost per pound is very expensive.

Rate of establishment: Purple lovegrass establishes readily from seed (USDA Plant Fact Sheet). Purple lovegrass has a high percentage of germination (60% in Qing et al. 2013) and establishes rapidly. Seeds of purple lovegrass go through a period of dormancy as indicated by no germination of freshly collected seed (Baskin and Basin 1969). Seed germination of purple lovegrass increased to 97% when stratified at 3-5^{o}C for 10 weeks. Ten weeks is a relatively short period of stratification and suggests that seeds are ready to germinate in the spring. However, germination is delayed until spring temperatures reach at least 30^{o}C (Baskin and Baskin 1967) to 35^{o}C (Qing et al. 2013).

Ease of maintenance: Purple lovegrass is a relatively low-stature plant that requires no irrigation or fertilizer. It can be used in no-mow conditions. Because it produces a striking purple plumage in the summer it should not be mowed in the summer for maximum effect. The grass should be cut back in the winter for best spring growth.

Erosion control: The root system of lovegrass is fibrous as well as deep. Purple lovegrass developed a mean maximum root length of 76 cm among rooting columns in Rhode Island (Brown et al. 2010). Rooting distribution was exceptional even compared to other grasses. The combination of deep rooting, even root distribution and relatively short stature suggests that purple lovegrass can be an excellent species for anchoring roadside slopes in low-maintenance conditions (Brown et al. 2010).

Ecosystem benefits: Purple lovegrass is native to North America. It provides nesting cover for ground birds such as the Botteri's sparrow. The seeds have high nutritional value and are therefore a valuable food resource for song birds and small mammals. Butterflies and moths, such as paradoxical grass moth (*Heliochelius paradoxus*) and purple-top sun moth (*Heliochelius turbata*) are attracted to plants. The leaf hopper *Flexamia areolate* and caterpillars of *Poanes zabulon* use the foliage and juices for food (Illinois Wilflowers Info). Wildlife will graze purple lovegrass during spring and summer, and deer may dig up the basal part of the stem in the winter (Lorenz's OK Seeds). Purple lovegrass may be referred to be farmers as 'ice-cream plant' for their livestock (Illinois Plant Information Network).

Resilience:

Drought: Purple lovegrass is drought and heat tolerant. Growth response of purple lovegrass to drought was compared to that of non-native ornamental grass *Miscanthus sinensis* (maiden grass) (Alvarez et al. 2006, 2007). Greater biomass gain and higher water stress integrals indicated that purple lovegrass continued to photosynthesize during drought by keeping stomata open and tolerating low water potentials. *Miscanthus* on the other hand, closes its stomata during drought, which preserves water potential but shuts down growth. In contrast, in a roadside backslope trial in Rhode Island, purple lovegrass was one of 8 species (out of 14) that did not survive a drought (Brown et al. 2010) although the authors attribute this mortality to be due to the use of a non-local ecotype (from Florida) than due to a lack of drought tolerance.

Low fertility: Purple lovegrass thrives on soils of low fertility.

Freezing*:* Purple lovegrass is cold tolerant.

Salinity: Purple lovegrass thrives along roadsides that receive salt (Prairie Moon Nursery). Among 10 species studied, close cousin sand lovegrass (Eragrostis trichoides) was one of the most salinity tolerant species studied, only second to 'Kentucky 31' tall fescue, when a saline solution was applied to established turf (Roberts and Zybura 1967). However, when salt was applied to seeded soil, sand lovegrass, with three Bouteloua species, was one of the slowest to establish.

Acidity: Purple lovegrass has low tolerance for $CaCO_3$ (Lady Bird Johnson Wildflower Center). pH range is 4.6 to 7.8.

Wear tolerance: Unknown

Competition: Purple lovegrass can be excluded by faster growing species in areas that are moist and fertile. However in drier, infertile sites, purple lovegrass is a good competitor.

Mixes: Purple lovegrass grows in colonies and is not a dominant species in grassland communities (USDA plant fact sheet). Purple lovegrass can be used alone in mass plantings or mixed with native flowering plants such as *Rudbeckia fugida*, *Ruellia humilis*, and *Eurybia divaricate* (North Creek Nurseries). Brown et al. (2010) suggest planting purple lovegrass with fine fescues to enhance vegetative spread, minimize winter dormancy, and decrease costs.

Species/Cultivars: Tiny lovegrass, also called lacegrass, is a small stature (culms are 15-60 cm and leaves are 6-30 cm long) native plant that may be an excellent choice for low-maintenance roadsides. However, the species is not available commercially and too little is known about its biology to assess the suitable of this species for Maryland right-of-ways. In Maryland, tiny lovegrass has been documented to occur in the Piedmont of Montgomery, Prince Georges, and Anne Arundel Counties (Maryland Biodiversity Project).

Little bluestem

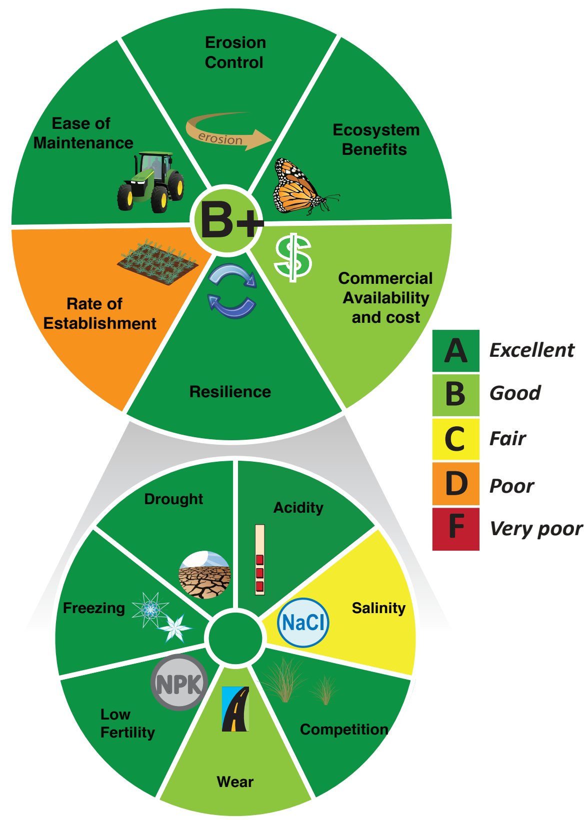
Schizachyrium scoparium = Andropogon scoparius

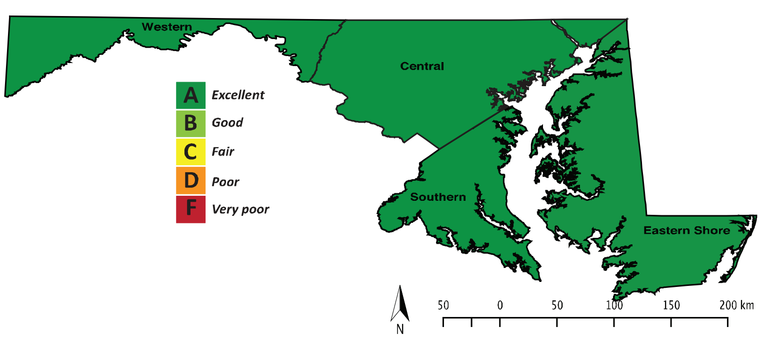
Little bluestem is a native grass that provides excellent ecosystem benefits for wildlife and disturbed soils reclamation. It can be mixed with other native species for biodiversity enhancement. Plants are short-statured requiring little maintenance, deep-rooting for anchoring soil, and resilient to many stressful environmental conditions including low fertility and acid soils, freezing temperatures, and drought. Little bluestem is rated as Good to Excellent (grade = B+) for use as a roadside species with a few management concerns:


Little bluestem seed is commercially available but the cost of seeds is high. Due to low sowing rates, it is affordable when planted in large areas.


Germination rate can be low and rate of establishment is slow, typically requiring > 2 years. Once established, however, it is a superior performer.

Little bluestem is sensitive to salinity, which decreases its resilience in areas that receive road salt in high concentrations.





Little bluestem is adapted to environmental conditions throughout Maryland.


Cultivars that are available commercially are Carousel, The Blues, Standing Ovation and Pastura, but none are native to the mid-Atlantic region. Local ecotypes should be used to maximize plant adaptation to local environmental conditions.

Biology: Little bluestem is a native perennial warm season (C_4) bunchgrass that is wide-spread in North America (Leithead et al. 1971, Steinberg 2002, Tober and Jensen 2013) and can grow in the eastern United States at low elevations in coastal prairie up into the higher elevations of the Appalachian Mountains (Small and Wentworth 1998). Little bluestem occurs most commonly on dry sites, especially ridges, hilltops and steep slopes (Tober and Jensen 2013). It is commonly used in restoration plantings and native turf meadow mixes (Johnson 2008, Tober and Jensen 2013). Little bluestem is so common in native prairie that it is the official state grass for Nebraska and Kansas.

Seeds per pound: 225,000-250,000 (Steinberg 2002, Tober and Jensen 2013)
Cost per pound: \$16 per pound from Chesapeake Valley Seed and Ernst Conservation Seed
Cost per acre: \$192.00 per acre
Suggested sowing rate: 12 pounds per acre (Chesapeake Valley Seed); 2.5 to 4.5 pounds per acre (Tober and Jensen (2013), or when broadcasting 7-12 pounds per acre (USDA plant fact sheet).
Sowing depth: ¼ to ¾ inch (USDA plant fact sheet)
Germination time: 6 days with proper stratification (30-60 days at 105.8^{o}F) and daytime temperature of 86^{o}F (Steinberg 2002)
Seeding timing: Little bluestem should be seeded as early in the spring as possible (USDA plant fact sheet).
Length of growing season: Late spring to fall if moisture is adequate (Leithead et al. 1971) until the first killing frost (USDA plant fact sheet).
Leaf height: 6-10 inches (Leithead et al. 1971), 3-20 inches (Steinberg 2002), 2-12 inches (Tober and Jensen 2012)
Height at seed head stage: 2-4 feet (Leithead et al. 1971), 1.6-6.6 feet (Steinberg 2002), 1-3 feet (Tober and Jensen (2013)
Shade tolerance: Little bluestem grows best in full sun.
Suggested mowing height: unknown
Tolerance of wet conditions: Little bluestem is adapted to well-drained soil. It has poor to fair flooding tolerance (USDA plant fact sheet).
Humidity tolerance: unknown
Disease resistance: Little bluestem is susceptible to leaf spot (Tober and Jensen 2013).

Services:

\$ *Commercial availability and cost*: Little bluestem seed production is consistent and is sold by most native plant nurseries. The cost of seeding a large area is affordable given the low sowing rates of little bluestem.

Rate of establishment: Germination in the field appears to be low (Steinberg 2002) and requires stratification as well as daytime temperatures between 20-30^{o}C (68-86^{o}F). Tinsley et al. (2006) report a germination rate of 66% for little bluestem; however, when sown in field plots in Texas, little bluestem establishment success relative to initial sowing was only 0.7% within a 60-day period and composed 1-6% of total plant density. Biesboer and Jacobson observed 50% germination in field plots in Minnesota; and Gibson and Carrington (2008) observed 9-14% germination in laboratory petri dishes and 1-3% germination in field plots. Little bluestem establishes slowly (Mischkolz et al. 2013, Miller et al. 2013, Tober and Jensen 2013) because plants invest in root growth before shoot growth. Thus, full establishment may require more than 2 years (Mischkolz et al. 2013, Miller et al. 2013). When a 4 and 7 year old restoration planting was sampled, Yurkonis et al. 2010 observed little bluestem to be one of the dominant species that had established from seed mixes.

Ease of maintenance: Little bluestem is a moderately low-stature plant and can grow successfully in low maintenance conditions. Miller et al. (2013) selected little bluestem as the dominant species (53%) in a native seed mix and found that it performed well in Minnesota in the second and third year especially under no-mow conditions.

Erosion control: Little bluestem is generally non-rhizomotous but has a sod-forming habit with deep and fibrous roots (Steinberg 2002, Tober and Jensen 2013). Little bluestem developed a mean root length between 46 to 76 cm in Rhode Island rooting column experiments (Brown et al. 2010). Steinberg (2002) reports a rooting depth between 1.3 and 1.75 m (4.5-5.5 feet). The good combination of deep rooting, even root distribution and short stature highlights little bluestem as an excellent species for anchoring roadside slopes in low-maintenance conditions such as roadsides (Brown et al. (2010).

Ecosystem benefits: Little bluestem is a valuable forage species for livestock (Leithead et al. 1971) and is considered to be one of the best grasses for nesting and roosting habitat (Tober and Jensen 2013). It provides food and cover for many upland bird species such as the Baltimore Oriole (Steinberg 2002), and chipping, field, and tree sparrows (Tober and Jensen 2013). Butterfly caterpillars may overwinter above the base of little bluestem clumps (Tober and Jensen 2013). Little bluestem is used for reclamation of mine spoils and is most successful when soils are amended with organic matter (Steinberg 2002). It is also used extensively in native landscaping (Tober and Jenson 2013). Native American tribes used little bluestem in ceremonial sweat lodges and as lining and insulation for moccasins (Tober and Jensen 2013).

Resilience:

Drought: Little bluestem can withstand prolonged drought periods (Leithead et al. 1971) due to its long roots that can access water resources and its association with arbuscular mycorrhizae, which increase in abundance with declining water levels (Steinberg 2002). During the severe drought in the 1930's in Kansas, however, little bluestem was replaced by more drought resistant sideoats grama. (Albertson 1937). During the seedling stage, little bluestem is less tolerant to drought than grama grasses but more tolerant than big bluestem, switchgrass, indiangrass, prairie junegrass, basin wildrye and western wheatgrass (Mueller and Weaver 1942). Little bluestem was able to survive a drought in a backslope trial when planted along a roadside in Rhode Island whereas 8 out of 14 species planted did not survive (Brown et al. 2010). In a frontslope trial, however, little bluestem and most other species with exception of prairie junegrass had poor survival as a result of nutrient deficiency and drought stress (Brown et al. 2010).

Low fertility: Little bluestem thrives on low fertility soils and will be competitively excluded from communities when resources are more abundant.

Freezing*:* Little bluestem has excellent tolerance to cold environments and can thrive in the northern United States as well as Canada.

Salinity: Little bluestem is tolerant of salinity concentrations commonly encountered along roadsides (Biesboer and Jacobson 1994, Gibson and Carrington 2009). Biesboer and Jacobson (1994) seeded little bluestem into experimental plots in Minnesota and subjected soils to salt treatments ranging from 0 to 20,000 ppm salt. Percent germination was 50% when no salt was added and decreased to 12% in 2,500 ppm, 10% under 5,000 ppm, 6% under 10,000 ppm and no germination at higher concentrations. In another experiment, they observed 15% germination by day 15 but none of the seedlings survived past day 25. In Minnesota, roadside soils rarely approached 2,500 ppm, suggesting that little bluestem would be able to germinate although at a reduced rate. In a similar experiment in Illinois, Gibson and Carrington (2008) observed 9-14% germination in seeded plots subjected to a range of salinity treatments. Percent germination was not affected by salinity and even increased slightly.

Acidity: Little bluestem prefers neutral to alkaline soils (Leithead et al. 1971) of pH 7 and higher (USDA plant fact sheet). pH of 5.5 or higher is sufficient for establishment (USDA plant fact sheet) and Thorne and Cardina (2011) report a pH range from 4.8 to 8.

Wear tolerance: Little bluestem is adapted to grazing but is negatively affected by intense grazing. Little bluestem is not tolerant of low mowing heights (Johnson 2008).

Competition: Little bluestem is competitive when resources are limited but will decline in cover and be excluded in more productive habitats.

<u>Mixes</u>: Brown et al. (2010) recommends mixing little bluestem (which is dormant in the winter months) with cool season grasses that have minimal winter dormancy. Little bluestem was used in a native grass mixture to test which of eight mixtures performed better in low maintenance trials in Minnesota (Miller et al. 2013). The mixture containing little bluestem (53%) also included 32% side-oats grama, 10% blue grama, 3% prairie junegrass, 1% poverty oat grass, and 1% kalm's brome. The mixture was the slowest among the eight mixtures to establish with 47% cover 56 days after seeding as opposed to 95% cover for the best performing mixtures (tall fescue blend and fine fescue mixture). However, after underperforming in the first year of establishment, the native mixture received very good turf quality ratings in the second and especially the third year of growth under minimal mowing conditions. Percent weeds in the third year was moderate (12%) and significantly lower than a Kentucky bluegrass blend. Under no-mow conditions, the mixture obtained the best quality ratings by the third year and supported few weeds (7%). Fine fescues also performed well but were affected by diseases (leaf spot and melting out) even though these did not affect quality ratings. Miller et al. (2013) conclude that native warm season grass mixtures are well suited for no mow conditions owing to their interesting foliage and seed heads. Selecting seed mixtures is important to allow for species to self-organize into communities that are adapted to the local environment.

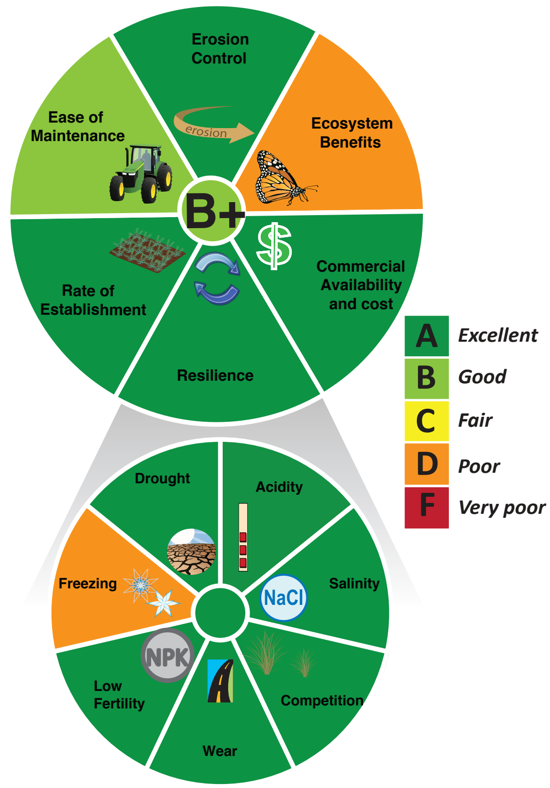
<u>Cultivars</u>: Little bluestem exhibits a broad range of ecotypic variation due to its broad distribution (Tober and Jensen 2013). Cultivar 'Carousel' is a compact plant developed by Chicagoland Grows. Cultivars 'The Blues' and 'Standing ovation' have ornamental utility. Cultivar 'Pastura' originates from New Mexico and is a prolific seed producer (Steinberg 2002). Local ecotypes may be available from local seed venders (USDA plant fact sheet).

Weeping lovegrass

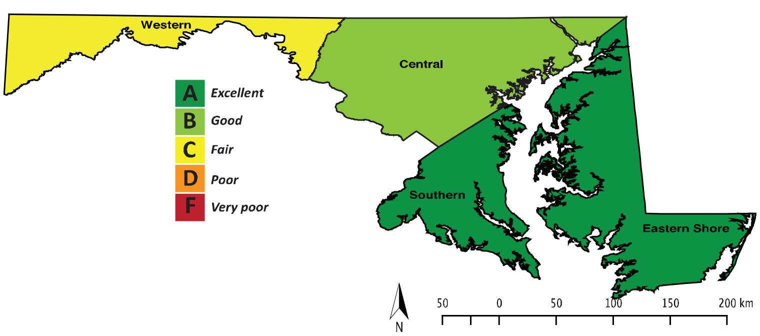
Eragrostis curvula = Eragrostis curvula var. conferta = Eragrostis curvula var. curvula = Eragrostis robusta = Eragrostis chloromelas

Weeping lovegrass is frequently used along roadsides in Mid-Atlantic States but is currently not planted in Maryland. The species establishes rapidly, produces a deep root system that is important for erosion control and bank stabilization, and it is resilient to most roadside conditions. Unlike its native cousin, purple lovegrass, weeping lovegrass is commercially available at reasonable cost. Weeping lovegrass, is rated as Good to Excellent (grade = B+) owing to several management concerns:

Weeping lovegrass can be an aggressive competitor in ecosystems and is considered an invasive species in some states.



Weeping lovegrass is a low-maintenance grass but produces taller plants. Thus, it may require more mowing in areas where site distance needs to be maintained.



Weeping lovegrass is sensitive to cold temperatures but can survive as an annual. It is not recommended for use in Western Maryland.

Weeping lovegrass includes several cultivars that are commercially available. Their suitability in Maryland is unknown.

Biology: Weeping lovegrass is a commercially available perennial warm season grass that was introduced in 1935 into the United States from East Africa. Weeping lovegrass is commonly used in West Virginia (Rentch et al. 2005), Virginia, and Pennsylvania (Landschoot *pers. communication*) along highway corridors. It is also commonly found along roads, fencerows, and railroads in Missouri (Missouri Botanical Garden) and Illinois (Illinois plant information network). In Maryland, weeping lovegrass has been documented to occur in 7 counties of Central and southern Maryland, including the Eastern Shore (Maryland Biodiversity Project).

Seeds per pound: 1,482,000 seeds per pound
Cost per pound: $8.00 per pound from Chesapeake Valley Seed and Ernst Conservation Seed
Cost per acre: $24.00 per acre
Suggested sowing rate: 3 pounds per acre (Chesapeake Valley Seed)
Sowing depth: Seeds should not be covered; germination percentage decreases with soil depth between 1-4 cm (Qing et al. 2013).
Germination time: 14-21 days
Seeding timing: Seed in mid- to late spring
Length of growing season: early spring to late fall (Heuze et al. 2015)
Leaf height: 19.5 inches (Heuze et al. 2015)
Height at seed head stage: 4-6 feet (Heuze et al. 2015)
Shade tolerance: prefers full sun but can tolerate partial shade
Suggested mowing height: unknown
Tolerance of wet conditions: requires well drained soils
Humidity tolerance: adapted to the humid climate of eastern United States
Disease resistance: no serious disease or insect problems

Services:

Commercial availability and cost: Weeping lovegrass is commercially available at a price that is lower than upland bentgrass. Weeping lovegrass is an affordable species to plant over large areas.

Rate of establishment: Weeping lovegrass establishes readily from seed (USDA Plant Fact Sheet).

Ease of maintenance: Weeping lovegrass produces taller plants than purple lovegrass but can still be considered a low-maintenance grass.

Erosion control: The root system of weeping lovegrass is fibrous as well as deep.

Ecosystem benefits: Weeping lovegrass can be important ground cover in areas where conditions are too stressful for other species to thrive. The foliage turns a red-bronze in the fall, and the plumage produces a purplish haze in the summer. In 2012, the US Forest Service added weeping lovegrass to the Southern Research Station Forest Inventory and Analysis Manual SRS-FIA manual (version 6.0) as an invasive species. Owing to its abundant seed production that can spread into disturbed areas, it is considered a serious weed in most areas of Australia (Heuze et al. 2015). Thus, it is a highly successful species in southern locations to the extent that it can become invasive to neighboring native ecosystems. This may not be as much of an issue in northern states owing to an intolerance of weeping lovegrass to cold temperatures that cause mortality in plants and effectively change weeping lovegrass into an annual species that reseeds itself every year (USDA plant fact sheet).

Resilience:

Drought: Weeping lovegrass is drought and heat tolerant (Heuze et al. 2015).

Low fertility: Weeping lovegrass thrives on soils of low fertility (Heuze et al. 2015).

Freezing*:* Weeping lovegrass is susceptible to cold winter temperatures, which will prevent regrowth and force plants to re-establish from seeds (USDA Plant Fact Sheet). It can grow from sea level to 3,500 m (Heuze et al. 2015).

Salinity: Weeping lovegrass thrives along roadsides that receive salt.

Acidity: Weeping lovegrass has a pH range from 4.6 to 7.8 but prefers neutral to basic soils (Heuze et al. 2015).

Wear tolerance: Weeping lovegrass can be grazed and mown regularly (Heuze et al. 2015).

Competition: Weeping lovegrass formed a dominant part of the plant canopy during the first year of establishment but cover in the second and third year decreased due to competition with other species (Punshon et al. 2002).

Mixes: Weeping lovegrass grows in colonies and can be used alone in mass plantings or mixed with other species.

Cultivars: Weeping lovegrass cultivars include ‘A-67’, ‘Ermelo’ and ‘Morpa’.

Blue grama

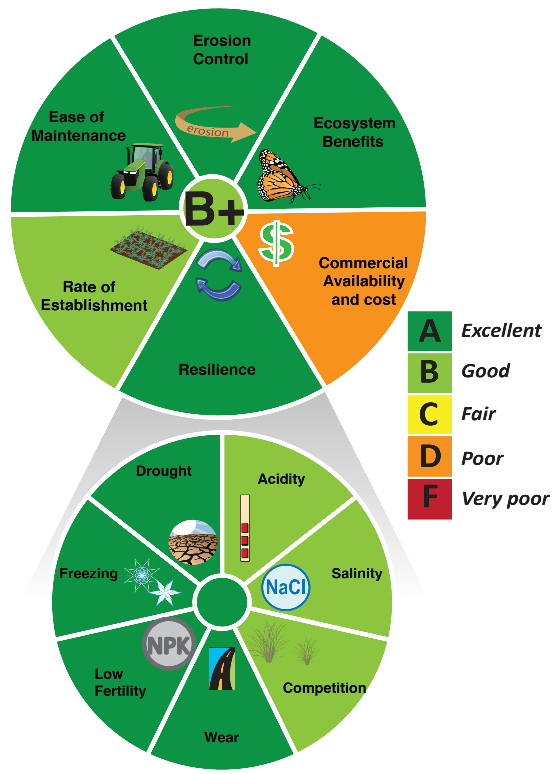
Bouteloua gracilis

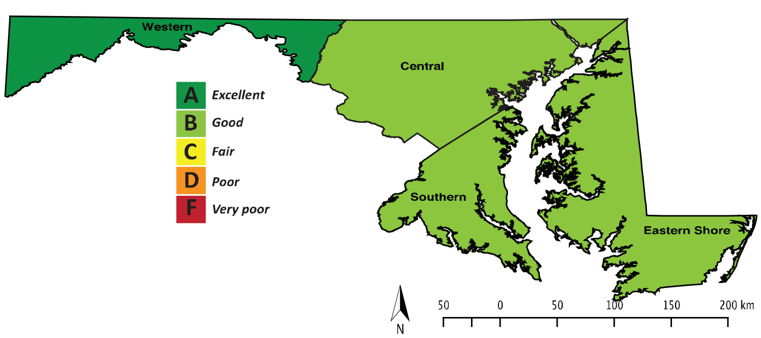
Blue grama is native to the short-grass prairies of North America and is therefore well adapted to drought. It is used extensively in low-maintenance and low-input environments, such as roadsides and mine reclamations, owing to its excellent ecosystem benefits, ability to stabilize soil to reduce erosion, and short growth habit that reduces the need for mowing. Blue grama has excellent resilience to most roadside conditions such as drought, freezing, traffic, and low soil fertility. Rated as Good to Excellent (grade = B+), blue grama may be a suitable species for Maryland roadsides with a few challenges:

Blue grama is commercially available but seed costs are high.

Blue grama germinates rapidly but establishes slowly, requiring herbicide use within the first 1-2 years to suppress weeds.

Competitive ability may be reduced in humid environments such as the mid-Atlantic region, which may decrease long-term persistence without management intervention.





Humidity tolerance may be low. Thus, blue grama is best suited for the drier climates of Western Maryland near Green Ridge but may perform adequately throughout the state.

Cultivar Bad River is adapted to cooler climates and therefore suitable for planting in Maryland.

Biology: Blue grama is a perennial warm season grass species that is native to the Great Plains region of North America and adapted to transitional, warm subhumid, warm semiarid, and warm portions of the cool subhumid regions (Beard 1973). It is a dominant species of the short grass steppe, comprising >60% of basal cover (Lowe et al. 2003) and often associated with buffalograss (Johnson 2008). Blue grama is rare outside of the Great Plains region. Owing to its drought tolerance and fast recovery rate after drought, blue grama was an important species for conservation and agriculture after the 1930's drought (Savage and Jacobson 1935, Albertson 1937, Albertson and Weaver 1944). In cooler environments or where grazing pressure is intense, blue grama will form a dense sod, whereas in warmer climates it occurs predominantly as a bunch grass (USDA Plant Guide). Blue grama is used mostly in non-use and low-maintenance environments such as roadsides and similar non-irrigated areas where culture intensity is low and turfgrass quality is less important (Beard 1973, Sedivec et al. 2001). It is also used in surface mine reclamation (USDA Plant Guide).

Seeds per pound: 700,000 to 800,000 seeds per pound (USDA Plant Guide)
Cost per pound: $15 per pound from Chesapeake Valley Seed
Cost per acre: $525.00 per acre
Suggested sowing rate: 35 pounds per acre (Chesapeake Valley Seed)
Sowing depth: 0.25 to 0.5 inches (Sedivec et al. 2001)
Germination time: 3-6 days (Biesboer and Jacobson 1994, Biesboer et al. 1995)
Seeding timing: April to mid-May (USDA Plant Guide)
Length of growing season: late May, becomes dormant in the summer and grows again in the fall (Leithead et al. 1971)
Leaf height: 9-18 cm (Lowe et al. 2003)
Height at seed head stage: 12-16 inches (Leithead et al. 1971), 10-24 inches (Simmons et al. 2011), 6-25 inches (USDA Plant Guide)
Shade tolerance: Low
Suggested mowing height: Mowing may be needed to control weeds. Blue grama will tolerate a variety of mowing heights that are similar to those of buffalograss.
Tolerance of wet conditions: Hard fescue needs well-drained soil but can tolerate higher soil moisture than sheep fescue.
Humidity tolerance: Low
Disease resistance: Grasshoppers and white grub larvae will feed on leaves and roots, respectively (USDA Plant Guide). Blue grama is susceptible to leaf and tar spot and rust diseases in South Dakota (USDA Plant Guide).

Services:

Commercial availability and cost: Blue grama is commercially available but, has a high cost per pound of seed. Even with a lower sowing rate, planting this species over a large area can be moderately expensive.

Rate of establishment: Beard (1973) considers establishment of blue grama to be rapid and easy; however, survival of seedlings depends on adequate moisture while seedlings are growing adventitious roots (USDA Plant Guide). In a germination study (Biesboer and Jacobson

1994, Biesboer et al. 1995), blue grama started germinating within 3 days of planting and reached 40-50% germination after 6 days. In contrast, buffalograss started germinating after 6 days and reached 75-80% after 10 days. However, in a salinity experiment, emergence of blue grama was 44% in a control (no salinity) treatment whereas it was 81% in alkaligrass and 85% in Kentucky bluegrass (Neid and Biesboer 2004). In a Virginia roadside trial (Doak et al. 2004), blue grama averaged 94% cover at a study location in the Piedmont region suggesting that blue grama may be better adapted to Piedmont areas where competition from other more aggressive warm season grasses is reduced. However, in Minnesota native plant trials (Meyer and Pederson (1999), blue grama planted as plugs did not provide acceptable cover, color, or overall quality ratings and had major winter injury after the first year. Blue grama was slow to establish and had poor turf quality across 2 years at almost all 8 locations in the North Central Region of the United States (Watkins et al. 2011). Native grass mixtures containing 10-17% blue grama by weight were slow to establish in Minnesota low-input trials (Miller et al. 2013). Blue grama did not survive past the establishment year on reclaimed mine soil in southeast Ohio (Thorne and Cardina 2011) whereas eastern gamagrass and western wheatgrass established well. Blue grama established well when plots were sprayed with herbicide prior to seeding and when the establishment year was suitably wet (MacDougall et al. 2008). Once established, the native community dominated by blue grama was able to resist invasion by exotic species.

Ease of maintenance: Blue grama has a short growth habit (Beard 1973) and therefore requires less mowing (McKernan et al. 2001). Under no-mow conditions, two native grass mixtures containing blue grama produced the best quality and had low weed cover compared to 6 other turfgrass mixtures (Miller et al. 2013).

Erosion control: Blue grama produces short, stout rhizomes that result in high shoot densities and a dense sod (Beard 1973). The root system is fibrous, dense and extensive (Beard 1973) such that blue grama is used with other grasses for erosion control. Beard (1973) rated the roots system as shallow, but the depth of rooting may have been underestimated.

Ecosystem benefits: With buffalograss, blue grama is one of the most important forage plants of the short-grass prairie (USDA Plant Guide). Blue grama is a choice forage for livestock and wildlife and may be harvested for hay (Leithead et al. 1971).

<u>Resilience</u>:

Drought: Blue grama has excellent drought and heat tolerance (Beard 1973, Mintenko et al. 2002, Zhang et al. 2012) owing to a medium low evapotranspiration rate (Kim 1983, Kim and Beard 1988). Motivated by the severe drought of the 1930’s, Mueller and Weaver (1942) experimented with the drought tolerance of 14 species and observed blue grama seedlings to be the most resistant to drought compared to buffalograss > dropseed > side-oats grama > prairie junegrass. Blue grama had intermediate evapotranspiration rates when compared to 11 other turfgrass species and cultivars (Kim 1983), higher than buffalograss, zoysia, bahiagrass, centipedegrass, and common and ‘Tifgreen’ bermudagrass but lower than ‘Tifway’ bermudagrass, St. Augustinegrass, sand knotgrass, and tall fescue. However, blue grama had significantly higher leaf extension rates (6.31 mm/day) under water stress compared to all other species and cultivars (Kim 1983). Blue grama used in a Virginia roadside trial was able to maintain 60-77% cover across 5 years and was only marginally impacted by a severe drought (Doak et al. 2004). Blue grama, hard fescue, and sheep fescue had superior long-term area coverage at two sites in Alberta that were impacted by drought (McKernan et al. 2001). Additionally, blue grama was one of the most drought tolerant species at both Alberta sites (McKernan et al. 2001), similar to wheatgrasses, Canada bluegrass and 'Washington' Kentucky bluegrass and higher than fine fescues, tall fescue, and junegrass. Blue grama and buffalograss had superior plant vigor and color than tall fescue and Kentucky bluegrass under rain-fed conditions whereas the reverse was observed under irrigated conditions (Islam et al. 2013). Cultivar 'Bad River' showed the most promise as a drought resistant blue grama cultivar compared to cultivars 'Alma' and 'Hachita' (Islam et al. 2013).

Low fertility: Blue grama grows best on loams and sandy loams and does not grow well on sand, gravel, or clay (Leithead et al. 1971). It responds well to nitrogen fertilization of 0.1 to 0.3 pounds per 1000 sq. ft. (Beard 1973). In low-input trials in Minnesota (Miller et al. 2013), two native grass mixtures containing 10-17% blue grama by weight performed well after the initial establishment year.

Freezing: Blue grama has excellent low-temperature tolerance (Beard 1973, Mintenko et al. 2002, Stier and Fei 2008), grows at elevations between 3,500 to 7,000 ft in New Mexico, and has been reported to grow up to 10,000 ft (USDA Plant Guide).

Salinity: Blue grama is ranked as moderately tolerant to salinity (Leithead et al. 1971, Harivandi et al. 1992, Uddin 2013) to salt sensitive (Marcum 2008a). In a salinity experiment, Biesboer and Jacobson (1994) observed blue grama to be the most salt tolerant of all species planted, including buffalograss > side oats grama > little bluestem > prairie dropseed > sand dropseed. In contrast, Roberts and Zybura (1967) rank blue grama as lower in salinity tolerance to buffalograss < side-oats grama < sand lovegrass < fescue. Blue grama and buffalograss were the most capable of germinating under high salt concentrations (Biesboer and Jacobson 1994) but higher salt concentrations reduced germination success, seedling survival, and seedling root and shoot biomass (Biesboer et al. 1995). Blue grama attained high germination under moderate to high deicer concentrations similar to buffalograss, little bluestem, mountain brome, and slender wheatgrass (Dudley et al. 2014). In a salinity experiment, blue grama emergence decreased by 12% in a salt solution compared to a no-salt control with higher levels of fertilizer decreasing emergence. In comparison alkaligrass decreased 8% and Kentucky bluegrass 37% in salt solution (Neid and Biesboer 2004). Cultivars 'Lovington' and 'Bad River' had the best germination rates (80-95%) of 8 blue grama and buffalograss cultivars tested under four salinity treatments suggesting blue grama cultivars, on average, have higher salinity tolerance than buffalograss (Zhang et al. 2012). Germination declined to below 40% when salinity was increased from 5 to 10 g NaCl per liter and to less than 5% at higher salt concentrations. Although blue grama had higher salinity tolerance during germination, blue grama showed a greater reduction in vegetative growth than buffalograss when treated with saline water (Zhang et al. 2012) with cultivars 'Lovington' and 'Bad River' performing better than cultivar 'Hachita' under salinity stress.

Acidity: Blue grama tolerates alkaline soils (Beard 1973) and grows on soils ranging in pH from 6.6 to 8.4 (Thorne and Cardina 2011).

Wear tolerance: Blue grama requires a low intensity culture with infrequent mowing at a height of at least 2-3 inches (Beard 1973). Growing points are close to the ground such that plants can withstand close grazing or mowing (Leithead et al. 1971). In a northern

Great Plains study that compared the performance of 25 native species and cultivars (Mintenko et al. 2002), two blue grama varieties (‘Bad River’ and a Minnesota ecotype) and ‘Barkoel’ prairie junegrass had the highest turf quality at all mowing heights, across three years, and across both study locations.

Competition: Blue grama is a competitive species at low nitrogen levels. However, at higher nitrogen levels its growth is affected by competition from exotic invaders (Lowe et al. 2003). Blue grama has good seedling vigor and will dominate stands when seeded together with buffalograss (Johnson 2008). Similarly, blue grama was able to coexist well in polyculture with buffalograss and resist invasion by weeds (Simmons et al. 2011). In restoration plantings, blue grama dominated restored plots in the first couple of years after planting but was subsequently replaced by *Elymus lanceolatus* (Bakker and Wilson 2004). Weeds within blue grama turf may be controlled by mowing, grazing or herbicide applications (USDA Plant Guide).

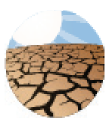
Mixes: Blue grama is rarely planted alone and is often mixed with buffalograss (Johnson 2000). Blue grama frequently occurs in native communities with buffalograss and side-oats grama (Beard 1973). In a Minnesota low-input study of 8 seed mixtures, Miller et al. (2013) included blue grama at 10-17% by weight in two native seed mixtures. Both mixtures were the slowest to establish and had low quality and high weed cover in the establishment year. However in the second and third year of the study, turfgrass quality ratings were second and third only to a tall fescue blend. Weed cover sowed in native grass mixtures was higher or equal to plots seeded with tall fescue and fine fescues but lower than plots containing Kentucky bluegrass. Virginia roadside trials (Doak et al. 2004), used blue grama alone and in mixtures with little bluestem and buffalograss. Blue grama alone and the mixture with buffalograss maintained >70% cover in most years after the first establishment year and despite a severe drought. The mixture with buffalograss performed better than blue grama by itself.

Cultivars: Blue grama is mostly available as ecotypes but none have been selected for turfgrass applications (Johnson 2008). Cultivar ‘Lovington’ from New Mexico was released in 1963 (USDA Plant Guide). Cultivar ‘Hatchita’ from New Mexico was released in 1980 and is the most drought tolerant blue grama cultivar; cultivar ‘Alma’ from New Mexico was released in 1992 for rangeland improvement; and cultivar ‘Bad River’ from South Dakota establishes rapidly and was released in 1996 to be used in cooler regions (Johnson 2008, USDA Plant Guide). Plugs and sod are also available from a variety of commercial sources.

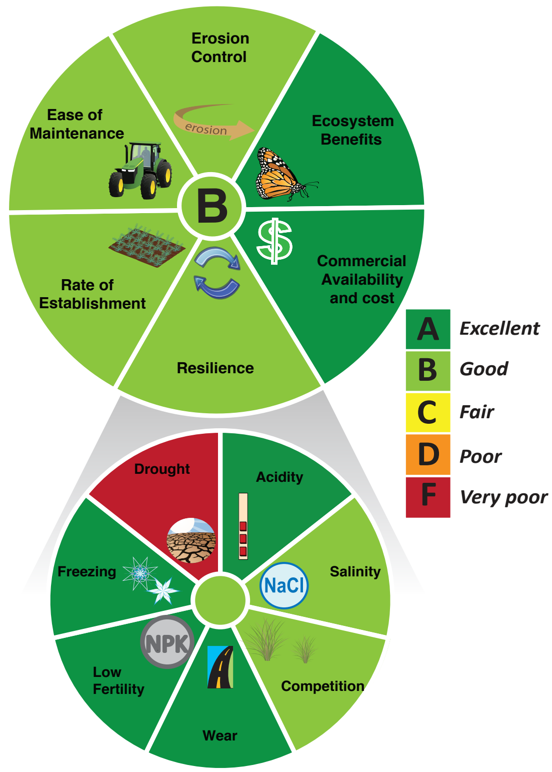
Tufted hairgrass

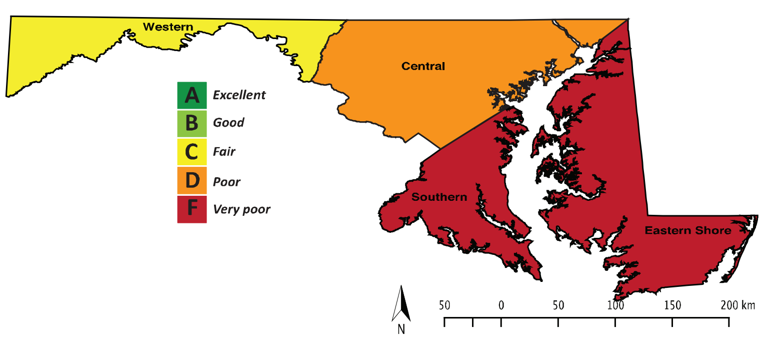
Deschampsia cespitosa

Tufted hairgrass is a native low-stature grass species with a wide geographic distribution. It is often used in restoration and reclamation projects because of its ability to thrive in soils with heavy metal concentrations, high acidity and low fertility. Cost of seed is affordable due to low recommended sowing rates. One major management concern, however, limits the use of tufted hairgrass along roadsides, which results in a Good rating (grade = B):



As a facultative wetland species that prefers poorly drained soils, tufted hairgrass has poor drought and heat tolerance which limits its wide spread use along roadsides.





Tufted hairgrass would not withstand the summer heat in Southern Maryland or on the Eastern Shore.

Tufted hairgrass turf type cultivars include Barcampsia, ShadeChamp, Spike, Norcoast, Humbolt Bay, and SR 6000. Nortran and Peru Creek are used for restoration and reclamation projects.

Biology: Tufted hairgrass is a native perennial cool season bunchgrass that is listed as highly state rare (S1) in Maryland (Maryland Biodiversity Project), as well as Kentucky and Massachusetts; considered rare in Indiana and is listed as being of special concern in Connecticut (USDA Plant Guide, Brede 2000). The species has been documented to occur in Maryland only in Baltimore and Cecil Counties (Maryland Biodiversity Project). Tufted hairgrass has a worldwide distribution; in the United States it can be found from Alaska to the Western United States with limited distribution in the Great Plains (USDA Plant Guide). Tufted hairgrass is also found from Minnesota to Maine, with some distribution in Iowa, Illinois, Ohio, and Georgia (USDA Plant Guide). Tufted hairgrass is considered a native wetland grass but has adapted to many different environments (Johnson 2008, Brilman and Watkins 2003) including serpentine barrens, sandy shores, and thickets (Rhoads and Klein 1993). It is a useful species for restoration of wet prairies (USDA Plant Guide, USDA Fact Sheet) and for stabilizing disturbed sites (USDA Fact Sheet). Tufted hairgrass also has reclamation applications for heavy metal mines, boreal re-vegetation work, bio swales, wetland restoration and riparian plantings (USDA Fact Sheet, Alderson and Sharp 1994). The species has potential to be used as a low-input turfgrass where heavy wear is a concern (Brilman and Watkins 2003).

Seeds per pound: 1,308,000 (Ernst Conservation Seed)
Cost per pound: $17.64 per pound from Ernst Conservation Seed
Cost per acre: $35.28 per acre
Suggested sowing rate: 2 pounds per acre (Chesapeake Valley Seed)
Sowing depth: >1/4 inch (USDA Plant Guide)
Germination time: In greenhouse experiments the first emergence took place within 3 to 5 days of planting under moist and warm conditions; a full stand of tufted hairgrass can take up to 12 days (Tilley 2010).
Seeding timing: Spring, late summer, or fall non-dormant seeding is recommended for low elevation regions with mild winters (USDA Plant Guide). For those areas in interior or alpine regions, a dormant planting should occur in late fall or early winter (USDA Plant Guide).
Length of growing season: Summer
Leaf height: 2-20 inches (USDA Plant Guide)
Height at seed head stage: 8-60 inches (USDA Plant Guide)
Shade tolerance: Prefers full sun but can tolerate partially shaded areas (USDA Plant Guide). Tufted hairgrass is rarely found in densely shaded areas (USDA Plant Guide, Lawrence 2005).
Suggested mowing height: Tufted hairgrass turf varieties from European sources can tolerate mowing at 1/3 to 1/2 inches (USDA Fact Sheet).
Tolerance of wet conditions: Tufted hairgrass commonly occurs on sites that are waterlogged or occasionally moist with precipitation amounts greater than 20 inches per year (USDA Plant Guide).
Humidity tolerance: Tufted hairgrass is susceptible to disease in humid environments.
Disease resistance: Tufted hairgrass has relative high susceptibility to disease (Bill Meyer personal communication). Diseases include ergot, rust, stripe smut, blind seed, leaf spot, rapid blight, and take-all patch (USDA Plant Guide, USDA Fact Sheet). Aphids, billbugs and leafhoppers are also known to affect tufted hairgrass (USDA Plant Guide, USDA Fact Sheet). During warm and humid summer months, tufted hairgrass suffered from rust disease, which greatly decreased the turf quality in low maintenance trials in Canada (Mintenko and Smith 1999).

Services:

Commercial availability and cost: Some native nurseries carry this species. The seed is expensive per pound; however, small seeds lead to a low sowing rate per acre. The cost is also alleviated when used in a mixture with other native grasses.

Rate of establishment: Tufted hairgrass grown from seeds or plugs have high establishment rates (Lawrence 2005). The species can also be established by using sod (Walsh 1995). Dormant tufted hairgrass seeds can persist in a seedbank (Ghering and Linhart 1992). Cold storage and light assist tufted hairgrass in germination (Walsh 1995). Choosing a tufted hairgrass variety from a similar geographic region and elevation to the planting site is beneficial for a better establishment rate (USDA Fact Sheet). The quick and aggressive establishment of tufted hairgrass lends itself to use in restoration and reclamation projects (Brown et al. 1988). Despite a fast establishment rate, tufted hairgrass does not produce a dense canopy. However, it can dominate an area by year three if seeding rates are heavy (USDA Plant Guide).

Ease of maintenance: Tufted hairgrass has only recently shown potential for use as a turf grass (Johnson 2000). It has a small stature and therefore does not require frequent mowing. Owing to its poor drought tolerance, however, this species may need to be irrigated along dry roadsides.

Erosion control: In Montana, the root distribution of tufted hair grass was measured in the first 4 inches of soil and 45% of the root mass was found in the top 0.8 inch of soil (Weaver 1982). However, tufted hairgrass is used in restoration projects when erosion control is a concern because plants can produce a dense sword. Christopherson and Johnson (1992) note that tufted hairgrass is useful for erosion control on stream banks. Tufted hairgrass was also used in an erosion control meadow mixture in Utah (Cobourn and Skelly 2009).

Ecosystem benefits: Tufted hairgrass provides a larval food source for many butterfly species in the United States and elsewhere throughout its distribution (USDA Plant Guide, USDA Fact Sheet). Tufted hairgrass has a poor to good food value rating and is sometimes foraged upon by rabbits, deer and songbirds (USDA Fact Sheet).

Resilience:

Drought: Tufted hairgrass cultivars may have a difficult time surviving the heat stress of summer months in many parts of the United States (Brilman and Watkins 2003). Due to poor tolerance of summer stresses, tufted hairgrass has limited wide-scale use as a turfgrass (Watkins et al. 2014, Watkins et al. 2011). However, in higher elevations, tufted hairgrass has moderate drought tolerance (Lawrence 2005). Summer turf quality of 'Barcampsia' and 'ShadeCamp' cultivars of tufted hairgrass was not acceptable during turf trials in the Midwest (Watkins et al 2014). In trials by Watkins et al. (2007), all of the physiological parameters of tufted hairgrass that were studied (photosynthetic rate, leaf photochemical efficiency and relative water content) maintained higher levels for a longer period of time under heat stress than drought stress. In Europe, tufted hairgrass distribution is driven by temperature more so than precipitation amounts (Davy 1982). It is not typically found in areas where mid-summer temperatures are above 68^{o}F (Davy 1982).

Low fertility: Tufted hairgrass can tolerate low fertility sites (USDA Plant Guide). Tufted hairgrass also performed adequately in shaded conditions with low fertility inputs (Brilman and Watkins 2003). In another low-input trial by Watkins et al. (2011), areas where adequate moisture and billbug damage is not a concern, tufted hairgrass performed well with minimal fertilization.

Freezing*:* Tufted hairgrass has a good cold tolerance of temperatures at -13^{o}F (Lawrence 2005). Tufted hairgrass from Oregon used in low maintenance trials in Canada had substantial winterkill from exposure to freezing temperatures. This was due to snow depths that were less than average and therefore did not provide insulation from freezing temperatures (Mintenko and Smith 1999). Davy (1982) found that at least 14-19 weeks of cold temperatures were required in the field to produce one panicle. The exposure to winter temperature conditions increases the number of panicles that tufted hairgrass produces (Davy 1982).

Salinity: Tufted hairgrass generally is considered to have a low salinity tolerance but cultivars appear to vary in tolerance. However, populations in coastal areas may show an increased tolerance to salinity (USDA Plant Guide, USDA Fact Sheet). In winter deicer experiments, Dudley et al. (2014) observed that tufted hairgrass was more sensitive to magnesium-based deicer products than to those that were sodium based during germination. In the same study, tufted hairgrass was among the most tolerant species to the highest concentration (3,000ppm of a chloride solution) of pure salt (Dudley et al 2014). Brown and Gorres (2011) found that tufted hairgrass had a moderate salt sensitivity in roadside trials. In salt tolerance turfgrass trails by Friell et al. (2013), 'Humbolt Bay' and 'SR 6000' tufted hairgrass were subjected to a 14dS/m salt exposure for two weeks and had between 50% and 75% green tissue remaining at the end. Thus, tufted hairgrass performed better than Kentucky bluegrass cultivars and had similar salinity tolerance as alkaligrass and perennial ryegrass. After a salt exposure of 24dS/m for two weeks, the same tufted hairgrass cultivars had between 25% and 50% of green tissue remaining (Friell et al. 2013), which was just below the levels of alkaligrass. During these trials, 'Humbolt Bay' tufted hairgrass performed better than 'SR 6000' (Friell et al 2013).

Acidity: Tufted hairgrass is found on soil type textures ranging from gravel to clay with a pH of 3.5 to 7.5 (USDA Plant Guide, USDA Fact Sheet). Some tufted hairgrass populations tolerate heavy metal concentrations and high soil acidity of disturbed sites (USDA Plant Guide, USDA Fact Sheet, Brown et al. 1988).

Wear tolerance: Tufted hairgrass is a densely tufted grass; this increases its tolerance to trampling and grazing (Lawrence 2005). In a low-input fairway trial with six passes of traffic per week (high level of wear), tufted hairgrass 'SR 6000' did not perform at an acceptable level (Watkins et al 2010). Thus, this cultivar was not recommended for high traffic areas.

Competition: Tufted hairgrass does not compete well with volunteer seedlings, especially ryegrass (USDA Plant Guide). On disturbed sites, tufted hairgrass can colonize very quickly and aggressively (Brown et al. 1988).

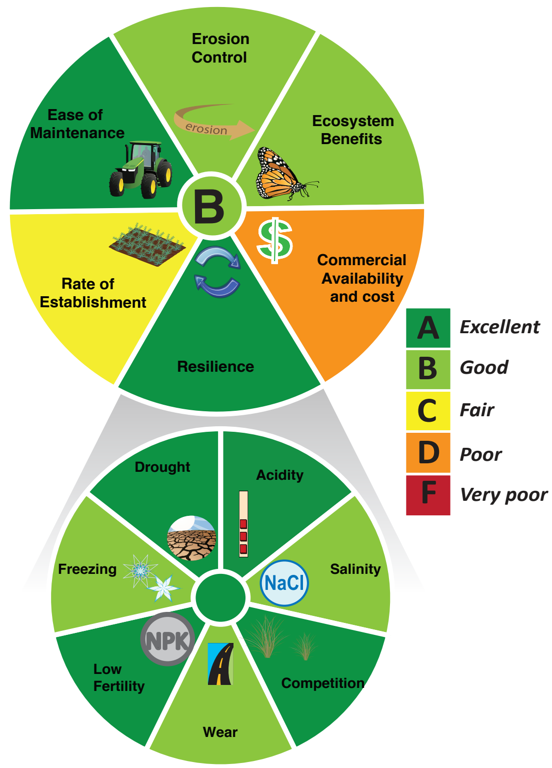
Mixes: When species diversity is important in a mixture, the use of tufted hairgrass should be limited to ¼ to ½ pound per acre (USDA Plant Guide). In turfgrass germination and establishment trials where seeds were planted either with a polymer coating or without, Leinauer et al. (2010) used a mixture of Kentucky bluegrass (10%), perennial ryegrass (20%), and tufted hairgrass (70%). This mixture was the slowest to reach 50% coverage in the trials when coated seeds were used. With uncoated seeds the mix never achieved 50% coverage (Leinauer et al. 2010). In Utah, the use of different grass mixtures for erosion control is recommended around the Lake Tahoe basin; one of these low-maintenance mixtures includes tufted hairgrass (10%) as well as cultivars of sheep fescue (30%), sandberg bluegrass (30%), mountain brome (15%), and slender wheatgrass (15%; Cobourn and Skelly 2009). This mixture is a low-growing option that can be planted with hard and red fescues in order to increase ground cover (Cobourn and Skelly 2009).

Cultivars: Tufted hairgrass has eight turf variety cultivars that are available across America and Europe; 'Barcampsia', 'Shade Champ', 'Spike', 'Norcoast', 'Humbolt Bay', and 'SR 6000' are among them (USDA Plant Guide, Alderson and Sharp 1994). 'Nortran' was developed in Alaska in the mid-1980's from four plant lines; two from Iceland and two from Alaska (USDA Plant Guide, Alderson and Sharp 1994). 'Nortran' tufted hairgrass tolerates acidic soils, low fertility, and cold, wet conditions (USDA Plant Guide). It shows some resistance to snow molds and rusts, and can reseed itself on disturbed soils (USDA Plant Guide). 'Peru Creek' was developed in Colorado in 1994 and is recommended for use in areas with a low pH and a high altitude (USDA Plant Guide).

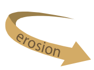
Hard fescue

Festuca trachyphylla, F. ovina var. duriuscula, F. duriuscula, F. longifolia, F. brevipila

Hard fescue is a low-growing perennial turf grass that is considered to be one of the best species to use in low-maintenance areas. The species is resilient to environmental conditions encountered along roadsides in the mid-Atlantic region including drought, salinity, low fertility, and freezing temperatures. It is an excellent competitor against weeds yet it can be mixed with other desirable species. Hard fescue is widely available commercially and requires mowing only twice a year in late spring and fall. For these reasons, hard fescue receives a rating of Good (grade = B) for use along roadsides in Maryland with only a few management concerns:

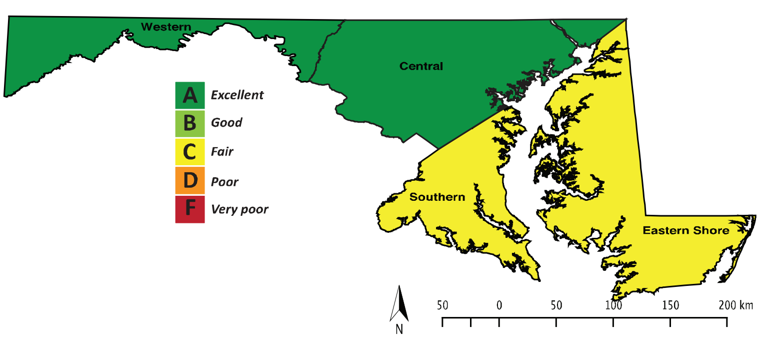


Hard fescue has excellent tolerance to summer heat through dormancy. While dormant, however, the species is very susceptible to traffic and should therefore not be mowed between early June and early October during the heat of the mid-Atlantic summer.



Hard fescue develops dense sod, but produces a shallow root system under some conditions. Although it is a good species to use for erosion control, it may not be the ideal species to plant on steep slopes where slope failure may be a concern.

Hard fescue is moderately expensive due to a high sowing rate. Seed per pound, however, is affordable and only marginally more expensive than tall fescue seed.



Hard fescue is particularly well adapted to grow in Western and Central Maryland. It is less suitable for use along roadsides in Southern Maryland and the Eastern Shore where heat stress may limit performance.

Hard fescue cultivars that are recommended for Maryland include Beacon, Gotham, Spartan II, and Sword (T. Turner *pers. communication*).

Biology: Hard fescue is a perennial species that is found in native to open forests and forest edge habitats of Central Europe (Beard 1973, Ruemmele et al. 2003). It was introduced throughout the United States and is now naturalized. It produces densely tufted narrow blades that are wider and tougher than its close cousin sheep fescue (Beard 1973). Hard fescue plants do not produce rhizomes. Hard fescue is now used for turf and reclamation with multiple uses along roadsides, railways, parks and sports grounds, and is considered as one of the best species to use in low-maintenance areas and along roadsides (Beard 1973, Watschke 1990, Ruemmele et al. 2003).

Seeds per pound: 592,000 (Ernst Conservation Seed)
Cost per pound: $3.45 per pound from Ernst Conservation Seed
Cost per acre: $603.75 per acre
Suggested sowing rate: 175 pounds per acre (Cheasapeake Valley Seed)
Sowing depth: <1/4 inch (USDA Plant Fact Sheet)
Germination time: 7-14 days (University of California IPM)
Seeding timing: early spring
Length of growing season: spring and fall
Leaf height: 35 cm = 13.5 inches (McKernan et al. 2001)
Height at seed head stage: 30 inches (USDA Plant Fact Sheet)
Shade tolerance: Hard fescue tolerates a variety of light conditions, including shade (Beard 1973, Watschke 1990, Ruemmele et al. 2003)
Suggested mowing height: Hard fescue does not tolerate mowing <1 inch (Beard 1973). >6 inch mowing height and no scalping is successful for Virginia roadsides (Booze-Daniels pers. communication).
Tolerance of wet conditions: Hard fescue needs well-drained soil but can tolerate higher soil moisture than sheep fescue.
Humidity tolerance: Hard fescue is adapted to cool humid climates (Beard 1973) is therefore tolerates humidity.
Disease resistance: Hard fescue is relatively disease resistant (Beard 1973, Watschke 1990). It is noted to have poor leaf spot resistance with variation among cultivars (Ruemmele et al. *2003).* Hard fescue has superior *Laetisaria fuciformis* resistance compared to chewings fescue and creeping red fescue and improved resistance to *Drechslera dictyoides, Colletotrichum graminicola,* and *Sclerotinia homeocarpa.*

Services:

Commercial availability and cost: Hard fescue is commercially available and seed is only marginally more expensive than tall fescue. While the cost of hard fescue per pound is affordable, the seeding rate per acre makes it moderately expensive.

Rate of establishment: Establishment rate was slow in old varieties but have improved with the new varieties (Watschke 1990). Hard fescue outperformed tall fescue under low maintenance conditions but only in years 2 and 3 of a 3-year study (Dernoeden et al. 1994). Among 80 cultivars tested in New York, hard fescue cultivar 'SR6000' and two strong creeping red fescue cultivars were among the top 3 fine fescue cultivars showing high seedling vigor (Bertin et al. 2009). However, this high seedling vigor did not translate into high turfgrass quality, seedling density or weed suppression.

Ease of maintenance: Hard fescue is a low growing species, low maintenance species that requires little mowing, irrigation, or fertilizer to produce acceptable turf quality (Watschke 1990). New varieties grow slower than other fine fescues (Watschke 1990). Hard fescue exhibited adequate turf quality under low maintenance regimes in a wide range of climates (Diesburg et al. 1997, Watkins et al. 2011, 2014). Hard fescue does not have to be mowed between mid-June and mid-September because the species becomes dormant during these months. In fact, it should not be mowed at all while dormant because maintenance equipment will severely damage the turf (Willmott et al. 2000).

Erosion control: Hard fescue has an extensive root system (Beard 1973) and is thought to be vigorous enough to control erosion (Watschke 1990). However Brown et al (2010) observed 85-95% of hard fescue root mass to occur within the top 7.5 cm of the soil. Mean rooting depth for hard fescue in field trials along roadsides that compared 7-19 species (Brown et al. 2010) was 39.5-51.3cm, which was relatively shallow. Despite the shallow rooting, hard fescue produced a high root mass as opposed to red fescue in one trial, but suffered from drought in another trial to produce longer roots but less root biomass (Brown et al. 2010)..

Ecosystem benefits: Hard fescue is non-native but naturalized. Because hard fescue does not spread by rhizomes, its sod is not as dense as creeping red fescue. Thus, it may be found in association with other native species and can be mixed with other species in seed mixes.

<u>Resilience</u>:

Drought: Hard fescue avoids drought by having a lower evapotranspiration rate (Beard and Kim 1989, McCann and Huang 2008) and a high root biomass. It can maintain evapotranspiration, quality and leaf growth under limited soil moisture compared to Kentucky bluegrass and perennial ryegrass, which declined rapidly when soil water potential reached -50 to -80 kPa (Aronson et al. 1987). Fifteen fine fescue cultivars were planted in 4-year low-maintenance trials in Virginia (Doak et al. 2004). The six seeded hard fescue cultivars germinated and established well with 4 and 5 cultivars maintaining >70% after recovering from a severe drought at a Virginia Piedmont and a Virginia Ridge and Valley site, respectively. The only other cultivars that performed as well as the hard fescues were one strong creeping fescue cultivar and one chewings fescue cultivar at the Ridge and Valley site and a sheep fescue cultivar at the Piedmont site. Thus, hard fescue appears to be the most drought tolerant of the fine fescues, but cultivar performance differs among climatic regions in Virginia with cultivars 'Defiant' and 'Minotaur' the most consistent across sites. In a separate 6-year trial in Blacksburg, VA, Doak et al. (2004) observed hard fescue cover to range between 72% (first year) to 90%. After a drought in the fifth year, cover continued to be maintained at 82-83%. This resilience contrasts with tall fescue, which decreased from 83% in the second year after establishment to 8% in the 6th year. In a 3-year study comparing 25 species and cultivars at two sites in southern Alberta, two hard fescue cultivars ('Aurora' and 'Spartan'), a sheep fescue cultivar, and blue grama maintained long-term superior area coverage despite a drought (McKernan et al. 2001). Hard fescue drought tolerance is less than sheep fescue but greater than red fescue (Beard 1973), and was rated higher than chewings fescue in Rhode Island trials (Watschke 1990).

Low fertility: Hard fescue (cultivar 'Berkshire') was a top performing species across 2 years in a low-maintenance eight-state study in the North Central US (Watkins et al. 2011). In the same region, hard fescue cultivars ('SR 3150', 'Predator', 'Firefly', and

‘Reliant IV) had acceptable turf quality ratings in low-maintenance trials across most states (Watkins et al. 2014). Ratings were some of the highest in the fall among the 25 turfgrass cultivars used in the study, but were lower during the summer months. Hard fescue has somewhat higher nitrogen fertility requirements than sheep fescue (Beard 1973). Hard fescue showed the best quality under low-input conditions in Maryland (Dernoeden et al. 1998), and good quality in Iowa, Indiana and Illinois but not in Missouri, Michigan, Ohio, and Wisconsin (Diesburg et al. 1997). Of 23 species of turfgrasses tested (McKernan et al. 2001), persistence of hard fescue cultivars ‘Aurora’ and ‘Spartan’ was high in low fertility environments. After two years of growth (but not after the first year), Watkins et al. (2010) observed hard fescue turf quality to be lower than sheep fescue, equal to chewings fescue and higher than tall fescue, perennial ryegrass and Kentucky bluegrass in a Minnesota study comparing 17 turfgrass species.

Freezing*:* Hard fescue has medium cold hardiness with a lethal temperature of -21^{o}C (-5.8^{o}F) (Bhowmik et al. 2008).

Salinity: Hard fescue has lower tolerance to salinity than red fescue (Ahti et al. 1980, Harivandi et al. 1992, Rose-Fricker and Wipff 2001, Marcum 2008a, Krishnan 2010, Brown et al. 2011, Friell et al. 2012, 2013, Zhang et al. 2013) and is generally ranked as salt sensitive (Marcum2008a; but Uddin and Juraimi (2013) rank hard fescue as moderately tolerant). Percent germination in cultivar ‘Discovery’ decreased from 92% in distilled water to 33% in 5000 ppm salt bath to 0% in 15,000 ppm brine. In contrast, percent germination in two red fescue cultivars was lower in distilled water but was up to 64% in the brine solution (Rose-Fricker and Wipff 2001). Hard fescue generally has lower tolerance to salinity than perennial ryegrass (Wang et al. 2011, Friell et al. 2013, but see Friell et al. 2012) and tall fescue (Krishnan 2010, Wang et al. 2011, Friell et al. 2013, but see Friell et al. 2012). Hard fescue has similar salt tolerance to sheep fescue (Marcum 1999, 2008a, Krishnan 2010, Wang et al. 2011, Friell et al. 2012, 2013, Zhang et al. 2013) and chewings fescue (Friell et al. 2012, 2013, Zhang et al. 2013), but appears to have higher salt tolerance to salt-sensitive Kentucky bluegrass (Wang et al. 2011, Friell et al. 2012, 2013, Zhang et al. 2013).

Acidity: Hard fescue has tolerance to acid soil and aluminum (Liu et al. 2008).

Wear tolerance: Hard fescue is wear tolerant although traffic, including mowing, will cause severe mortality while plants are dormant during the summer months. Dernoeden et al. (1998) in a Maryland low-input study showed that hard fescue cultivar ‘Reliant’ maintained acceptable quality despite being mowed once per month during the summer months with a rotary mower; Doak et al. (2002) in a 4-year low-maintenance study in Virginia observed no difference in percent cover of hard fescue when never mowed, mowed only in May, mowed in May and September or mowed in May, July, and September. A 6 inch mowing height that reduces risk of scalping is recommended (Booze-Daniels pers. communication). Horgan et al. (2007) observed hard fescue and chewings fescue to be more wear tolerant than other fine fescues in a 3-year study; Willmott et al. (2001) found that hard and chewings fescue maintained better quality than tall fescue and prairie junegrass in an orchard that was mowed in the summer; and, similarly, Watkins et al. (2010) observed hard fescue to be less wear tolerant than sheep and chewings fescue but more wear tolerant than 14 other cool season grasses, including tall fescue, perennial ryegrass, and Kentucky bluegrass. This effect, however, only emerged after in the second growing season. In contrast, in a low-input study established at 8 sites in 7 states of the Upper Midwest (Diesburg et al. 1997), hard fescue provided the best quality when not mowed. Similarly, hard fescue suffered damage from maintenance equipment (Willmott et al. 2000). Damage was most severe in the summer during heat and drought stress. Thus, equipment traffic on hard fescue during heat and drought stress needs to be avoided (Willmott et al. 2000). In a similar study in Missouri, hard fescue overseeded on bermudagrass was severely damaged by traffic (Dunn et al. 1994).

Competition: Hard fescue resists invasion and weed encroachment (Watschke 1990, McKernan et al. 2001). Hard and chewings fescue maintained the best quality and the lowest weed populations in a 3-year orchard study (Willmott et al. 2000). Tall fescue was less competitive than hard fescue in cooler regions of Virginia but hard fescue will most likely be excluded by tall fescue in coastal areas of Virginia (Doak et al. 2004). Hard fescue and sheep fescue maintained better quality and better resisted weed invasion than two tall fescue cultivars in a three-year study in Maryland without irrigation (Dernoeden et al. 1994). Similarly, hard fescue cultivar 'Reliant II' had excellent weed suppression, which may have been due to allelochemical exudates (Bertin et al. 2009). In contrast, cultivar 'Rescue 911' had poor weed suppression, suggesting that hard fescue cultivars have a wide range of abilities in suppressing weeds.

Mixes: In a New Mexico field study, a mix of 70% hard fescue, 25% sheep fescue, and 5% Kentucky bluegrass showed good germination, excellent turfgrass coverage, and was fastest in achieving 50% coverage at normal and reduced seeding rate and at lower irrigation (Leinauer et al. 2010). Hard fescue (20-25%) mixed with sheep fescue (20-25%), red fescue (20-25%), slender wheatgrass (0-20%), and Canada bluegrass (20-25%) had the highest cover ratings in a 3-year low maintenance study in southern Alberta (McKernan et al. 2001). Weed density in these mixes was lower than in monocultures of the species suggesting a synergistic effect among species. In Pennsylvania, mixtures of hard and creeping red fescue showed the best season-long quality under low maintenance conditions (Watschke 1990). Watschke (1990) mentions that the PA DOT seeds roadsides with 60% red and 40% hard fescue in areas that are not mowed or only mowed once. For shoulders and mowed low-maintenance areas, PA DOT recommend planting 70% tall fescue and 30% fine fescue. In Minnesota, hard fescue was used in a 'no-mow mix' containing 25% chewings fescue, 25% sheep fescue, 25% red fescue, and 25% hard fescue, and also in a 'fine fescue mix' containing 33% each of hard, sheep and red fescue (Meyer and Pedersen 1999). The fine fescue mix ranked higher than the no-mow mix, especially in turf color but also in turf quality and cover over three years (Meyer and Pedersen 1999). Both mixes generally ranked higher than any of the species planted in monoculture. The fine fescue mixes were also used in Minnesota by Miller et al. (2013) to test performance under low maintenance conditions over 3 years. The fine fescue mixtures had acceptable quality ratings. They ranked lower in quality than a tall fescue cultivar blend and native species mixtures but ranked higher than Kentucky bluegrass. Hard fescue is used for overseeding turfgrasses that are dormant in the winter such as bermudagrass (Nelson et al. 2005) and buffalograss (Severmutlu et al. 2013) to maintain adequate winter color and cover.

Cultivars: 'Durar' = 'P-2517' is an early cultivar of hard fescue that was released in 1949 (Beard 1973). 'Scaldis' and 'Waldina' are also early cultivars with slower vertical growth rate and greater heat resistance. Rutgers University released cultivars 'Reliant', 'Apartan', 'Ecostar', 'SR 3000', 'Oxford' and 'Nordic'. 'Ecostar' exhibits excellent shade tolerance, summer density, drought, cold and heat tolerance, and resistance to some diseases. 'Reliant', the projeny of 43 clones, is low in stature, uniform, winter hardy, and disease resistant, and has high seed yield. 'Spartan' was released in 1984 as the progeny of 142 clones. It is persistent, leafy, low growing, cold, heat and drought tolerant, and resistant to diseases. 'Aurora' was developed for reduced vertical growth, high seed yield, early maturity, and resistance to diseases. 'SR 3100' exhibits a dwarf growth habit, heat and drought tolerance, high endophyte levels, and high disease resistance. 'Discovery' was released in 1996 as a low growing cultivar with high disease resistance. Cultivar 'Valiant' is associated with non-choke inducing endophytes, which improves summer performance and increases resistance to *Blissus leucopterus* (Ruemmele et al. 2003).

In low-maintenance trials in Virginia to select hard fescue cultivars for use along roadsides, Doak et al. (2004) showed that cultivars 'Attlia E', 'Defiant', 'Minotaur', 'Osprey', and 'Rescue' reached 80-90% cover after 3 years of growth in a Ridge and Valley site. Cultivars 'Defiant', 'Minotaur', and 'Scaldis' reached 75-80% cover after 3 years at a Piedmont site.

<u>Hybrids</u>: Hard fescue was crossed with blue fescue (*Festuca glauca*) to produce a synthetic hybrid released as the cultivar 'Minotaur'. The hybrid produces dark green to blue-green turf with short plants that contain high levels of endophytes (Ruemmele et al. 2003). The cultivar 'SR 3200' also originated from a blue fescue x hard fescue cross (Ruemmele et al. 2003).

Upland bentgrass

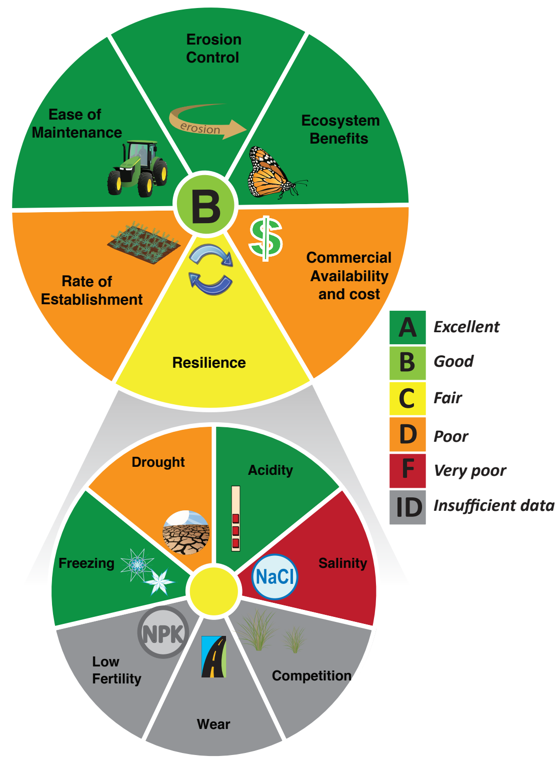
Agrostis perennans and synonyms

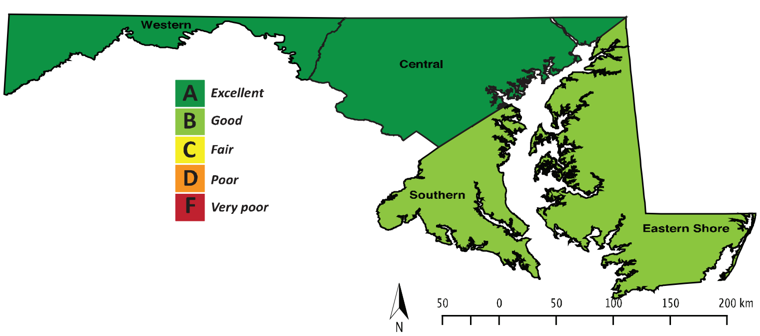
Upland bentgrass (also called autumn bentgrass) is a native grass that provides excellent ecosystem benefits in terms of food for wildlife. It is best used in seed mixes as a biodiversity enhancer. Plants are somewhat short-statured, which may decrease mowing frequency, and their root system stabilizes soil through deep and fibrous roots. Some unknowns decrease confidence in the resilience rating, but tolerance of cold temperatures and acidic soils is known to be excellent. Upland bentgrass is rated as Good (grade = B) for use as a roadside species with several management concerns:

Rate of establishment for upland bentgrass is slow owing to growth occurring in the summer months rather than the spring.

Seed cost per pound is high for upland bentgrass and although the species has a lower sowing rate, seeding upland bentgrass over a large area is moderately expensive.

Upland bentgrass is sensitive to salinity, and drought tolerance can be low owing to high water use. Resilience under roadside conditions may therefore be low although more research is needed.





Given its wide distribution in Maryland, upland bentgrass has excellent suitability for growth along roadsides in Western and Central Maryland. Ratings for Southern Maryland and the Eastern Shore are slightly lower (Good) owing to potential drought sensitivity.

Local ecotypes should be used to maximize plant adaptation to local environmental conditions.

Upland Bentgrass (*Agrostis perennans* = 55 synonyms including the most commonly used synonyms *Agrostis perennans* var. *aestivalis* = *Agrostis perennans* var. *elata* = *Agrostis altissima* = *Agrostis elata* = *Agrostis oreophila* = *Agrostis schweinizii* = *Cornucopiae perennans*. See ITIS for all synonyms)

Biology: Upland bentgrass is a perennial cool season (C_3) bunchgrass that is native to North and South America. It is common in fields, open woods and along roadsides and is adapted to many conditions from dry to moist soils, and sun as well as partial shade. The National Park Service reports that upland bentgrass grows in the coastal piedmont mountain range in the Chesapeake Bay region. Rhoads and Klein (1993) report occurrences of upland bentgrass in all Pennsylvania counties. The Maryland Biodiversity Project reports upland bentgrass to be common on the piedmont and coastal plain and to occur in all but 6 counties (Baltimore, Charles, Kent, Queen Annes, Talbot, and Somerset), including the higher elevations of Western Maryland.

Seeds per pound: 8,000,000
Cost per pound: $14.65 per pound from Ernst Conservation Seed
Cost per acre: $439.50 per acre
Suggested sowing rate: 30 pounds per acre (Ernst Conservation Seed)
Sowing depth: unknown
Germination time: unknown
Seeding timing: unknown
Length of growing season: unknown
Leaf height: 2-10 inches (Illinois Wildflowers Info)
Height at seed head stage: Up to 4 feet (Ernst Conservation Seed)
Shade tolerance: Upland bentgrass can grow in partial shade or full sun.
Suggested mowing height: unknown
Tolerance of wet conditions: Upland bentgrass prefers wet but well drained soil. Upland bentgrass is not a wetland plant but can occasionally be observed growing in wetlands.
Humidity tolerance: tolerant of humidity
Disease resistance: unknown

Services:

Commercial availability and cost: Upland bentgrass is sold as autumn bentgrass by Ernst Conservation Seed. The species is not widely commercially available. Cost per pound of seed is high and although the sowing rate is low, seeding upland bentgrass over a large area is moderately expensive.

Rate of establishment: Upland bentgrass is slow to develop because most of its growth occurs in the summer rather than the spring(Illinois Wildflower Info).

Ease of maintenance: Upland bentgrass is a low-stature plant and is therefore suited for use in low-maintenance areas.

Erosion control: The root system is fibrous without rhizomes. Upland bentgrass developed a mean root length between 46 to 76 cm in Rhode Island experiments (Brown et al. 2010). It is therefore adequate for use in erosion control but not as good as some other species such as purple lovegrass or tall fescue.

Ecosystem benefits: Seeds were harvested by Native Americans for food. Upland bentgrass is a valuable food resource for moths, butterflies and their caterpillars, such as the leaf-mining moths *Elachista irrorata* and *Elachista illectella*, the Common Roadside Skipper (*Amblyscirtes vialis*), Leonard's Skipper (*Hesperia leonardus*), and Fiery Skipper (*Hylephila phyleus*). Other insects that feed on these grasses include the Black Cutworm (*Agrotis ipsilon*), the Toothed Flea Beetle (*Chaetocnema denticulata*), several species of aphids that feed primarily on the roots, adults of the Prairie Spittlebug (*Philaenarcys bilineata*), and larvae of the gall wasp *Tetramesa agrostidis*. Bent grasses in general are palatable to many mammalian herbivores and they are readily eaten by horses and livestock, especially when their foliage is young (Illinois Wildflower Info).

<u>Resilience</u>:

Drought: Water use, like all Agrostis species, is high, and drought tolerance is therefore generally low (Ernst Conservation Seed). Despite this physiological limitation, upland bentgrass was the only species out of 11 grass species to increase in cover in a summer drought along a roadside (Brown et al. 2010). However, similar to all other species except prairie junegrass, upland bentgrass decreased to below 5% cover over the subsequent 12 months.

Low fertility: unknown

Freezing*:* Upland bentgrass occurs from the coastal plain region to the Appalachian Mountains. Given its broad elevational range, the species is expected to have excellent freezing tolerance.

Salinity: Upland bentgrass has no salinity tolerance (Ernst Conservation Seed).

Acidity: Upland bentgrass grows in soil pH of 5.5 to 7.5 (Ernst Conservation Seed) and is not tolerant of $CaCO_3$.

Wear tolerance: unknown

Competition: unknown

<u>Mixes</u>: Upland bentgrass is best suited as a component in a native grass mix.

<u>Cultivars</u>: None reported.

Red fescue

Festuca rubra ssp. litoralis and Festuca rubra ssp. rubra and others

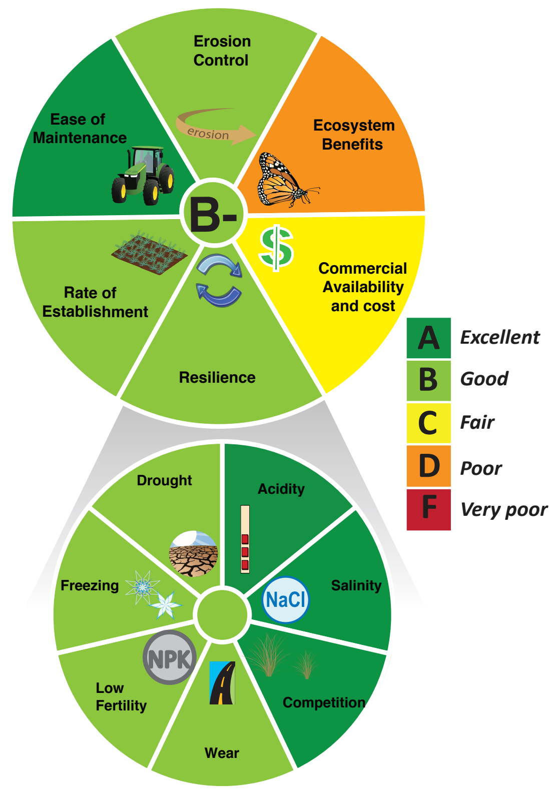
Red fescue is an introduced fine fescue species that produces rhizomes and hence dense sod. A low-growing species that establishes quickly, is tolerant of saline soils, and is commercially available at low cost; this species is a preferred roadside species in New England. Several species attributes make red fescue less suitable for Mid-Atlantic States resulting in an overall rating of Good to Fair (grade = B-):

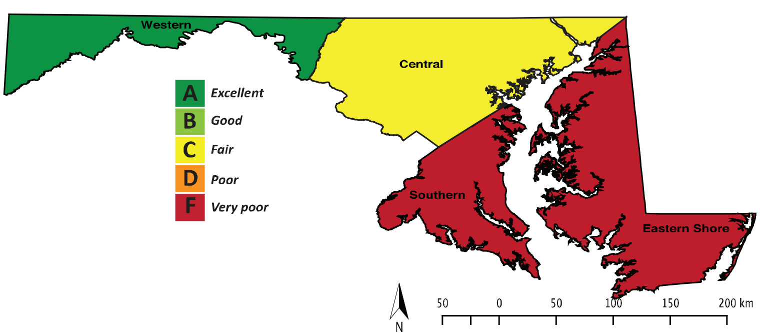
Red fescue is disease prone compared to hard and chewings fescue and may also become weedy in Maryland.

Red fescue produces a shallow root system, which may lead to slope failure when planted on steep slopes.

Red fescue is more drought and heat sensitive than other fine fescue species and is therefore less resilient in the summer heat of Maryland.

Red fescue has the cheapest cost per pound of the fine fescues, however it has a high sowing rate which leads to a moderate cost per acre.





Owing to its heat sensitivity, red fescue is only suitable for Western Maryland. Its use is not recommended for Southern Maryland and the Eastern Shore.

Red fescue cultivars that are recommended for Maryland in 2016 are from the strong creeping red fescue subspecies and include Chantilly (new variety) and Navigator II. Updates to recommended cultivars in Maryland are published annually in the University of Maryland Turfgrass Technical Update TT77 (Maryland Turfgrass Council).

Creeping red fescue (Festuca rubra)

Slender creeping red fescue (*Festuca rubra ssp. litoralis = Festuca rubra var litoralis = Festuca rubra ssp. tricophylla = Festuca rubra ssp. eu-rubra var. genuina subvar. vulgaris*)

Strong creeping red fescue (*Festuca rubra ssp. rubra = Festuca rubra ssp. vulgaris = Festuca rubra ssp. eu-rubra var. genuina = Festuca glaucescens = Festuca rubra ssp. glaucodea = Festuca rubra var. glaucescens = Festuca rubra var. lanuginosa*)

Biology: Creeping red fescues are perennial cool-season grasses within the red fescue species complex. Two subspecies of creeping red fescue are recognized – slender creeping (42 chromosomes; *Festuca rubra ssp. trichophylla = Festuca rubra ssp. litoralis)* and strong creeping (56 chromosomes; *Festuca rubra ssp. rubra*) red fescue (Marcum 2008a). Both subspecies produce rhizomes with strong creeping fescue producing strong, long rhizomes and slender creeping fescue producing finer, shorter rhizomes. In both cases, plants form sod that is fine textured with high shoot density. Creeping red fescues originated in Europe (Ruemmele et al. 2003 but USDA also lists Asia and North America as sites of origin) and are the most widely used of the fescues for turfgrass purposes (Beard 1973). Creeping red fescues are particularly well adapted to New England where summer heat is not as intense as further south. In New England, creeping red fescue is an important roadside grass (Brown et al. 2010). Creeping red fescues are used for low-input turf purposes (Krishnan 2010) including mine reclamation (Ruemmele et al. 2003), and are planted in lawns, athletic fields, golf courses, and playgrounds (John et al. 2012). Red fescue has the ability to accumulate metals in its leaf tissue and is therefore useful for phytoremediation (John et al. 2012).

Seeds per pound: 615,000 seeds per pound (University of Tennessee extension)
Cost per pound: $1.80 per pound from Chesapeake Valley Seed
Cost per acre: $315.00 per acre
Suggested sowing rate: 175 pounds per acre (Chesapeake Valley Seed)
Sowing depth: <1/2 inch (John et al. 2012)
Germination time: 7-14 days (University of California IPM)
Seeding timing: spring or early fall
Length of growing season: spring to fall with a period of dormancy in hot summers
Leaf length: 4.25 inches grown in gravel and full sun to 17.75 inches grown in peat and shade (Kjellqvist 1961); 2-12 inches (Ruemmele et al. 2003); 2-6 inches (John et al. 2012).
Height at seed head stage: maximum height reached = 13 inches (McKernan et al. 2001); 24-35 inches (Barkworth et al 2007 in Brown et al. 2010); 24 inches for slender creeping red fescue and 43 inches for strong creeping red fescue (Ruemmele et al. 2003); 12-39 inches (John et al. 2012).
Shade tolerance: good (Beard 1973, VanHuylenbroeck and VanBockstaele 1999)
Suggested mowing height: 4-6 inches (Doak et al. 2004); avoid scalping because it will cause substantial mortality (Booze-Daniels pers. communication)
Tolerance of wet conditions: Does not tolerate wet and poorly drained soils (Beard 1973, Ruemmele et al. 2003) but can tolerate spring flooding (John et al. 2012).
Humidity tolerance: Red fescue is adapted to cool humid climates (Beard 1973) and therefore is very tolerant of high humidity.
Disease resistance: Most prone to *Helminthosporium* and red thread and more

susceptible to *Fusarium* patch and *Typhula* blight than Kentucky bluegrass (Beard 1973). Slender creeping red fescue is susceptible to *Laetisaria fuciformis* and *Sclerotinia homeocarpa* (Ruemmele et al. 2003). Strong creeping red fescue has good resistance to *Erisyphe graminis* and *Magnaporthe poae*; and resistance to *Drechslera dictyoides, Laetisaria fuciformis* and *Sclerotinia homeocarpa* has only been moderately improved in newer cultivars (Ruemmele et al. 2003). Endophytes are introduced to enhance disease resistance (Ruemmele et al. 2003).

<u>Services</u>:

Commercial availability and cost: Creeping red fescue seed is produced in high quantity in the United States and abroad. Commercial availability is excellent. Seed of creeping red fescue is the least expensive of the fine fescues. However, the sowing rate of red fescue is high which leads to a moderately expensive cost per acre.

Rate of establishment: Establishment of red fescue in general is good; somewhat slower than perennial ryegrass but faster than Kentucky bluegrass (Beard 1973). Using photosynthetic measurements, VanHuylenbroeck and VanBockstaele (1999) found that creeping red fescue had a faster growth rate than chewings fescue. Among 80 cultivars tested in New York, 4 cultivars of red fescue ('Salsa' and 'Boreal', 'SRX 52961', and 'Aberdeen') were among the top six fine fescue cultivars for high seedling vigor, which affected turf quality even into the next growing season as well as weed infestation (Bertin et al. 2009). Nutrient seed coating slightly increased germination capacity in red fescue (Sochorec et al. 2013).

Ease of maintenance: Creeping red fescue requires a low culture intensity with minimal to no irrigation and fertilization (Beard 1973). Vertical growth is slower than most cool season species and the growth habit is creeping (Beard 1973). Creeping red fescue is a low stature plant but it can reach heights of up to 60-90 cm when culms are included (Barkworth et al. 2007). In most cases, however, plants will be 30 cm tall or less (Ruemmele et al. 2003, John et al. 2012). Creeping red fescue was shorter in stature than tall fescue and perennial ryegrass cultivars in roadside trials (Brown and Gorres 2011). Creeping red fescue grew from 21.6 to 42.8 cm mean height and was one of the shortest species tested in Brown et al. 2010.

Erosion control: Creeping red fescue has an extremely dense and fibrous root system (Beard 1973). It has a high root-to-shoot ratio compared to 5 other turfgrass species (Dziamski et al. 2012) and higher root mass in the upper soil layers compared to its close cousin chewings fescue (Ruemmele et al. 2003). For this reason, creeping red fescue is considered an excellent soil stabilizer and is therefore used extensively for stabilizing slopes, banks, cuts and fills (USDA Plant Guide). However, roots are shallow with most of the root mass distributed within the top 5-15 cm. Brown et al (2010) observed 66% to 84.3% of creeping red fescue root mass to occur within the top 7.5 cm of the soil. Mean rooting depth for creeping red fescue was 33.4 to 43.1 cm, which was one of the shallowest rooting depths in three field trials along roadsides that compared 7-19 species. This shallow root distribution can lead to slope failure beneath the root zone (Simon and Collison 2002) and sod sloughing during heavy rains (Brown et al. 2010). Water retention in the soil cultivated with creeping red fescue was not as high as tall fescue and perennial ryegrass owing to differences in root morphology among species (Glab and Szewcyk 2014). Therefore, creeping red fescue is poor in maintaining infiltration capacity, an important factor in erosion control, relative to other cool season grasses.

Ecosystem benefits: Creeping red fescue is non-native although John et al. (2012) propose that some red fescue varieties also have North American origins. Owing to creeping red fescue's use throughout the United States and the world, original ecological or geographical distribution patterns are complex and therefore challenging to determine (Ruemmele et al. 2003). Red fescue produces a dense sod, in cooler climates, which decreases weed invasion but also limits species diversity (John et al. 2012). In hotter climates, such as Maryland, red fescue often becomes disease-prone and weedy. Wildlife will feed on leaves but creeping red fescue is not recommended for forage production owing to its low nutritional value and some endophyte containing cultivars (John et al. 2012). Cover value for small birds and mammals is fair (U.S. Forest Service Information System).

<u>Resilience</u>:

Drought: Fescues as a group are drought tolerant (Carroll 1943, Ruemmele et al.2003, Bertin et al. 2009) because they have low evapotranspiration rates (Beard and Kim 1989, McCann and Huang 2008) compared to other cool-season grasses, and summer dormancy (Johnson 2003). Creeping red fescue can avoid drought by increasing root-to-shoot ratios in response to drought (Dziamski et al. 2012). Drought tolerance is higher than Kentucky bluegrass or creeping bentgrass (Beard 1973, Wallner et al. 1982) but lower than bermudagrass (Wallner et al. 1982). Beard (1973), however, argues that red fescue does not persist in warm humid climates owing to a lack of heat tolerance (but see Wallner et al. 1982). In a British study comparing 16 turfgrass species (Carroll 1943), red fescue performed poorly (25-45% survival) compared to chewings fescue (65-70% survival) under low-input conditions when subjected to higher soil temperatures. Under high air temperatures, red fescue had one of the lowest survival rates (20%) among the 16 species (Carrol 1943). In the same study (Carroll 1943), red fescue survived lower soil moisture conditions well. It was not as drought tolerant as chewings fescue in low fertility soils but more drought tolerant in high fertility soils. In a low-maintenance study in the Ridge and Valley of Virginia (Doak et al. 2004), four strong creeping red fescues produced 60-70% cover, whereas the slender creeping cultivar 'Dawson' produced 80% cover after 4 years, which included a severe drought in the third year of the study. In contrast, six hard fescue cultivars maintained 80-90% cover suggesting that hard fescue is more drought and hear tolerant than creeping red fescue. At a Piedmont site, the same cultivars produced up to 53% cover (Dawson produced 15% cover) whereas hard fescue produced up to 80% cover and tall fescue up to 75% cover after the severe drought in year 3 (Doak et al. 2004). Generally, creeping red fescue will not tolerate hot and dry summers of Central and Eastern Maryland (Turner personal communication). However, because western Maryland is cooler and wetter than the rest of the state, red fescue may perform better in the western part of Maryland.

Low fertility: Wakefield et al. (1974) evaluated persistence of turfgrass species along roadsides in Rhode Island and found that creeping red fescue had the best coverage along roadsides 1 and 2 years after seeding. Similarly, Brown et al. (2011) in a Rhode Island roadside study found that creping red fescue showed the best persistence and cover (~30%) in a plain soil treatment, which increased up to 82% when the soil was treated with biosolids. Survival of slender creeping red fescue cultivar 'Dawson' was high in a low fertility environment; however, the environment needed to be mesic (McKernan et al. 2001). After comparing turf quality of four cultivars of fine fescues and one cultivar of tall fescue, Dernoeden et al. (1998) concluded that creeping red fescue cultivar ‘Flyer’ would not be as good of a choice in low input environments as hard, chewings, or sheep fescue.

Freezing*:* Red fescues are distributed from sea level to 11,000 ft (3,350 m; John et al. 2012). Creeping red fescue has medium freezing tolerance, comparable to tall fescue and zoysiagrass but lower than Kentucky bluegrass (Beard 1973, Stier and Fei 2008). Percent survival of creeping red fescue was 60-80% up to -10^{o}C, which was a lower survival rate than chewings fescue (Carroll 1943). No survival was observed at -15^{o}C and below. Cold acclimation is rated less than creeping bentgrass and Kentucky bluegrass but superior to perennial ryegrass (Ruemmele et al. 2003).

Salinity: Red fescues have a wide range of reported salinity tolerances (Humphreys 1981, Marcum 2008, Krishnan 2010) from 3-6 dS/m (Marcum 1999), 6-10 dS/m (Uddin and Juraimi 2013) and 8-12 dS/m (Butler et al. 1985). Different authors therefore rank salinity tolerance of creeping red fescue between poor to moderately tolerant (Marcum 2008a). The most tolerant cultivars belong to the hexaploid slender creeping group (Harvandi et al. 1992, Rose-Fricker and Wipff 2001, Brown et al. 2011, Friell 2012), followed closely by the octoploid strong creeping fescues, although differences within creeping red fescue may not be a distinction among species but rather a difference in origin (Humphreys 1981, Marcum 2008a). Cultivar ‘Dawson’ shows salinity tolerances as high or higher as known salt tolerant species such as alkaligrass (Torello and Symington 1984, but see Harivandi et al. 1982). Percent germination of Red fescue decreased from 65% in controls to up to 30% at the highest NaCl concentration (Wrochna et al. 2010). Percent germination decreased from 65% to 11% and from 85% to 64% in cultivars ‘Dawson’ and cultivar ‘Seabreeze’, respectively, when subjected to salt baths ranging from distilled water to 15,000ppm brine (Rose-Fricker and Wipff 2001). Seedling growth and root length were also affected by salinity levels ranging from 0 to 12 g/dm^3 (Wrochna et al. 2010). Dry matter yield was not affected by salt treatment but foliage injury was high (Greub et al. 1985). Other studies of red fescue cultivars have shown that cultivars ‘Dawson’ and ‘Golfrood’ were most salt tolerant whereas cultivars ‘Ruby’, ‘Rainier’, ‘Steinacher’, ‘Illahee’, ‘Pennlawn’, and ‘Common’ were less tolerant (Marcum 2008a). Overall, studies comparing red fescue with other turfgrasses typically show high salinity tolerance in red fescue. In a comparison of 74 turfgrass species and cultivars along two Minnesota roadsides (Friell et al. 2012), some cultivars of slender (‘Shoreline’, ‘ASR 050’, ‘Seabreeze GT’) and strong creeping red fescue (‘Navigator’, ‘McAlpin’, ‘Cardinal’, and ‘OR1’) survived the winter better than many other fine fescue cultivars, tall fescue, perennial ryegrass and Kentucky bluegrass. Slender creeping red fescue exhibited similar salt tolerance to perennial ryegrass and tall fescue and higher salt tolerance compared to 8 other fine fescue cultivars (sheep, hard, and chewings) on agar and in hydroponics (Zhang et al. 2013). Similarly, creeping red fescue had higher salinity tolerance than Kentucky bluegrass (Torello and Symington 1984), chewings fescue, hard fescue, and sheep fescue, in decreasing order, after 71 days of exposure to 20,000 ppm NaCl (Ahti et al. 1980). Red fescue exhibited higher salt tolerance than tall fescue, sheep fescue and hard fescue in decreasing order (Krishnan 2010). In contrast, red fescue had lower salinity tolerance in germination trials on germination paper compared to sheep fescue, tall fescue, and creeping bentgrass, but had higher salinity tolerance than these species in a hydroponic system (Zhang et al. 2011).

Acidity: Red fescue prefers soil with pH between 5.5 and 6.5 (Beard 1973) but can tolerate pHs ranging from 5-8 (Ernst Conservation Seed). Creeping red fescue has less resistance to acid soils with high aluminum content than hard fescue and chewings fescue (Liu et al. 2008). Aluminum tolerance, however, is increased by some endophyte infected cultivars (Liu et al. 2008).

Wear tolerance: Beard (1973) ranks the wear tolerance of creeping red fescue as moderate, similar to colonial bentgrass but less than perennial ryegrass and Kentucky bluegrass (Ruemmele et al. 2003). Wear tolerance of slender creeping red fescue is reported to be higher than for strong creeping red fescue (Ruemmele et al. 2003). In an experiment that compared wear tolerance of 7 cool season species, creeping red fescue was ranked last (Canaway 1981). After two years growth, red fescue turf cover ranged between 51% to 88% in control plots and 2-17% in plots subjected to a traffic simulator while turf cover for tall fescue, Kentucky bluegrass and perennial ryegrass maintained >50% cover (Glab et al. 2015). Red fescue cultivars ‘Bargreen II’ and ‘Barpearl’ were the most wear tolerant cultivars. Turf quality and shoot density decreased as well. In all, creeping red fescue ranked 5th out of 7 species in wear tolerance. Red fescue overseeded on Bermudagrass in California showed marginal tolerance to traffic simulation (Cockerham et al. 1990), and were severely damaged by traffic in a similar experiment in Missouri (Dunn et al. 1994). As another form of wear, moderate grazing will not impact yield of red fescue; overgrazing will decrease yield, however, similar to most species (John et al. 2012).

Competition: Red fescue can resist invasion and weed encroachment (Davis 1958, McKernan et al. 2001). In a low-input study in Utah, creeping red fescue (cultivar ‘Vista’) and chewings fescue were more competitive than buffalograss in mixtures (Johnson 2003). Red fescue is more competitive than Kentucky bluegrass in low-input environments (Beard 1973, Ebdon and Skogley 1985) but Kentucky bluegrass will dominate in high input environments (Davis 1958). Bertin et al. (2009) found that red fescues as a group were strongly weed suppressive with >70-80% weed suppression. Red fescue cultivars with the best weed suppression included ‘Shademater II’, ‘Salsa’, ‘ABT-CR2’, ‘PST 47T’, and ‘SRX52LAV’. Weed suppression may be a function of fast establishment as well as bioherbicidal activity from root-derived photochemicals (Bertin et al. 2009). Even as living mulch or killed sod strong creeping red fescue was highly weed suppressive (Weston 1990).

Mixes: Creeping red fescue (20-25%) mixed with sheep fescue (20-25%), hard fescue (20-25%), slender wheatgrass (0-20%), and Canada bluegrass (20-25%) had the highest cover ratings in a 3-year low maintenance study in southern Alberta (McKernan et al. 2001). Weed density in these mixes was lower than in monocultures of the species suggesting a synergistic effect among species. Creeping red fescue was mixed with perennial ryegrass (68%) and clover (~1%) in an ‘Ecology Lawn Mix’; with perennial ryegrass (30%), Kentucky bluegrass (25%) in a ‘Sunnylawn mix’; and with sheep fescue (33%) and hard fescue (33%) in a ‘Fine Fescue mix’ with good quality and color ratings over three years in a low maintenance study in Minnesota (Meyer and Pederson 1999). The fine fescue mixes were also used in Minnesota by Miller et al. (2013) to test performance under low maintenance conditions over 3 years. The fine fescue mixtures had acceptable quality ratings. They ranked lower in quality than a tall fescue cultivar blend and native species mixtures but ranked higher than Kentucky bluegrass. A mix of red fescue with buffalograss may allow irrigation levels to be lowered; however red fescue tends to be more competitive than buffalograss in mixture (Johnson 2003). In West Virginia, creeping red fescue is used at a rate of 2.5-5kg/ha in mixture with tall fescue (2.5-5kg/ha), annual ryegrass (0.875-1.75 kg/ha) and birdsfoot trefoil (2.5kg/ha) and native species (Venable and Skousen 2005, Rentch et al. 2005). Kentucky bluegrass is frequently used in mixture with creeping red fescue (Juska and Hanson 1959, Beard 1973, Ebdon and Skogley 1985) because strong creeping red fescue has shown higher compatibility with Kentucky bluegrass and perennial ryegrass than other fine fescue species (Ruemmele et al. 2003). Seed mixtures containing at least 50% creeping red fescue were able to maintain the desired species composition (Juska and Hanson 1959). An initial seed mixture of 48% Kentucky bluegrass and 52% creeping red fescue maximized turf quality that was acceptable when lawns received 150 and 300 lb/acre deicing salts. Kentucky bluegrass and red fescue appear to offer the best combination of good persistence and slow vertical growth droughty and infertile conditions (Brown and Gorres 2011), where red fescue will dominate (Beard 1973, Ebdon and Skogley 1985). Red fescue may be used to overseed warm-season lawns such as bermudagrass and zoysiagrass to enhance color during the winter (Ruemmele et al. 2003, Rimi and Macolino 2014).

<u>Cultivars</u>: More than 300 varieties of red fescue have been released (John et al. 2011). Selection criteria include increased seed yield, improved heat, drought and disease tolerance and improved turf quality (Ruemmele et al. 2003). Endophytes were introduced into slender creeping red fescue to produce cultivar 'Dawson' with higher disease resistance. Cultivar 'Dawson' was further developed to produce dwarf cultivars 'Logro' and 'Elfin' and cultivar 'Count' with enhanced color (Ruemmele et al. 2003). Despite these improvements, many cultivars of slender creeping red fescue do not show good stress tolerance and have poor seed yields. Early cultivars of strong creeping red fescue included 'Boreal' with high seed yields and 'Wintergreen' with excellent winter hardiness and shade tolerance (Ruemmele et al. 2003). Many cultivars have been introduced since then including cultivars that grow low ('Vista') or have strong vigorous rhizomes to make them suitable for erosion control ('SR 5200E). Cultivars 'Seabreeze GT', 'Sealink', 'Shoreline', and 'ASR050' were the top-performing fine fescue entries following salinity exposure (Friell et al. 2013), with 'Shoreline' performing well among roadsides where exposure to NaCl can be a problem (Friell et al. 2012). Because cultivars differ in their performance in different roadside locations, Friell et al. (2012) suggest the use of a mix of cultivars.

<u>Hybrids</u>: Many inter- and intrageneric hybrid experiments have been conducted with many not producing viable offspring (Ruemmele etal. 2003). Cultivar 'Seabreeze' is a hybrid between slender creeping red fescue and chewings fescue but is released as a slender creeping red fescue cultivar. It is a low growing cultivar with excellent winter color, cold, and shade tolerance, and improved disease resistance for several diseases such as *Sclerotinia homeocarpa* (Ruemmele et al. 2003).

Sheep fescue

Festuca ovina ssp. hirtula

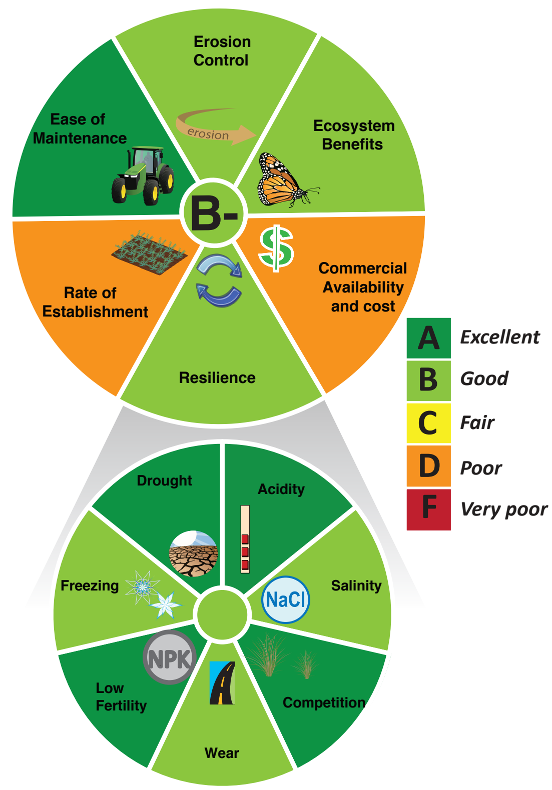
Sheep fescue is a low-growing turf grass with ecotypes that are native to North America. A species that is closely related to hard fescue, sheep fescue has many of the same traits including high resilience to environmental conditions encountered along roadsides, such as excellent drought and low fertility tolerance, and superior competitiveness against weeds. Sheep fescue is available commercially, is an excellent species to plant in areas where infrequent mowing is desired, and can be mixed with other species to enhance biodiversity. Owing to its superior ability to provide services for roadside management, sheep fescue is rated as Good to Fair (grade = B-) for use along Maryland right-of-ways.

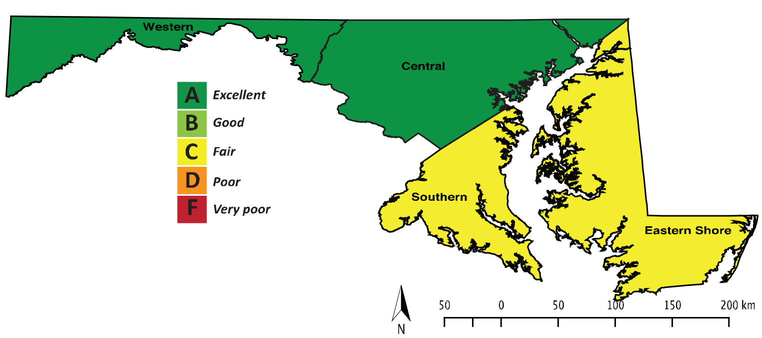
Sheep fescue establishes slowly such that superior performance in most cases will not be realized until after 2 years of growth.

Sheep fescue has the most expensive seed cost compared to other fine fescues. Seeding in a large area is moderately expensive.

Sheep fescue can produce a shallow root system and should therefore not be planted on steep slopes where slope failure is a concern.

Sheep fescue has excellent tolerance to summer heat through summer dormancy, which increases susceptibility to traffic. For maximum establishment, performance and survival, sheep fescue should not be mowed between early June and early October.





Sheep fescue is well adapted to grow in Western and Central Maryland. Although performance is good on sandy and gravelly soils, it is less suitable for use along roadsides in the coastal plain of Southern Maryland and the Eastern Shore, where heat stress may limit growth and survival.

Sheep fescue cultivars that are recommended for Maryland include Bighorn GT, which is more closely related to hard fescue than sheep fescue. Cultivar Quatro may be the only true sheep fescue commercially available. Growers should consider producing native ecotypes for regional plantings.

Biology: Sheep fescue is a perennial cool season turfgrass that is considered native to North America and Eurasia (Beard 1973, Ruemmele et al. 2003, Johnson 2008). The species grows best on sandy and gravelly soils (Beard 1973) and frequently dominates hill and mountain grasslands (Ruemmele et al. 2003). It thrives from sea level to 1,220 m elevation (Ruemmele 2003). Sheep fescue has a fine leaf texture with a densely tufted growth habit. Although it does not spread by rhizomes, it can spread via tillering up to 10 cm per year (Ruemmele et al. 2003). Sheep fescue has been generally overlooked as a turfgrass in favor of the introduced fine fescue species creeping hard fescue, red fescue, and chewings fescue (Johnson 2008). Yet, it produces reasonable quality turf with curving leaves that produces a 'swirly' naturalized appearance (Johnson 2008). Some cultivars have a distinct blue color that provides a unique look to the landscape (Johnson 2008), although these cultivars tend to be genetically more similar to hard fescues. Sheep fescue is typically used in areas that are hard to mow and at mowing heights greater than 3.5 cm and is therefore a valuable species for low-maintenance roadsides, reclamation sites, roughs and railway banks (Ruemmele et al. 2003). It may be sown alone but is also frequently used in lawn and wildflower mixtures (Ruemmele et al. 2003).

Seeds per pound: 680,000 – 720,000 (Cebeco International Seeds)
Cost per pound: $3.75 per pound from Chesapeake Valley Seed
Cost per acre: $656.00 per acre
Suggested sowing rate: 175 pounds per acre (Chesapeake Valley Seed)
Sowing depth: ¼ to ½ inch (Cebeco International Seeds)
Germination time: 8-11 days (Pickseed)
Seeding timing: spring or fall when soil temperatures >60^{o}F (Cebeco International Seeds)
Length of growing season: Growth is in the spring and fall; growth in the summer is minimal and dependent on dormancy (Ogle et al. 2010).
Leaf length: 0.80-3.15 inches (Ruemmele et al. 2003)
Height at seed head stage: maximum height reached = 16.5 inches (McKernan et al. 2001); 4-18 inches (Ruemmele et al. 2003)
Shade tolerance: tolerant of moderate shade (Beard 1973, Ruemmele et al. 2003, Johnson 2008)
Suggested mowing height: does not tolerate low cutting heights (<0.5 inches)
Tolerance of wet conditions: Will not tolerate high water tables or flooding (Ogle et al. 2010).
Humidity tolerance: Sheep fescue is adapted to cool humid environments (Beard 1973) and therefore tolerates high humidity.
Disease resistance: Sheep fescue is susceptible to red thread, *Fusarium* patch, powdery mildew, brown patch, and stripe smut (Beard 1973). Sheep fescue appears to be particularly susceptible to leaf spot and is susceptible to *Laetisaria fuciformis, Microdochium nivale, Erisyphye graminis, Rhizoctonia solani, and Ustilago striiformis* (Ruemmele et al. 2003). Overall, however, it is considered to be relatively resistant to common turf diseases (Ogle et al. 2010).

Services:

Commercial availability and cost: Sheep fescue is not used as much as other fine fescue species in turfgrass culture. However, because of its use in land reclamation, sheep fescue seed is commercially available and affordable. Cost of seed ($3.75 per pound) is the highest of all fine fescue species sowing rate per acre is high such that sowing the species across large areas is expensive.

Rate of establishment: Sheep fescue establishes as seedlings in 21-28 days (Cebeco International Seeds) but stands are slow to develop and seedlings may be hard to find in the establishment year (Ogle et al. 2010). Turf quality, under low input and low maintenance regimes, can be superior. However, superior performance is slow to develop and only emerges after two years of growth (Dernoeden et al. 1994, Watkins et al. 2010). At this time, however, sheep fescue turf quality surpasses tall fescue (Dernoeden et al. 1994, Watkins et al. 2010).

Ease of maintenance: Sheep fescue exhibited adequate turf quality under low maintenance regimes in a wide range of climates (Diesburg et al. 1997, Ogle et al. 2010, Watkins et al. 2011, Watkins et al. 2014). It grows best under nonirrigated and nominal soil fertility (Beard 1973) and was the top performing species among 13 turfgrasses under a no-mow treatment (Watkins et al. 2011).

Erosion control: Rooting depth of sheep fescue tends to be shallow (Beard 1973), especially under close mowing. Given its relatively shallow root system, sheep fescue may not be an effective species for erosion control on steep slopes. However, once established, sheep fescue has excellent ground cover. Thus, it is considered ideal for long-term stabilization of disturbed soils and for protecting roadsides, airport landing strips, skid trails, clear cuts, ski hills and other areas against erosion (Ogle et al. 2010).

Ecosystem benefits: Sheep fescue is native to North America (Beard 1973, Johnson 2008); however many if not all commercially available cultivars originate from Europe. Because sheep fescue does not spread by rhizomes, its sod is not as dense as creeping red fescue. Thus, it can be found in association with other native species and can be mixed in seed mixes with other grass and forb species. Sheep fescue is not considered to be an important forage grass and provides little cover for hiding or nesting habitat (Ogle et al. 2010).

Resilience:

Drought: Sheep fescue, and its cousins within the *Festuca ovina* complex, tolerates droughty, infertile soils and is therefore used in the landscape where soils are infertile and irrigation is minimal, if not absent (Ruemmele et al. 2003). Johnson (2008) contends that native sheep fescue is more drought tolerant than the introduced fine fescue species red, chewings and hard fescue. This may be because of its low evapotranspiration rate of 7-8 mm per day (Cebeco International Seeds). Heat resistance is generally considered poor (Beard 1973, Johnson 2008), as is typical for the fine fescues, although cultivar 'Quatro' is advertised by the breeder (Cebeco Seeds) as having arid climate heat resistance. In a 3-year study comparing 25 species and cultivars at two sites in southern Alberta, sheep fescue cultivar 'Nakiska', two hard fescue cultivars and blue grama maintained long-term superior area coverage despite a drought (McKernan et al. 2001). Similarly, in a low-maintenance study in the Piedmont of Virginia (Doak et al. 2004), two sheep fescue cultivars ('Quatro' and 'MX86AE') were as drought tolerant as hard fescue with mean percent cover of 67.5%

and 69%, respectively, after 4 years of growth and a severe drought in year 3 (Doak et al. 2004). In contrast, creeping red fescue and chewings fescue cultivars only maintained 40% and 51.5% cover, respectively, in the 4^{th} year. Sheep fescue ranked lower in drought tolerance in the cooler climate of the Ridge and Valley of Virginia with equal to slightly higher drought tolerance than chewings fescue but lower tolerance than some creeping red fescue cultivars and most hard fescue cultivars (Doak et al. 2004).

Low fertility: Sheep fescue prefers infertile soils (Beard 1973, Johnson 2008) and requires minimal nitrogen inputs (Ruemmele et al. 2003). Diesburg et al. (1997) argue that sheep fescue and tall fescue are the best adapted species for low-input conditions. However, heat tolerance may be poor (Beard 1973, Diesburg et al. 1997). Once established, sheep fescue showed good quality under low-input conditions in Maryland (Dernoeden et al. 1994, 1998), Minnesota (Watkins et al. 2010), and southern Alberta (McKernan et al. 2001). Sheep fescue (cultivar 'Blacksheep') was a top performing species, especially when not mowed, across 2 years in a low-maintenance eight-state study in the North Central US (Watkins et al. 2011). In the same region, three sheep fescue cultivars ('Azure', 'Barok', and 'Azay') had acceptable turf quality ratings in low-maintenance trials in some but not all of the eight North Central state locations (Watkins et al. 2014). Turf quality ratings were relatively poor in the summer compared to many of the other 22 turfgrass cultivars used in the study but, ratings improved in the fall. Overall quality ratings for sheep fescue were lower than ratings for chewings, hard, and tall fescue. Wakefield et al. (1974) evaluated persistence of turfgrass species along roadsides in Rhode Island and found that sheep fescue had better coverage along roadsides after 2 years of establishment. Persistence of sheep fescue cultivar 'Nakisha' was high in low fertility environments in southern Alberta (McKernan etal. 2001) and the Upper Midwest (Diesburg et al. 1997).

Freezing*:* As a cool-season grass, sheep fescue has excellent cold tolerance (Ogle et al. 2010).

Salinity: Sheep fescue is generally considered to be salt sensitive (Brod and Presse 1980, Brown et al. 2011) although some cultivars show higher tolerance to salinity. Sheep fescue 'Marco Polo' had as high or higher salinity tolerance in germination trials than tall fescue (Wang et al. 2011, Zhang et al. 2011, Friell et al. 2012) and red fescue 'Smirna' (Zhang et al. 2011) but showed reduced salinity tolerance than red fescue in a hydroponic system (Zhang et al. 2011, 2013). In a roadside trial in Minnesota, sheep fescue was among the most salt tolerant species in a trial of 75 cool-season turfgrass cultivars (Friell et al. 2012). Although germination was equal to tall fescue, visual quality of sheep fescue was lower than tall fescue in a greenhouse experiment when exposed to salinity treatments (Wang et al. 2011). Sheep fescue is similar in salt tolerance to hard fescue (Marcum 2008a).

Acidity: Similar to other fine fescue species, sheep fescue is adapted to acidic soils (Beard 1973). It has the least resistance to aluminum toxicity among 58 cultivars tested (Liu et al. 2008).

Wear tolerance: Wear tolerance of sheep fescue is considered to be good (Beard 1973, Ruemmele et al. 2003), including tolerance to mowing and grazing (Ruemmele et al. 2003). It can withstand moderate equipment traffic (Ogle et al. 2010) as long as plants are not dormant. In a Maryland low-input study, Dernoeden et al. (1998) showed that sheep fescue cultivar 'Bighorn' maintained acceptable quality despite being mowed once per month during the summer months with a rotary mower. Similarly, in a low-input study established at 8 sites in 7 states of the Upper Midwest

(Diesburg et al. 1997), common sheep fescue and tall fescue maintained the best quality among 11 turfgrass species despite being mowed once per week while leaves were elongating (i.e., when plants were not dormant). Watkins et al. (2010) showed that out of 15 species, sheep fescue ('SR 3100') had significantly better turfgrass quality than all other species when planted on fairways in Minnesota that were subjected to three levels of traffic. Average turfgrass quality for all other species besides chewings fescue was not acceptable for fairways. This superior performance, however, was only manifested in the second year of growth whereas sheep fescue was ranked 7th in wear tolerance (below Kentucky bluegrass, supine bluegrass perennial ryegrass, tall fescue and several bentgrasses) in the first year. After two years growth in field plots, sheep fescue turf cover ranged between 23% to 71% in control plots and 0-3.3% in plots subjected to a traffic simulator while turf cover for tall fescue, Kentucky bluegrass and perennial ryegrass maintained > 50% cover (Glab et al. 2015). Turf quality and shoot density decreased also. Given these data, Glab et al. (2015) ranked sheep fescue as the least wear tolerant of 7 species.

Competition: Sheep fescue resisted invasion and weed encroachment (McKernan et al. 2001) and is considered a good weed control species once stands are established (Ogle et al. 2010). Sheep and hard fescue cultivars maintained better quality and better resisted weed invasion than two tall fescue cultivars in a three-year study in Maryland without irrigation (Dernoeden et al. 1994). In a fine fescue trial comparing 80 fine fescue cultivars, the only sheep fescue cultivar tested, 'Quatro', did not stand out as being particularly superior or poor in suppressing weeds (Bertin et al. 2009); however the breeder of 'Quatro' (Cebeco International Seeds) indicates that the cultivar is competitive under low-maintenance conditions, advising that it should not be represented in the seed mixture by more than 20%.

<u>Mixes</u>: Sheep fescue (20-25%) mixed with hard fescue (20-25%), red fescue (20-25%), slender wheatgrass (0-20%), and Canada bluegrass (20-25%) had the highest cover ratings out of 10 seed mixes in a 3-year low maintenance study in southern Alberta (McKernan et al. 2001). Weed density in these mixes was lower than in monocultures of the species suggesting a synergistic effect among species. In a New Mexico field study, a mix of 70% hard fescue, 25% sheep fescue, and 5% Kentucky bluegrass showed good germination, excellent turfgrass coverage, and was fastest in achieving 50% coverage at normal and reduced seeding rate and at lower irrigation (Leinauer et al. 2010). In Minnesota, sheep fescue was used in a 'no-mow mix' containing 25% chewings fescue, 25% hard fescue, 25% red fescue, and 25% sheep fescue, and also in a 'fine fescue mix' containing 33% each of hard, red and sheep fescue (Meyer and Pedersen 1999). The fine fescue mix ranked higher than the no-mow mix, especially in turf color but also in turf quality and cover over three years (Meyer and Pedersen 1999). Both mixes generally ranked higher than any of the species planted in monoculture. The fine fescue mixes were also used in Minnesota by Miller et al. (2013) to test performance under low maintenance conditions over 3 years. The fine fescue mixtures had acceptable quality ratings. They ranked lower in quality than a tall fescue cultivar blend and native species mixtures but ranked higher than Kentucky bluegrass. In a road decommissioning study in Montana, Grant et al. (2011) used sheep fescue (20%), orchard grass (20%) and Italian ryegrass (60%) in a non-native seed mix. One year after establishment, each of the three seeded species was only present at less than 1% cover whereas native species established more rapidly. The authors conclude that native seed mixes result in faster vegetative establishment.

Cultivars: Sheep fescue has relatively few cultivars available in the United States compared to the introduced fine fescue species. Cultivars include ‘Azay’, ‘Covar’, ‘Ovina’, ‘Paradise’, and ‘Quatro’ (Pawnee Buttes Seed, Inc) although what is labeled as sheep fescue may be genetically more similar to hard fescue than sheep fescue. Cultivar ‘Quatro’ (Cebeco International Seeds, Netherlands) was released in 1977 by the Washington Agricultural Research Center as the first tetraploid sheep fescue available within the United States. It originated from Turkey and is bred for low-maintenance conditions and remains green under drought-induced dormancy. ‘Quatro’ can dominate polycultures under low-maintenance conditions and the breeder therefore suggests that the cultivar should not be represented by more than 20% of the seed mixture. Cultivar ‘Quatro’ may be the only true sheep fescue with all other cultivars actually being blue hard fescue (Brede 2000). Cultivar ‘Covar’ also originates from Turkey and it is unclear whether it is a true cultivar of sheep fescue or false sheep fescue (*Festuca valesiaca* = *Festuca pseudovina*; Ruemmele 2003). The cultivar is known to be an aggressive competitor and is suitable for planting along roadsides (Ruemmele 2003). Cultivar ‘MX-86’ (Jacklin Seed Company) originating from former East Germany and was released in 1988. ‘MX-86’ produces low-maintenance low-growing turf with improved seedling vigor and improved resistance to some diseases. Seed is enhanced with endophyte for improved disease resistance (Ogle et al. 2010). Accession ‘P-274’ was selected from material originating from Turkey by the Plant Materials Center at Pullman, Washington (Ruemmele et al. 2003) but never released as a cultivar. ‘P-274’ is a dwarf and densely tufted. Cultivar ‘Career’ was released in The Netherlands as a low-growing, drought-tolerant, and shade-resistant cultivar.

Hybrids: Hybridization within the *Festuca ovina* complex is not as extensive as in the *Festuca rubra* complex (Ruemmele et al. 2003). Artificial crosses with perennial ryegrass yielded nonviable seed.

Buffalograss

Buchloe dactyloides

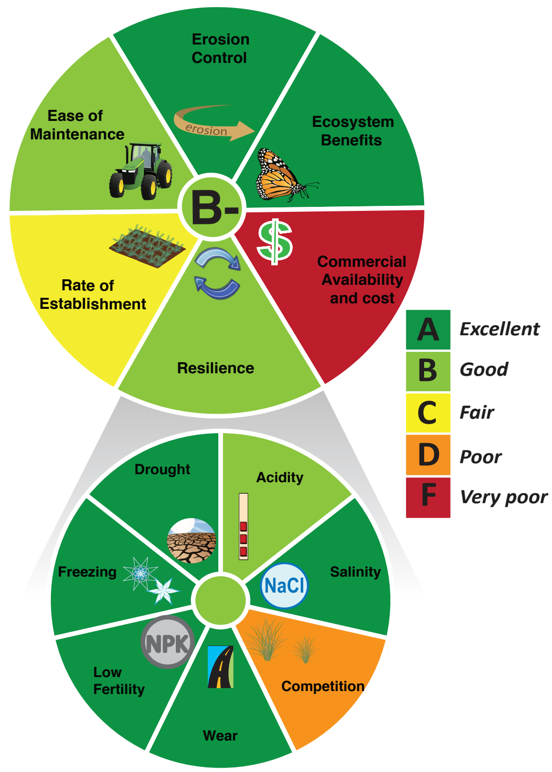
Buffalograss is native to the short-grass prairies of North America and therefore has excellent tolerance to drought, cold climates, and frequent traffic. Its low stature reduces the need for mowing, ecosystem benefits are excellent, and a dense sod stabilizes soil for erosion control. Buffalograss is therefore rated as Good to Fair (grade = B-) for use along Maryland roadsides; however several major management concerns may limit wide-spread use:

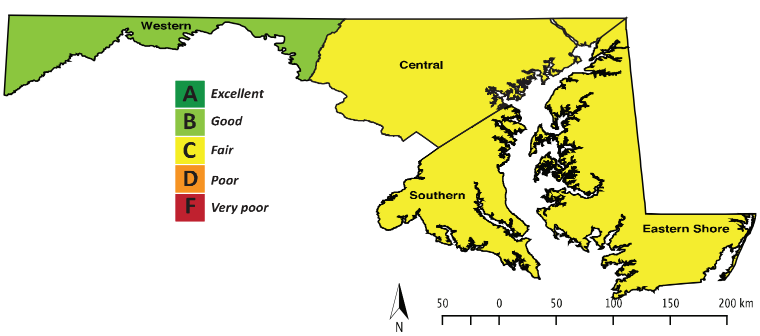

Buffalograss is commercially available but seed costs may prohibit use in larger areas.


Buffalograss often germinates poorly and requires 2 or more years for adequate establishment.


Buffalograss is a poor competitor in humid environments, such as the mid-Atlantic region.


Slow establishment and inferior competitive ability in humid environments require sustained herbicide use to suppress weeds, which increases maintenance costs.





Buffalograss may not be a high performer in Maryland owing to its low tolerance for humidity. Drier areas of Western Maryland may be suitable but other areas of Maryland may only be marginal for low-maintenance management.


Cultivars for use in Maryland will need to have northern origins. Vegetative cultivars from the northern Great Plains include Legacy, Prestige and Turffalo, and for seeded cultivars include Cody, Bowie, and Sharp’s Improved.

Biology: Buffalograss is a warm-season dioecious grass that is native to the short-grass prairies of North America (Leithead et al. 1971, Beard 1973, Wu et al. 1989, Riordan et al. 1993, Johnson 2000, 2008, Johnson et al. 2001, Riordan and Browning 2003, Duble 2012, Zhang et al. 2012) and has sometimes been called the bermudagrass of the north (Beetle 1950). The species was important in the recovery of the short-grass prairie after the 1930's drought (Albertson 1937, Albertson and Weaver 1944, Beetle 1950) and provided important forage for bison and sod for the houses of early settlers (Beard 1973, Duble 2012). Predominantly restricted to the short-grass prairie, it was introduced to Virginia in 1856 and was successfully introduced to New York (Riordan and Browning 2003). Owing to its low stature, adaptation to drought and good recuperative ability, tolerance to different mowing heights, and relatively quick establishment, it is the most commonly used native grass species in turfgrass applications (Riordan and Browning 2003, Johnson 2008). Buffalograss is now used in low maintenance conditions such as airfields, highway right-of-ways, cemeteries, parks and sports fields (Beetle 1950, Riordan et al. 1993, Johnson 2000, Sedivec et al. 2001, Riordan and Browning 2003, Duble 2012).

Seeds per pound: 335,000 seeds per pound (Ernst Conservation Seed)
Cost per pound: $16 per pound from Chesapeake Valley Seed and Ernst Conservation Seed
Cost per acre: $2,000.00 per acre
Suggested sowing rate: 125 pounds per acre (Chesapeake Valley Seed)
Sowing depth: 0.5 inches (Heckman et al. 2002, Riordan and Browning 2003), < ½ inch (Beetle 1950, Koski 2012)
Germination time: 7-10 days of treated seed with adequate moisture (Duble 2012), 7-21 days with warm soil and consistent irrigation (Koski 2012)
Seeding timing: late April or May, or fall with germination in the spring (Duble 2012). Mid to late May (Koski 2012). Optimum moisture is important (Riordan and Browning 2003). Seeding in July, August and September do not produce successful stands (Frank et al. 1998, Koski 2012)
Length of growing season: Late May through early September (Leithead et al. 1971, Koski 2012)
Leaf height: 3-6 inches (Leithead et al. 1971), 8-10 inches (Duble 2012), 4-6 inches (Riordan and Browning 2003)
Height at seed head stage: 4-6 inches (Leithead et al. 1971), 8-10 inches (Duble 2012), 8 inches (Simmons et al. 2011).
Shade tolerance: Not shade tolerant (Beetle 1950)
Suggested mowing height: does not need to be mowed to remain attractive (Koski 2012), 2-3 inches in lawns (Duble 2012), 2-3 inches (Frank et al. 2004), most commonly mowed at 3 inches (Johnson 2008), no mowing will result in a turf that is 6-8 inches tall (Johnson 2008). Mowing however may be needed to control weeds.
Humidity tolerance: Not adapted to humid climates. Higher rainfall will allow taller growing species to outcompete buffalograss (Duble 2012).
Disease resistance: Buffalograss is highly susceptible to western chinch bug (Blissus occiduus) in Nebraska (Riordan and Browning 2003, Carstens et al. 2007), and can be damaged by white grubs, grasshoppers, leafhoppers, prairie ants, buffalograss webworm, rhodesgrass mealybug and others (Riordan and Browning 2003). False smut caused by *Cercospora seminalis* affects burs in areas with higher rainfall (Riordan and Browning 2003). Leaf blotch caused by the fungus *Helminthosporium inconseicuum* causes plants to look brown (Riordan and Browning 2003). Infections, however are seldom severe (Riordan and Browning 2003).

Services:

Commercial availability and cost: Buffalograss is commercially available from a variety of vendors. However, seed is relatively expensive compared to fescues, Kentucky bluegrass, and perennial ryegrass. High seed cost and sowing rate make buffalograss an undesirable species to plant in large areas.

Rate of establishment: Buffalograss has a stoloniferous growth habit (Riordan and Browning 2003), which results in a uniform and complete turf in a short time (Johnson 2008). Planted plugs provided complete cover within 8-12 weeks (Koski 2012) with hexaploid cultivar 'Legacy' establishing faster from sprigs than tetrapoid cultivar 'Prestige' (Peterson et al. 2010).

Buffalograss seed germination can be poor owing to seed dormancy (Beetle 1950, Riordan and Browning 2003) and inhibitor substances in the glumes that delay germination (Wu et al. 1989, Riordan and Browning 2003, Duble 2012). Only 40% of new seed germinated the first year after planting and thus stratification, chemical treatment, and/or dehulling is necessary to increase germination rate (Beetle 1950, Beard 1973, Riordan and Browning 2003). Seed chilled at 5-10^{o}C for 6-8 weeks or treated chemically have 80-90% germination as opposed to 20% germination of untreated seed (Duble 2012). Harrington and Meikle (1992) reported 80% germination for buffalograss. Likewise, Tinsley et al. (2006) reported a germination rate of 93% for buffalograss, 73% for side-oats grama, and 66% for little bluestem. In germination experiments (Biesboer and Jacobson 1994, Biesboer et al. 1995), buffalograss reached 75-80% maximum germination after 9-10 days but germination was delayed by 5-10 days and reduced to 30-50% when treated with salinity. In contrast, blue grama maximum germination was 40-50% and was reached after 5 days, and little bluestem germination never exceeded 10% germination (Biesboer and Jacobson 1994). Thus, buffalograss germination is excellent when seeds are dehulled, soaked, stratified, and/or chemically treated (Riordan and Browning 2003).

Rate of establishment (reaching 70-100% cover), however, is slow (Johnson 2000, Simmons et al. 2011). In a Virginia roadside trial, buffalograss cover in the second year of growth never exceeded 60% cover and most plots covered less than 40% at a sowing density of 40 pounds PLS per acre (Doak et al. 2004). In the third year, however, four buffalograss cultivars had an average ground cover above 70% despite a severe summer drought. In Minnesota native plant trials by Meyer and Pederson (1999), buffalograss planted as plugs did not provide acceptable cover, color, or overall quality ratings and did not compete well with weeds. By the end of the first full year of growth, buffalograss covered only 10%. Cultivar 'Bowie' developed acceptable quality and cover ratings at slightly over 1 month after seeding at bur seeding rates of 20-40 g/m^2 (Shearman et al. 2005). At lower seeding rates, however, adequate establishment required two years. Weed interference is a major limiting factor for establishment such that seeding in April and May is recommended (Frank et al. 1998) and results in complete coverage within 7 to 13 weeks (Fry et al. 1993). Soaking burrs prior to seeding resulted in complete coverage one week sooner than unsoaked seeds (Fry et al. 1998). Seeding in July, August, and September leads to unsuccessful establishment (Fry et al. 1993, Frank et al. 1998). Buffalograss was slower to establish 95% cover than bermudagrass, bahiagrass and seashore paspalum, equal in establishment rate to centipedegrass and faster than zoysia (Severmutlu et al. 2011). Native grass mixtures containing 39% buffalograss by weight were slow to establish in Minnesota low-input trials (Miller et al. 2013). Establishment rate can be improved by nitrogen fertilization of up to 147 kg/ha (Frank et al. 2002) and irrigation (Beard 1973, Duble 2012). In a low input turfgrass trial of 12 species across seven states in the Upper Midwest of the United States, buffalograss establishment was excellent in Ohio and southern Illinois, similar or higher than the best performing tall fescue and sheep fescue cultivars (Diesburg et al. 1997). However, buffalograss establishment was poor in Iowa, Michigan, Indiana, central Illinois, Missouri and Wisconsin.

Ease of maintenance: Buffalograss, as a low-stature species, has a low requirement for mowing (Riordan et al. 1989 but see Brede 2002) and will not persist under intensive management (Duble 2012). In high rainfall areas, buffalograss is competitively inferior such that weed control may need to be used to maintain buffalograss presence (McCarty and Colvin 1992, Riordan et al. 1993). Under no-mow conditions, one native grass mixture containing buffalograss produced the best quality and had no weed cover compared to 6 other turfgrass mixtures, which contained up to 47% weed cover (Miller et al. 2013).

Erosion control: Buffalograss produces a dense sod (Beard 1973, Johnson 2000) that is effective in binding soil to prevent wind and water erosion (Riordan et al. 1993, Riordan and Browning 2003). It rapidly spreads vegetatively through extensive stolons (Riordan and Browning 2003) but does not possess rhizomes (Duble 2012). Beard (1973) considered the root system of buffalograss to be shallow although Riordan and Browning (2003) summarize several studies that observed the root system of buffalograss to be 60-120 cm long with some roots excavated at depths of up to 3 m. Similarly, Huang (1998) observed 18 to 31% of buffalograss total root dry weight to occur in the 40-80 cm soil layer in well-watered and drought conditions, respectively, whereas zoysia distributed 8-13% of its roots within that same soil layers and conditions. In a study of four turfgrasses (Qian et al. 1997), buffalograss roots reached 67 cm soil depth, which was less than tall fescue, equal to bermudagrass, and deeper than zoysia. Almost 50% of buffalograss roots were located below 30 cm soil depth as opposed to 43% in bermudagrass and 30% in zoysia. In addition to binding soil, buffalograss sod has high water-holding capacity that is between 57 to 60% field capacity (Beetle 1950, Riordan and Browning 2003).

Ecosystem benefits: Buffalograss is native to the central United States. Owing to its dense sod and tolerance to grazing, buffalograss was able to sustain vast herds of bison before the turn of the century and is still highly regarded as a good forage grass (Riordan and Browning 2003). Buffalograss sod provided building material for early settlers (Riordan and Browning 2003). It is used for seeding grass waterways on farms, lawns and recreational areas (Leithead et al. 1971) and is associated with numerous beneficial arthropods including spiders, predatory ants, ground beetles, rove beetles, big eyed bugs, and several species of hymenopterous parasitoids (Riordan and Browning 2003, Carstens et al. 2007).

Resilience:

Drought: Buffalograss has excellent drought (Beetle 1950, Leithead et al. 1971, Beard 1973, Wallner et al. 1982, Riordan et al. 1989, Riordan and Browning 2003) and heat tolerance (Beard 1973, Zhang et al. 2012). Drought tolerance is conferred through high water holding capacity (Riordan et al. 1993, Huang 1998, Riordan and Browning 2003), low evapotranspiration rate (Feldhake et al. 1984, Kim 1983, Kim and Beard 1988, Beard and Kim 1989, Riordan and Browning 2003), leaf rolling during drought stress (Savage and Jacobson 1935, Riordan et al. 1993, Riordan and Browning 2003), and deep roots (Qian et al. 1997, Johnson 2008) or plasticity in root distribution (Huang 1998). Buffalograss can go dormant quickly with drought stress and also revive quickly when the drought is alleviated (Beard 1973, Riordan et al. 1993, Riordan and Browning 2003, Johnson 2008). Its reestablishment after the 1930's drought was important for conservation and agriculture (Savage and Jacobson 1935, Albertson and Weaver 1944, Beetle 1950, Riordan et al. 1993, Riordan and Browning 2003). Motivated by the 1930's drought, Mueller and Weaver (1942) experimented with the drought tolerance of 14 species and observed buffalograss seedlings to be less drought tolerant than blue grama but more drought tolerant than dropseed > side-oats grama > prairie junegrass. Buffalograss had the lowest evapotranspiration rate of 12 turfgrass species and cultivars under water limiting conditions (Kim 1983). Buffalograss and blue grama had superior plant vigor and color than tall fescue and Kentucky bluegrass under rain-fed conditions whereas the reverse was observed under irrigated conditions (Islam et al. 2013). In a field experiment (Qian and Engelke 1999), buffalograss maintained acceptable turf quality at 26% pan evaporation, which was lower than tall fescue (67%), Zoysia (68%), and St. Augustinegrass (44%) and bermudagrass (35%). Osmotic adjustments of buffalograss (0.84 MPa) were the highest during dry down in a controlled greenhouse experiment (Qian and Fry 1997), compared to zoysia (0.77 MPa), bermudagrass (0.60 MPa) and especially tall fescue (0.34 MPa). In a Virginia roadside trial, four buffalograss cultivars were able to maintain cover above 70% despite a severe drought (Doak et al. 2004). Cultivar 'Cody' showed the most promise as a drought resistant buffalograss cultivar compared to cultivars 'Bison' and 'Bowie' (Islam et al. 2013).

Low fertility: Buffalograss is adapted to heavy loamy clay soils (Riordan and Browning 2003) that are intermittently wet and dry (Leithead et al. 1971). Buffalograss is adapted to low input conditions (Riordan et al. 1989) and is reported to require very little fertilization in rangeland applications (Johnson 2008). However fertilizer application of 98 kg N/ha sustained quality, color and density of buffalograss whereas lower fertilizer applications decreased performance (Frank et al. 2004). In low-input trials in Minnesota (Miller et al. 2013), one native grass mixtures containing 39% buffalograss by weight performed well after the initial establishment year.

Freezing*:* Buffalograss is adapted to altitudes up to 2000 m (Beetle 1950) and can grow well in northern latitudes (Riordan et al. 1993, Bhowmik et al. 2008). It is therefore well adapted to cold temperatures (Beetle 1950, Beard 1973) and has excellent low-temperature tolerance (Stier and Fei 2008). Following freezing treatments, 'Tatanka' and 'NE91-118' maintained higher relative shoot and root regrowth than four other cultivars (Qian et al. 2001). Maximum freezing tolerance also differed among cultivars with cultivars 'Tatanka' (LT50 = -18 to -21^{o}C) and 'Texoca' (LT50 = -17 to -22^{o}C) being the most tolerant (Qian et al. 2001). Higher glucose, fructose, and raffinose endogenous soluble carbohydrates were higher in cultivar 'NE91-118' than in cultivar '609' and may be responsible for why 'NE91-118' was able to survive 4.5 to 4.9 ^{o}C colder temperatures (Ball et al. 2002).

Salinity: Buffalograss has some capacity to preferentially exclude sodium from its leaves (Wu and Lin 1994, Marcum 2002, 2008b) but is not adapted to highly saline soils (Johnson 2008) and is therefore ranked as moderately salt sensitive (Wu and Lin 1994, Marcum 2002, 2008a, b) or moderately tolerant (Harivandi et al. 1992, Uddin 2013). However, substantial variation in salt tolerance has been observed (Wu and Lin 1994, Zhang et al. 2012). Among seven species, buffalograss was less tolerant to salt than salt grass, dropseed, bermudagrass and zoysia but more tolerant than side-oats grama (Marcum 1999). Among eight species tested, buffalograss demonstrated the greatest tolerance to salt compared with side-oats grama, little bluestem and others (Harrington and Meikle 1992). In a salinity experiment, Biesboer and Jacobson (1994) observed buffalograss to be more salt sensitive than blue grama but more salt tolerant than side-oats grama, little bluestem, prairie dropseed, and sand dropseed. In contrast, Roberts and Zybura (1967) rank buffalograss as less sensitive to salt than blue grama but more sensitive than side-oats grama, sand lovegrass, and tall fescue. In greenhouse experiments, buffalograss was less tolerant to salinity than alkaligrass and tall fescue but more tolerant than blue grama (Marcum 2008a). Of six native species, buffalograss and blue grama were the most capable of germinating under high salt concentrations (Biesboer and Jacobson 1994) but germination was delayed by 5 to 10 days, survival reduced by 50%, and shoot and root biomass reduced by 75% when plants were treated with 5,000 ppm NaCl (Biesboer et al. 1995). Out of 5 buffalograss and 3 blue grama cultivars tested under four salinity treatments (Zhang et al. 2012), buffalograss on average was more salt sensitive than blue grama. The germination rate of buffalograss cultivar 'Texoka' at 5 g NaCl per liter was 63 - 66% and for the other buffalograss cultivars was <30%. Germination decreased rapidly to below 10% at 10 g NaCl per liter and was entirely inhibited at higher concentrations. In contrast, although germination was greatly reduced, blue grama cultivars were able to maintain limited germination at higher salinity levels (Zhang et al. 2012). At the vegetative stage, however, blue grama showed higher sensitivity to salt than buffalograss (Zhang et al. 2012). Seedlings are less tolerant of salt than young shoots from established clones (Wu and Lin 1994). Buffalograss attained high germination under moderate to high deicer concentrations similar to blue grama, little bluestem, mountain brome, and slender wheatgrass (Dudley et al. 2014).

Acidity: Buffalograss is adapted to neutral soils ranging in pH from 6.5 to 8.0 (Thorne and Cardina 2011) and has medium aluminum tolerance (Liu et al. 2008). Buffalograss consistently performed poorly, showing a 55% decrease in relative root mass and 72% decrease in phosphorus root recovery at high aluminum concentrations in the soil (Baldwin et al. 2005).

Wear tolerance: Growing points are close to the ground such that buffalograss can withstand close grazing and mowing (Leithead et al. 1971). Buffalograss can withstand moderate to heavy grazing (Riordan et al. 1993), which removes species that might otherwise be superior competitors (Riordan and Browning 2003). Thus, mowing can increase performance of buffalograss (Savage and Jacobson 1935, Riordan and Browning 2003). However, overgrazing and excessive traffic and mowing can weaken plants and lead to the deterioration of a stand of buffalograss (Beetle 1950, Leithead et al. 1971, Duble 2012, Koski 2012). Mowing can lead to scalping of buffalograss (Simmons et al. 2011), which exposes the lower, non-photosynthetic portion of tillers and weakens plants. A study that compared the performance of 24 native species and cultivars under different mowing heights (Mintenko et al. 2002) found that buffalograss did not perform as well as blue grama and prairie junegrass but better than most other native grasses including side-oats grama and alkaligrass. Fertilizer application of 98 kg nitrogen per hectare can improve traffic tolerance (Johnson 2008).

Competition: Weed management is very important in buffalograss turf (Koski 2012), especially when buffalograss is establishing (Meyer and Pederson 1999, Johnson 2008) or grown in suboptimal conditions such as higher rainfall. Nurse grasses are not recommended when planting buffalograss (Riordan and Browning 2003). Buffalograss cannot compete with taller species that grow where greater rainfall favors their growth (Riordan et al. 1993, Duble 2012). Thus, in high rainfall areas such as the eastern United States, buffalograss is not a superior competitor and will therefore not resist weed invasion (McCarty and Colvin 1992). Similarly, buffalograss will be an inferior competitor under disturbed conditions (overgrazing, heavy traffic, intensive management) when weeds may invade and outcompete buffalograss (Beetle 1950, Duble 2012). However, once established, buffalograss monocultures and polycultures with blue grama and other native species were able to suppress weeds better than a monoculture of bermudagrass (Simmons et al. 2011). Overseeding red fescue, blue fescue, and chewings fescue on buffalograss resulted in dominance of fine fescues (Johnson 2003, 2008, Severmutlu et al. 2005). Buffalograss is also an inferior competitor in southern locations when mixed with bermudagrass (Beetle 1950). Once fully established and in good condition, buffalograss competes well with weeds (Johnson 2008).

Mixes: Buffalograss frequently co-dominates native communities with blue grama and side-oats grama (Savage and Jacobson 1935, Beard 1973, Riordan and Browning 2003). Buffalograss and blue grama comprise 90% of vegetation on non-sandy soils of the short-grass prairie (Riordan and Browning 2003). On rocky calcareous slopes, buffalograss can grow naturally with blue grama, side-oats grama, hairy grama, sand dropseed, and little bluestem (Riordan and Browning 2003). Fine fescues are overseeded on buffalograss to enhance visual quality in the winter (Severmutlu et al. 2005, Abeyo et al. 2009). 'Legacy' buffalograss and 'DR-3200' blue fescue performed the best in terms of visual compatibility (Abeyo et al. 2009). However, fine fescues tend to dominate the mixture. In a Minnesota low-input study of 8 seed mixtures, Miller et al. (2013) included buffalograss at 39% by weight in one of two native seed mixtures. Both native grass mixtures were slow to establish and had low quality and high weed cover in the establishment year. However, the mixture containing buffalograss established faster with 63% cover 56 days after seeding than the other native grass mixture with 47% cover. In the third year of the study, turfgrass quality ratings were excellent and equal to a tall fescue blend. Weed cover sowed in native grass mixtures was higher or equal to plots seeded with tall fescue and fine fescues but lower than plots containing Kentucky bluegrass. Virginia roadside trials (Doak et al. 2004) used buffalograss alone and in mixtures with little bluestem, or blue grama, or side-oats grama, or with little bluestem and either blue grama or side-oats grama. Buffalograss alone and the mixture with blue grama performed the best with >70% cover in most years after the first establishment year and despite a severe drought. Texas DOT uses buffalograss in mixtures with side-oats grama, bermudagrass, indiangrass and green sprangletop (Tinsley et al. 2006) and observe good establishment of buffalograss and side-oats grama.

Cultivars: Improvement of buffalograss began in 1936 (Riordan and Browning 2003). Collections from northern and southern location showed differences in morphology and management requirements (Riordan and Browning 2003) with northern accessions being shorter and requiring less mowing. Southern accessions were vigorous growers with better disease resistance. Early cultivars 'Prairie' and '609' showed the best performance (Riordan et al. 1993) and were released as cultivars in 1990 (Duble 2012). Both are female plant selections and need to be established as sod or plugs (Duble 2012). Accessions of buffalograss differ greatly in root distribution (Klingenberg 1992) and response to climate (Peterson et al. 2010). Commercially available vegetative cultivars include 'Prairie', '609', 'Density', 'UC-Verde', and 'Scout' from southern Great Plains, as well as 'Legacy', 'Prestige', 'Turffalo', and '378' from northern Great Plains (Riordan and Browning 2003, Johnson 2008, Koski 2012). Winter hardy cultivars include 'Legacy', 'Prestige', and 'Turffalo'. Seeded cultivars include 'Bison', 'Plains', Topgun', and 'Texoca' from southern Great Plains, as well as 'Bowie' from northern Great Plains. 'Cody' and 'Sharp's Improved' are seeded cultivars from both southern and northern Great Plains. (Johnson 2008, Koski 2012). Cultivars 'Legacy', 'Scout', '609', '378', and 'Cody' showed the best performance according to 1999 NTEP results (Riordan and Browning 2003).

Chewings fescue

Festuca rubra ssp. commutata = Festuca rubra var. commutata = Festuca nigrescens = Festuca commutata = Festuca rubra var fallax = Festuca rubra ssp eu-rubra var commutata

Chewings fescue is part of the red fescue complex but the subspecies has very different growth habits, including no rhizomes but extensive tillering, which results in dense sod. Chewings fescue is commercially available at low cost and requires little maintenance owing to its low stature. However, it is rated only as Fair to Good (grade = C+) owing to several management concerns:

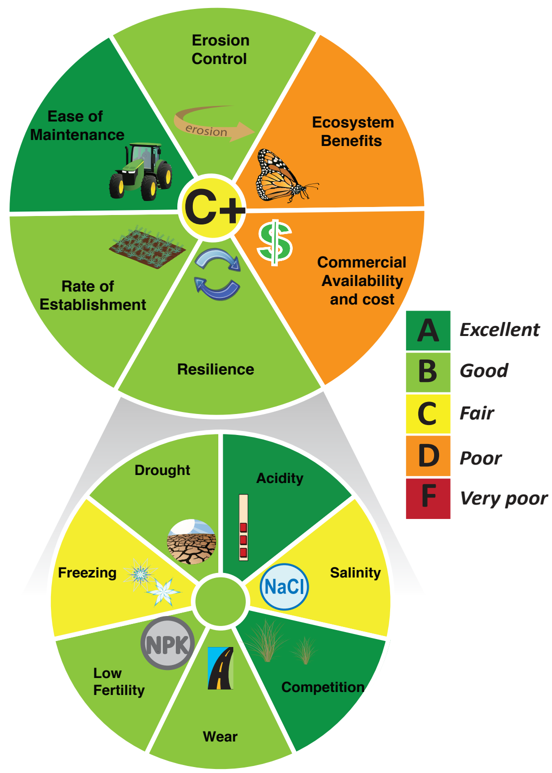
Chewings fescue resists weed invasion through dense turf but this attribute also limits diversity. Wildlife value is poor.

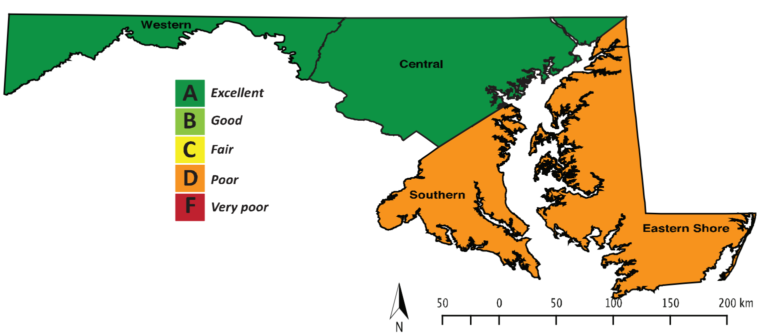
Chewings fescue is moderately expensive when planted over large areas.

Chewings fescue does not produce rhizomes. Combined with shallow rooting, this species may not be suitable for stabilizing steep banks.

Chewings fescue germinates well but turf quality establishes slowly, often requiring 6 months.

Chewings fescue is only fair in its tolerance to soil salinity and cold temperatures. Drought and heat negatively affect turf quality.





Chewings fescue is suitable for roadsides in Western and Central Maryland. However, its use is not recommended for Southern Maryland and the Eastern Shore.

Chewings fescue cultivars that are recommended for Maryland in 2016 include Fairmont, Intrigue 2, Longfellow 3, Treazure II, Wrigley 2, Zodiac (new varieties) and Radar. Updates to recommended cultivars in Maryland are published annually in the University of Maryland Turfgrass Technical Update TT77 (Maryland Turfgrass Council).

Biology: Chewings fescue is a perennial cool-season grass native to Europe that has been introduced widely in other parts of the world including New Zealand (first cultivation) and the United States (Ruemmele et al. 2003). Chewings fescue is part of the red fescue complex but is treated separately owing to its differences in growth habit from the creeping red fescues – chewings fescue is a bunch-type species that lacks rhizomes (Ruemmele et al. 2003). However, tillering is extensive (Beard 1973) and maintains high density in turfs (Ruemmele et al. 2003).

*Seeds per pound:*500,000 seeds per pound (University of Tennessee extension)
Cost per pound: $2.38 per pound from Ernst Conservation Seed
Cost per acre: $416.50 per acre
Suggested sowing rate: 175 pounds per acre (Chesapeake Valley Seed); 130 pounds per acre (Bertin et al. 2009)
Sowing depth: <1/2 inch (John et al. 2012)
Germination time: 7-14 days (University of California IPM)
Seeding timing: spring or early fall
Length of growing season: spring to fall with a period of dormancy in hot summers
Leaf height: 1.5-6 inches (Ruemmele et al. 2003)
Height at seed head stage: 10-35 inches (Ruemmele et al. 2003)
Shade tolerance: good (Beard 1973, VanHuylenbroeck and VanBockstaele 1999)
Suggested mowing height: 4-6 inches (Doak et al. 2004); avoid scalping because it will cause substantial mortality (Booze-Daniels pers. communication)
Tolerance of wet conditions: needs well-drained soil
Humidity tolerance: Adapted to cool humid climates (Beard 1973) and therefore tolerant of high humidity.
Disease resistance: Good overall disease resistance. Chewings fescue is susceptible to *Puccinia graminis* ssp. *graminicola*; leaf spot resistance is moderate; and resistance to *Laetisaria fuciformis* is intermediate between hard fescue and creeping red fescue (Ruemmele et al. 2003). The presence of endophytes in some cultivars ('Longfellow') is increasing disease resistance to *Blissus leucopterus* and *Sclerotinia homeocarpa.*

Services:

Commercial availability and cost: Chewings fescue seed is somewhat more expensive than creeping red fescue but less so than hard fescue and sheep fescue. It is commercially available.

Rate of establishment: Establishment rate from seed is good (Beard 1973). However, turf quality is slow to develop and only emerges after 6-18 months of growth (Erdmann and Harrison 1947, Bertin et al. 2009, Watkins et al. 2010, Turner *pers. communication*). Using photosynthetic measurements, VanHuylenbroeck and VanBockstaele (1999) found that chewings fescue had a slower growth rate than red fescue. Among 80 cultivars tested in New York, chewings fescue cultivar 'Sandpiper' was among the top 6 fine fescue cultivars showing high seedling vigor (Bertin et al. 2009).

Ease of maintenance: Chewings fescue, similarly to all fine fescues, prefers low-input environments with minimal fertility and irrigation (Beard 1973). Chewings fescue does not have to be mowed between mid-June and mid-September because the species becomes dormant during these months. During hot summers, mowing should even be avoided as it can damage the turf.

Erosion control: Chewings fescue does not produce rhizomes and therefore produces less root mass in the upper soil layers than creeping red fescue (Ruemmele et al. 2003). Thus, chewings fescue may not be as good at stabilizing soil as creeping red fescue. Depth of rooting is unknown.

Ecosystem benefits: Ecosystem benefits for chewings fescue are generally not differentiated from its close cousins the creeping red fescues. Red fescues are generally non-native although John et al. (2012) suggest that some red fescues have North American origins. Red fescue produces a dense turf (chewings fescue through extensive tillering and creeping red fescue through rhizomes), which decreases weed invasion but also limits species diversity (John et al. 2012). Bertin et al. (2009) showed that some chewings fescue cultivars produce phytotoxins that affect the growth and survival of other species in the community. Wildlife will feed on red fescue but red fescues are generally not recommended for forage production owing to their low nutritional value and some endophyte containing cultivars (John et al. 2012).

Resilience:

Drought: Chewings fescue is drought resistant and can tolerate dry soils (Ruemmele et al. 2003). Chewings fescue avoids drought by having a lower evapotranspiration rate (Beard and Kim 1989, McCann and Huang 2008) than other cool-season grasses such as tall fescue, perennial ryegrass and Kentucky bluegrass. Beard (1973) rates drought tolerance of chewings fescue as good; however, it does not tolerate temperature extremes. It maintained evapotranspiration, quality and leaf growth under limited soil moisture compared to Kentucky bluegrass and perennial ryegrass, which declined rapidly when soil water potential reached -50 to -80 kPa (Aronson et al. 1987). Chewings fescue had one of the highest survival rates among 15 turfgrass species when soil moisture was reduced and when soil temperature was increased. However, survival was severely reduced (20%) when air temperature was increased to 50^{o}C for 6 hours (Carroll 1943). Chewings fescue was more drought tolerant than creeping red fescue in low fertility soils but was less drought tolerant in higher fertility soils (Carroll 1943). In a low-maintenance study in the Ridge and Valley of Virginia (Doak et al. 2004), two chewings fescues produced 50% and 60% cover, after 4 years, including a severe drought in the third year of the study. Under the same conditions, two sheep fescue cultivars maintained 60% cover, five creeping red fescue cultivars produced 60-80% cover, and 6 hard fescue cultivars maintained 80-90% cover suggesting that drought tolerance in the Ridge and Valley of Virginia ranks chewings < sheep < creeping red < hard fescue. In contrast, at a Piedmont site, creeping red fescue had the least drought tolerance with cover mean = 40%, closely followed by chewings fescue at mean cover = 51.5%, then sheep fescue with mean = 67.5% and hard fescue at 69% (Doak et al. 2004). In a 3-year study in southern Alberta, McKernan et al. (2001) observed chewings fescue cultivar ‘Shadow’ to be drought sensitive. Drought resistant cultivars of chewings fescue are ‘Ambrose’, ‘Ambassador’, ‘Treazure’, and ‘Bridgeport’ (McCann and Huang 2008).

Low fertility: Chewings fescue cultivars (‘Intrigue’, ‘Jamestown II’, ‘Culumbra’) performed consistently well in the summer and fall across eight North Central states in low-maintenance trials that tested performance of 25 turfgrass cultivars representing 10 species (Watkins et al. 2014). Chewings fescue had one of the highest survival rates among 15 turfgrass species in low-N conditions (Carroll 1943). Chewings fescue cultivars 'Longfellow' and 'SR 5100' and a strong creeping red fescue and chewings fescue mix had the best turf quality among 15 monoculture and polyculture treatments at low rates of fertilizer use and also recovered faster after disturbance (Horgan et al. 2007). Watkins et al. (2010) also observed chewings fescue to be superior in quality among 17 species, including tall fescue, perennial ryegrass, and Kentucky bluegrass but only in the second growing season. In contrast, after comparing turf quality of four cultivars of fine fescues and one cultivar of tall fescue in a Maryland low-input study, Dernoeden et al. (1998) concluded that chewings fescue is not as tolerant to low fertility, low input environments than some of its fescue cousins.

Freezing*:* Although Stier and Fei (2008) highlight the cold-hardiness of all fescues, Bear (1973) suggests that chewings fescue does not tolerate extreme cold temperatures. Percent survival of chewings fescue was 75-90% up to -10^{o}C but no survival was observed at -15^{o}C and below (Carroll 1943). When also subjected to soil drying, survival decreased to 25%.

Salinity: Unlike its close cousins, strong creeping and slender creeping red fescue, chewings fescue is considered a salt sensitive species (Humphreys 1981, Marcum 2008a, Brown et al. 2011, Friell et al. 2013, Uddin and Juraimi 2013).

Acidity: Chewings fescue is adapted to acidic soils with high sand content (Beard 1973) and has good resistance to acid soils with high aluminum content (Liu et al. 2008). This tolerance is further increased by some endophyte-infected cultivars (Liu et al. 2008).

Wear tolerance: Beard (1973) suggests that chewings fescue has better wear tolerance than most cool-season turfgrasses, and Horgan et al. (2007) observed chewings fescue and hard fescue to be more wear tolerant than other fine fescues. Similarly, chewings fescue had better wear tolerance than red fescue (Canaway 1981, Ruemmele et al 2003). Watkins et al. (2010) showed that out of 17 species, chewings fescue ('Jamestown II') maintained acceptable quality on-low input fairways in Minnesota when subjected to three levels of traffic. Average turf grass quality for all other species besides sheep fescue was not acceptable for fairways. This superior performance, however, was only manifested in the second year of growth; chewings fescue was ranked low in wear tolerance (below Kentucky bluegrass, supine bluegrass, perennial ryegrass, tall fescue, and several bentgrasses) in the first year. Chewings fescue was only ranked 6th out of 7 species in wear tolerance (Glab et al. 2015), and Shearman and Beard (1975) observed that wear tolerance of chewings fescue was less than perennial ryegrass and Kentucky bluegrass. Chewings fescue overseeded on Bermudagrass in California showed marginal tolerance to traffic simulation (Cockerham et al. 1990), and was severely damaged by traffic in a similar experiment in Missouri (Dunn et al. 1994). Traffic, including mowing, will cause severe mortality while plants are dormant in the summer months (mid-June to mid-September). In a 3-year study, Willmott et al. (2001) found that chewings and hard fescue maintained better quality than tall fescue and prairie junegrass in an orchard that was mowed in the summer. However, hard and chewings fescue suffered damage from maintenance equipment and the damage was most severe in the summer during heat and drought stress. Thus, Willmott et al. (2000) stress that equipment traffic on chewings fescue during heat and drought stress needs to be avoided. In contrast, Doak et al. (2002) observed no change in cover in experiments in Virginia when chewings fescue was subjected to mowing once in May, twice in May and September, or three times in May, July, and September, suggesting some wear tolerance if mowing height is high (>6 inches) and scalping is minimized (Booze-Daniels *pers. communication*).

Competition: Ryegrass negatively affected the growth of chewings fescue in polyculture owing to the initial rapid growth of ryegrass (Erdmann and Harrison 1947). When grown together, chewings fescue and Kentucky bluegrass showed equal competitive ability and could therefore be used in mixture without a decrease in yield of either species (Erdmann and Harrison 1947). Chewings fescue is competitive in low-input environments. In a low-input study in Utah, chewings fescue (cultivar 'Jamestown II') and creeping red fescue were more competitive than buffalograss in mixture (Johnson 2003). Chewings and hard fescue maintained the best quality and the lowest weed populations in a 3-year orchard study (Willmott et al. 2000). Similarly, Bertin et al. (2009) found that chewings fescues, as a group, were strongly weed suppressive with >70-80% weed suppression. Chewings fescue cultivars with the best and consistent weed suppression included 'Sandpiper', 'Intrigue', and 'Columbra'. Root exudates of the chewings cultivar 'Intrigue' showed strong phytotoxicity that suppressed numerous weed species (Bertin et al. 2009). Thus, weed suppression in cultivars of chewings fescue may be a function of rapid establishment and the maintenance of a dense canopy and vigorous root system in combination with the production of allelochemicals (Bertin et al. 2009).

Mixes: Chewings fescue is used in seed mixes with Kentucky bluegrass (Beard 1973, Ruemmele et al. 2003) because the species are similar in competitive ability (Erdmann and Harrison 1947). This species combination can be used in sun or partial shade lawns either alone or with Agrostis species or red fescue (Ruemmele et al. 2003). A 'no-mow mix' containing 25% chewings fescue, 25% sheep fescue, 25% red fescue, and 25% hard fescue performed adequately in a low-maintenance study in Minnesota but was ranked lower in turf quality, color and cover over three years than other mixes containing perennial ryegrass (Meyer and Pedersen 1999). The fine fescue mixes were also used in Minnesota by Miller et al. (2013) to test performance under low maintenance conditions over 3 years. The fine fescue mixtures had acceptable quality ratings. They ranked lower in quality than a tall fescue cultivar blend and native species mixtures but ranked higher than kentucky bluegrass. Chewings fescue is sometimes used for overseeding lawns to maintain adequate winter color and cover (Ruemmele et al. 2003) in bermudagrass (Nelson et al. 2005) and buffalograss (Severmutlu et al. 2013). A mix of chewings fescue with buffalograss may allow irrigation levels to be lowered in semi-arid regions; however chewings fescue tends to be more competitive than buffalograss in mixture (Johnson 2003).

Cultivars: The first cultivars were released in New Zealand. In the United States, cultivar 'Checker' was released by the Oregon Agricultural Extension Service in 1978. Cultivar 'Victory' was released in 1988 for improved seed yield, disease resistance, uniformity, tolerance to close mowing, and tolerance to acidity, shade, and low fertility. Other cultivars such as 'Longfellow', 'Jamestown' and 'Banner' were released to contain endophytes and be more heat resistant. Other cultivars were released for their slow growth ('SR5000', 'Tiffany'), low maintenance ('SR5000', 'Silhouette'), and drought/heat tolerance ('Silhouette'; Ruemmele et al. 2003).

Hybrids: Cultivar 'Seabreeze' is a hybrid between slender creeping red fescue and chewings fescue but is released as a slender creeping red fescue cultivar (Ruemmele et al. 2003).

Poverty oatgrass

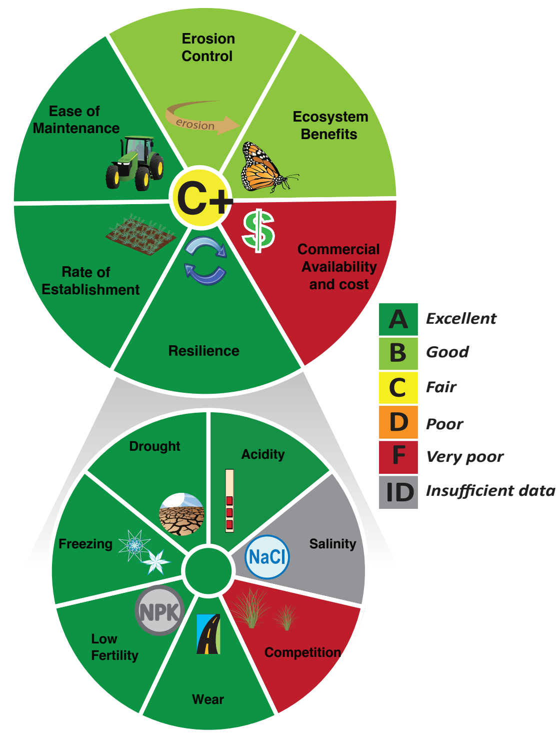
Danthonia spicata

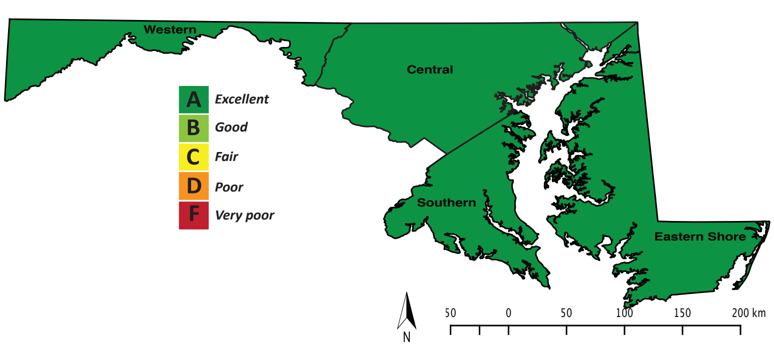
Poverty oatgrass is a native grass species that is widely adapted to a range of environmental conditions encountered along roadsides. It is best used in species mixtures. Poverty oatgrass requires minimal maintenance because of its low stature. It establishes quickly, is resilient to roadside conditions, provides erosion control in plant mixtures, and is a biodiversity enhancer. Poverty oatgrass is rated Fair to Good (grade = C+) with three major management concerns:

Commercial availability is poor and seed cost is currently prohibitive for use in larger quantities despite low seeding rates per acre.

Poverty oatgrass is a pioneer species which decreases in density as more competitive species establish. However, this trait is important in mixed communities that are established in highly disturbed areas such as roadsides.

Salinity tolerance of poverty oatgrass is unknown.





Poverty oatgrass is adapted to environmental conditions throughout Maryland.

If seed availability and cost can be improved, poverty oatgrass has the potential to become a highly rated roadside grass species.

Biology: Poverty oatgrass is a perennial cool season grass that is widespread in the United States except for in the Southwestern United States (USDA Plants Profile). It is particularly secure in the eastern United States and in temperate and boreal North America (Darbyshire and Cayouette 1989). Poverty oatgrass has no rhizomes or stolons (Darbyshire and Cayouette 1989) and therefore persists in the landscape through limited seed dispersal, a persistent seedbank, and by tillering (Darbyshire and Cayouette 1989). It forms low stature tufts in a variety of habitats including pastures, grasslands, and forests on poor, dry and rocky soils (Nature Serve Version 7.1) and is particularly known to occur on 'sterile' soil (Core 1929) such as cleared foothills, minelands and roadsides. Poverty oatgrass prefers sunny locations where it develops distinctive curled and twisted blades.

Seeds per pound: 400,000
Cost per pound: $480 per pound from Chesapeake Valley Seed
Cost per acre: $4,800.00 per acre
Suggested sowing rate: 10 pounds per acre (Chesapeake Valley Seed)
Sowing depth: unknown
Germination time: unknown
Seeding timing: spring
Length of growing season: Poverty oatgrass will grow in the early spring and in the fall. It is commonly dormant in the summer months (U.S. Forest Service).
Leaf height: 2.4-8 inches (Darbyshire and Cayouette 1989)
Height at seed head stage: 3.9-39.3 inches (Darbyshire and Cayouette 1989)
Shade tolerance: Poverty oatgrass is phenotypically plastic and can grow in both sunny and shady environments and exhibit different morphologies depending on light conditions (Darbyshire and Cayouette 1989).
Suggested mowing height: Can be used in no-mow or minimally mowed areas.
Tolerance of wet conditions: Requires well drained soil (Darbyshire and Cayouette 1989)
Humidity tolerance: Requires a precipitation rate of 9.8-11.8 inches per year (Darbyshire and Cayouette 1989).
Disease resistance: Susceptible to clavicipitaceous fungal parasites, which affect productivity, reproduction, and fitness. Also susceptible to a common fungal disease casued by the parasite *Atkinsonella hypoxylon,* which causes choke (Darbyshire and Cayouette 1989, Scheiner 1989).

Services:

$ *Commercial availability and cost*: Some native nurseries carry this species, however it is in short supply. The seed is expensive and could only be used in mixture with other native grasses. Planting in large areas as a monostand is cost prohibitive.

Rate of establishment: Poverty oatgrass produces a persistent seedbank that can stay viable in the soil for decades or more (NatureServe 2015). Although highly dormant (Darbyshire and Cayouette 1989), they will germinate readily on mineral soil (U.S. Forest Service). Seeds germinated best when alternating temperatures between room temperature and 35^{o}C. A 71% sulfuric acid treatment also facilitates germination by weakening the seed coat. Prechilling at 3^{o}C with a potassium nitrate treatment may also be effective for germination (Darbyshire and Cayouette 1989).

Ease of maintenance: Poverty oatgrass is a low-stature plant and can therefore be used in minimal mow or no-mow conditions (Miller et al. 2013).

Erosion control: Owing to its fibrous roots (Darbyshire and Cayouette 1989), poverty oatgrass is considered to be a useful grass for erosion control and protects the soil against excessive nutrient leaching (Darbyshire and Cayouette 1989). It will grow well in fire-disturbed areas and clearcuts of the eastern United States (U.S. Forest Service). However, plants are only loosely rooted and easily uprooted with attached soil (Darbyshire and Cayouette 1989) suggesting that poverty oatgrass would, by itself, be inadequate for stabilizing soil.

Ecosystem benefits: Poverty oatgrass is native and widespread in North America particularly in temperate and boreal regions (Darbyshire and Cayouette 1989, Nature Serve 2015). It is a common component of native grasslands that also include little bluestem, prairie junegrass, fescues, and bluestems but will occasionally be found as a weed on cultivated land (Darbyshire and Cayouette 1989). Because of its low stature, cover benefits for wildlife are negligible. Its forage value is generally considered poor (Dustman and Shriver 1929) but is an important spring forage species for wildlife (Dustman and Shriver 1929). Poverty oatgrass is the host of the leaf hopper *Latalus personatus*, the butterfly *Oeneis chryxus strigulosa*, grass aphids, and a chalcid wasp *Harmolita danthoniae* (Darbyshire and Cayouette 1989).

Resilience:

Drought: Poverty oatgrass grows well in varying environments including dry and rocky soils with low soil moisture (Darbyshire and Cayouette 1989). In central Ontario, the abundance of poverty oatgrass is reduced in areas of higher soil moisture (Reznicek and Maycock 1983 in Darbyshire and Cayouette 1989). Some ecosystems that are dominated by poverty oatgrass may be drought-dependent (U.S. Forest Service). When soils are dry, the leaves of poverty oatgrass curl and twist, which is a characteristic trait.

Low fertility: Poverty oatgrass is adapted to low-fertility environments and is therefore considered to be a useful grass for roadsides (U. S. Forest Service). It is known to invade agricultural fields that are depleted in nutrients ,which makes it a good indicator of soil fertility (Darbyshire and Cayouette 1989). A West Virginia pasture study observed an increase in poverty oatgrass populations with a decrease in phosphorus and potassium (Baker and Nestor 1979 in Darbyshire and Cayouette 1989).

Freezing*:* Poverty oatgrass is frost-heave resistant (Darbyshire and Cayouette 1989). As a cool-season grass, it is adapted to cold environments and is widespread even in boreal regions (Darbyshire and Cayouette 1989). Therefore, it has excellent freezing tolerance.

Salinity: unknown

Acidity: Poverty oatgrass has a wide tolerance to substrate pH and can be found on acid bedrock as well as limestone barrens (Darbyshire and Cayouette 1989). A West Virginia study observed an increase in poverty oatgrass populations with a decrease in pH (Baker and Nestor 1979 in Darbyshire and Cayouette 1989).

Wear tolerance: The cleistogamous flowers are basally located, which allows poverty oatgrass to be resilient to mowing and grazing. Active grazing favors poverty oatgrass (Darbyshire and Cayouette 1989, Dunwiddie 1997), suggesting that mowing would do the same.

Competition: Poverty oatgrass is a pioneer species (Darbyshire and Cayouette 1989, Dunwiddie 1997), which colonizes recently disturbed areas and then decreases in abundance as other more competitive species move in (Dustman and Shriver 1929). Therefore, it is not a competitive species and will decrease in abundance as resources, such as light, become limiting. Poverty oatgrass appears to grow well with goldenrod (Darbyshire and Cayouette 1989) but competes with vernalgrass (*Anthoxanthum*; Kelley 1985). Common grass species that co-occur with poverty oat grass include little bluestem, prairie junegrass, fescues, and bluegrasses (U.S. Forest Service).

<u>Mixes</u>: Poverty oatgrass was used in one of eight grass mixtures in low maintenance trials in Minnesota (Miller et al. 2013). The mixture contained only natives: 1% poverty oatgrass, 53% little bluestem, 32% side-oats grama, 10% blue grama, 3% prairie junegrass, and 1% kalm's brome. The mixture was the slowest to establish with 47% cover 56 days after seeding as opposed to 95% cover for the best performing mixtures (tall fescue blend and fine fescue mixture). However, after underperforming in the first year of establishment, the native mixture received very good turf quality ratings in the second and the third year of growth under minimal mowing conditions. Percent weeds in the third year was moderate (12%). Under no-mow conditions, the mixture obtained the best quality ratings by the third year and supported few weeds (7%).

<u>Cultivars</u>: No cultivars are reported. Phenotypic plasticity may be more important than genetic diversity in microhabitat selection. Variants are not correlated with habitat differences and are mixed within populations (Darbyshire and Cayouette 1989, Scheiner 1989). Different accessions are associated with vesicular arbuscular endogonaceous mycorrhizal fungi to varying degrees with some accessions showing no colonization (Darbyshire and Cayouette 1989).

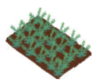
Tall fescue

Festuca arundinacea, Schedonorus arundinaceus, Lolium arundinaceum

Tall fescue is a popular species to use along roadsides in the mid-Atlantic region because it is widely available commercially; is a soil stabilizer; establishes relatively quickly, and is resilient to many environmental conditions, including management abuse. Tall fescue as a roadside grass is rated as Fair to Good (grade = C+) with several management concerns:

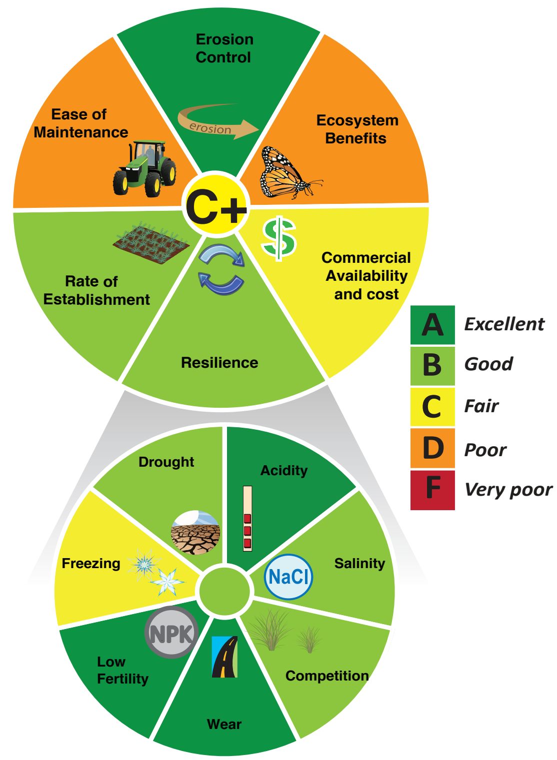
Tall fescue provides poor ecosystem benefits for pollinators, mammals, and birds, and has the capacity to become weedy in Maryalnd. Tall fescue is not a diversity enhancer; rather, through its production of allelochemicals in some cultivars, it suppresses other species where it is dominant.

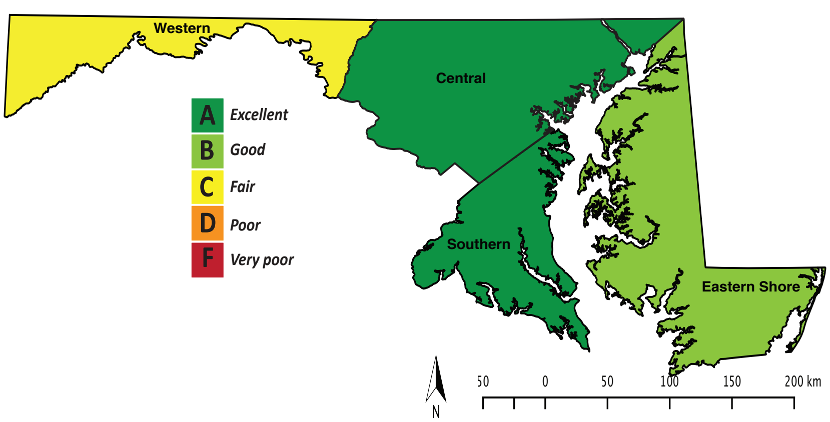
Because of its vigorous growth and tall growth habit, tall fescue has to be mowed frequently, which increases the maintenance costs of roadside habitat that needs to be maintained as low turf.



Tall fescue germinates rapidly but mature root systems establish slowly. Plants are therefore negatively affected by drought, frost heaving, and traffic within the first 6-12 months of growth.

$ Seed cost per pound for tall fescue is very affordable, however seeding rate per acre is high. Thus, planting over a large area can be moderately expensive.





Tall fescue is well adapted to grow throughout the Southern and Central portions of Maryland, including the Eastern Shore. It is prone to low temperature injury, resulting in thinning and weediness. Tall fescue is therefore not recommended as a roadside species for Western Maryland.

Cultivars that may enhance tall fescue performance in Maryland include ‘4th Millenium SRP’, ‘Titanium 2LS’, and ‘Traverse 2SRP’, which all are on the recommended list for Maryland and perform within the top 25% for drought tolerance, quality under low maintenance, and wear tolerance. Cultivar ‘Mustang 4’ is a slow growing variety and may therefore require less mowing. Updates to recommended cultivars in Maryland are published annually in the University of Maryland Turfgrass Technical Update TT77 (Maryland Turfgrass Council).

Biology: Tall fescue is a long-lived perennial cool season grass species that is native to Europe (Beard 1973) but was introduced to the United States by European settlers over 100 years ago (Meyer and Watkins 2003). Since then, it has proven to be pre-adapted to the Mid-Atlantic region of the Eastern US, thriving along roadsides in Maryland, Pennsylvania, and Virginia. Tall fescue is valued as a resilient grass that grows under a variety of growing conditions (Beard 1973, Meyer and Watkins 2003, Bughrara 2007, Watkins et al 2011, Watkins et al 2014) and is therefore a preferred turfgrass species when stressful environmental conditions are likely. Owing to its symbiotic association with the intercellular endophyte fungus Neotyphodium coenophialum (USDA Plant Guide), tall fescue can grow under marginal conditions including soils that are acidic (Park and Murphy 2016), poorly drained (Beard 1973), and have low fertility (USDA Fact Sheet); harsh management conditions such as heavy grazing or frequent mowing (Bughrara 2007); and drought (Qiang et al. 1997, Wilman et al. 1998, Fu et al. 2007). Tall fescue is now widely used in home lawns, sports fields, parks, pastures, and airfields, and is a popular species for use along roadsides for soil stabilization and erosion control (Beard 1973, Bughrara 2007). Short rhizomes can be produced in some habitats (Meyer and Watkins 2003) but vegetative spread is slow such that seed dispersal is the dominant form of propagation.

Seeds per pound: 227,000 seeds per pound
Cost per pound: $1.60 per pound from Chesapeake Valley Seed
Cost per acre: $320.00 per acre
Suggested sowing rate: 200 pounds per acre (Turner *pers. communication*)
Sowing depth: 1/8 inch
Germination time: 7-12 days
Seeding timing: Seeding in summer not recommended as plants will develop heat stress.
Length of growing season: Long
Leaf height: up to 24 inches (3 feet; Meyer and Watkins 2003)
Height at seed head stage: up to 6 feet (Meyer and Watkins 2003)
Shade tolerance: Performs best in the sun but is moderately shade tolerant (Beard 1972).
Suggested mowing height: 2-4 inches (1.5- 3 inches best mowing height; Meyer and Watkins 2003)
Tolerance of wet conditions: Tolerates wet soil conditions and extended periods of submersion. It can therefore be used in drainage ways (Beard 1972).
Humidity tolerance: Tall fescue has a very high water use and evapotranspiration rate (Feldhake et al. 1983, Kim 1983, Beard and Kim 1988, Carrow 1995, Qiang and Fry 1997) such that it requires more water to maintain good turf quality (Biran et al. 1981, Fu et al. 2004, Barnes et al. 2014). It is therefore not an ideal species to use in dry climates but thrives in humid climates such as the mid-Atlantic region.
Disease resistance: Diseases include snow molds, brown patch (*Rhizoctonia solani*), net blotch, red thread, ruse and pythium blight (Bughrara 2007). In non-irrigated areas, tall fescue can take longer to recover from brown patch disease (Dunn et al 2002).

Services:

Commercial availability and cost: Tall fescue is a valuable turf grass species in the United States. Commercial availability and cost of seed ($1.60 per pound) is excellent. Planting tall fescue over a large area can be moderately expensive due to a high sowing rate per acre.

Rate of establishment: Although the species germinates quickly (McKernan et al. 2001), a deep and extensive root system requires a full growing season to establish (Bughrara 2007). Thus, young tall fescue stands are susceptible to drought, freezing, and diseases in the first year of establishment (Bughrara 2007). Once fully mature, however, tall fescue has excellent tolerance to stressful conditions. Timing and rate of seeding are therefore critical considerations that can greatly affect outcomes, as are proper soil preparation, and adequate nitrogen fertilization and irrigation in the first year.

Ease of maintenance: Tall fescue is highly productive and produces higher biomass than many turfgrass species (e.g., Barnes et al. 2014). For that reason, roadsides planted with tall fescue need to be mowed frequently (at least 3 times during the growing season in Maryland), increasing maintenance costs and placing machinery operators into danger. Although cultivars have been developed that grow more slowly and are shorter in stature (see below), these new traits can yield a shallower root structure (but see Kim et al. 1999) with consequences for erosion control and drought resistance.

Erosion control: Tall fescue has an extensive and deep root system (Sprague 1933, Beard 1972) reaching 60-75cm in depth (Kim et al. 1999, Brown et al. 2010). Brown et al. (2010) in a Rhode Island study found that tall fescue had a significantly larger root system than 19 other species. However, in a California study that compared the root system of tall fescue with perennial ryegrass and the hybrid Festulolium showed no difference in root morphology among entries (Barnes et al. 2014). Water was not limiting in the study and so plants did not need to respond to drought conditions through extending roots deeper into the round. Owing to its deep and extensive roots, tall fescue can stabilize soil (Beard 1973) and is therefore considered to be one of the best choices for anchoring roadside slopes (Brown et al. 2010). Carbon sequestration increases in endophyte infected tall fescue because productivity is increased while the rate of decomposition is decreased. Higher soil organic matter increases infiltration, reduces erosion and increases soil fertility.

Ecosystem benefits: Tall fescue is a non-native species that has been planted in the United States for over 100 years. Old cultivars may be considered naturalized although new cultivars may not be depending on their origins. Through seed dispersal and some vegetative expansion, tall fescue has the capacity to become invasive in some states but not Maryland. In California native prairies, for example, tall fescue is considered a noxious weed. An endophyte fungus produces alkaloids in some cultivars, which deters insect and nematode herbivory and increases disease resistance of the species (Bughara 2007). Tall fescue exhibited the lowest soil nitrate concentrations and the lowest nitrate leaching potential compared to perennial ryegrass and Kentucky bluegrass (Liu et al. 1997). Cultivars differed significantly in their effects on nitrate loss. Effects were not consistent through time but were the lowest for tall fescue cultivars 'Rebel II' and 'SYN GA'.

Resilience:

Drought: Cool season grasses are generally not as tolerant of high temperature and drought stresses than warm season grasses (Su et al. 2007). However, owing to its deep and extensive roots, tall fescue can access soil water to withstand drought stress to a greater degree than other major cool season grasses (Beard and Kim 1989, Fry and Butler 1989, Cougnan et al. 1990, Wilman et al. 1998, Meyer and Watkins 2003, Barnes et al. 2014) and even some warm season grasses (Qian et al. 1997). Water shortage did not negatively affect tall fescue rooting and, at some rooting depths and irrigation levels, enhanced rooting depth (Fu et al. 2007). Similarly, Qian et al. (1997) determined that tall fescue roots were deeper during drought than three warm-season turfgrass species. This may explain why tall fescue survived 4 years with severe water shortage whereas meadow fescue, annual ryegrass, perennial ryegrass and Fescue x Lolium hybrids died within 12-24 months of water shortage (Wilman et al. 1998). Tall fescue has a very high evapotranspiration rate (Beard and Kim 1989) and therefore a higher water use rate with higher sustained stomatal opening (Sun et al. 2013), which maintains photosynthesis and root growth under high temperature and drought (Sun et al. 2013) and decreases heat injury compared to other cool season grasses (Wallner et al. 1982). Given this physiology, tall fescue is not actually drought tolerant, but a good drought avoider by avoiding low leaf water potential (Qiang and Fry 1997). Despite these favorable reports on tall fescue drought 'tolerance', some studies report failure of tall fescue to withstand drought. A study in Maryland (Dernoeden et al. 1994) found that tall fescue was invaded by smooth crabgrass (*Digitaria ischaemum*) to a greater extent than two fine fescues species after a drought, suggesting that tall fescue becomes less competitive under drought stress. In 4-year low-maintenance trials in Virginia (Doak et al. 2004), 19 out of 39 tall fescue cultivars maintained >70% after recovering from a severe drought at a Virginia Ridge and Valley site. However, only 4 of the 39 cultivars recovered to 70% cover at a Virginia Piedmont site. The best performing tall fescue cultivar across both sites was 'Regiment'. In another trial in Blacksburg, VA, Doak et al. (2004) observed tall fescue cover to decrease from 83% in the second year after establishment to 8% in the 6th year after a severe drought the previous year. Islam et al. (2013) in a study conducted in Wyoming found that tall fescue performance was highest among 4 species under irrigated conditions but not rain-fed conditions when warm-season grasses were superior. In a Canadian study, McKernan et al. (2001) found that tall fescue did not survive a drought period, where mortality may have also been compounded by overwinter freezing injury. A growth chamber study (Su et al. 2007) found no difference in drought resistance between tall fescue, Kentucky bluegrass and 'Thermal Blue', a hybrid between Kentucky bluegrass and Texas bluegrass (*Poa arachnifera*).

Low fertility: Tall fescue, hard fescue, and sheep fescue showed the best quality under low-input conditions in Maryland (Dernoeden et al. 1998). Similarly, an evaluation of the response of 11 turfgrass species to low-input maintenance (Diesburg et al. 1997) found that tall fescue and sheep fescue had the best persistence across locations. Wakefield et al. (1974) evaluated persistence of turfgrass species along roadsides in Rhode Island and found that tall fescue had the best coverage along roadsides one year after seeding, but cover was reduced after 2 years. Similarly, Watkins et al. (2010) compared 17 turfgrass species in a low-input fairway study and found that tall fescue turf produced the 5th best turf quality (after 3 bentgrass species and Kentucky bluegrass) the first year after establishment; however, turf quality declined to unacceptable levels the second year.

Freezing*:* Temperature extremes limit the distribution of tall fescue, where winter survival is affected by extended periods of ice sheeting and snow cover (Meyer and Watkins 2003, Watkins et al. 2014). Tall fescue had medium cold hardiness compared to 12 cool-season turfgrasses (Beard 1973, Bhowmik et al. 2008, Beard 1973) and is therefore prone to low temperature injury (Beard 1973), which leads to gradual thinning and eventual weediness. While spring seeding is popular to allow plants to establish before the next winter, germination may be delayed by cold temperatures (Meyer and Watkins 2003).

NaCl Salinity: Tall fescue is rated as moderately tolerant to salinity of 6-10 dS/m (Harvandi et al. 1992, Marcum 2008, Uddin 2013; Table 1). Tall fescue germination (Lunt 1961, Schiavon et al. 2013) and yield (Lunt 1964) were not sensitive to salinity, and tall fescue had the best salt tolerance of 10 species (Roberts and Zybura 1967). Tall fescue was more tolerant of salinity than Kentucky bluegrass owing to the maintenance of a high root to shoot ratio (Alshammary et al. 2004). At the end of salinity tolerance trials by Friell et al (2013), tall fescue cultivars showed the best performance over other species after two weeks of being exposed to 14-24 dS/m salinity levels. However, observations along Illinois roadsides that are treated with salt suggest that tall fescue is succeeded by quackgrass that is then invaded and outcompeted by weeping alkaligrass when salt content is high (Butler et al. 1971). Cultivars differed in salinity tolerance (Horst and Beadle 1984).

Acidity: Tolerance of alkaline soils is better than most cool season grasses (Beard 1972). Soils of pH 5.5. to 6.5 are preferred but soils of pH 4.7 to 8.5 are tolerated (Beard 1972).

Wear tolerance: Beard et al. (1973) argues that tall fescue is one of the most wear tolerant cool season grasses and can therefore be used in areas of intensive traffic. However, during establishment, tall fescue is sensitive to traffic, which negatively affects growth and allows weeds to outcompete tall fescue. Thus, tall fescue is not as effective in renovating disturbed areas than perennial ryegrass and Kentucky bluegrass, which can better withstand wear during establishment (Meyer and Watkins 2003). In a low-input fairway study in Minnesota, Watkins et al. (2010) observed similar declines in turfgrass quality in tall fescue and Kentucky bluegrass in the first year of the study whereas whereas bentgrasses, perennial ryegrass, and supine bluegrass were largely unaffected by traffic treatments; poor quality was further reduced by traffic in the second year. Similarly, wear tolerance trials showed that turf quality of tall fescue decreased when subjected to traffic (Cockerham et al. 1990). Bughrara (2007) suggests that tall fescue is less wear tolerant than Kentucky bluegrass and is therefore best used in areas that are not exposed to heavy traffic.

Competition: Despite having weed suppressive effects through the production of allelochemicals (Peters and Zam 1981), tall fescue is susceptible to competition with other species, especially perennial ryegrass (Harkess 1970). The only species that can be effectively mixed with tall fescue appears to be Kentucky bluegrass and then only 5-10% of Kentucky bluegrass, by seed weight, should be used (Meyer and Watkins 2003). Tall fescue produces coarse textured clumps when grown with fine fescue (Bughrara 2007) and is less competitive than hard fescue in cooler regions of Virginia (Doak et al. 2004). Tall fescue performed well within the first year of establishment with little input of irrigation, fertilizer, or herbicides, but after the first year, tall fescue was outperformed by fine fescues and invaded by smooth crabgrass and clover after a spring drought (Dernoeden et al. 1994). Large crabgrass, smooth crabgrass and, southern crabgrass are problematic weed species for tall fescue (Cutulle et al 2014).

Mixes: Because tall fescue does not produce abundant rhizomes, the species is often mixed with Kentucky bluegrass (Beard 1973) to increase sod strength especially under extreme wear conditions (Hunt and Dunn 1993). A 95/5 percent by weight tall fescue to Kentucky bluegrass mixture produces a stand with approximately equal number of both species; however, composition of the mixture can gradually shift to Kentucky bluegrass at lower mowing heights, greater nitrogen fertility and more frequent irrigation which are conditions that favor Kentucky bluegrass. Perennial ryegrass can also be used in mixes with tall fescue, however it tends be the more dominant species in the mix (Dunn et al 2002). Even small amounts of perennial ryegrass can result in 90% cover of perennial ryegrass after establishment (Park and Murphy 2016).

Cultivars: Cultivars 'Alta' and 'Kentucky 31' were the first cultivars released in the early 1940's (Meyer and Watkins 2003). 'Kentucky 31' was and still is the dominant cultivar grown in the US because of its vigor, wide adaptation to variable soil pH, rainfall and sunlight, drought tolerance, and resistance to pests (Meyer and Watkins 2003). In a 1967 study, Roberts and Zybura found that 'Kentucky 31' showed the best physiological and growth characteristics for placement along roadsides affected by salt. Since these early cultivars, breeders have created numerous cultivars with darker color, narrower leaves, better disease resistance, and shorter stature. The cultivar 'Rebel' was released in 1979 as the first turf-type tall fescue with reduced vertical growth to decrease mowing frequency. Rebel was soon followed by the cultivars 'Falcon' and 'Olympic' (Meyer and Watkins 2003). However, mature heights still ranged 130-145cm. Now dwarfing cultivars are available, such as 'Matador' and 'Bonsai', which attain the same height as the lower growing fine fescues. However, dwarf-type tall fescue is more prone to disease owing to higher tiller density and is subject to heat stress. Semi-dwarf cultivars are now showing the best performance in the United States and include 'Millenium', 'Rembrandt', and 'Plantation', as well as earlier maturing cultivars 'Prospect', 'Empress', and 'Endeavor'. Continued breeding is selecting for brown patch disease resistance, density, endophyte enhancement, acid tolerance, and genetic diversity (Meyer and Watkins 2003).

In low-maintenance trials in Virginia to select tall fescue cultivars for use along roadsides, Doak et al. (2004) showed that cultivars 'Anthem II', 'Aztec II', 'Crewcut', 'JT-1', 'SR 8300', and 'Tarhill' reached 85% cover after 3 years of growth in a Ridge and Valley site. Cultivars 'SR 8300', and 'Tarhill' performed at the same level (>85%) at a Piedmont site but at a coastal plain site these same cultivars only reached 60% and 43% cover, respectively after a severe drought. The best performing cultivars at the coastal plain site were 'Anthem II', 'Kittyhawk SST', 'Laramie', and 'Regiment' with 70-75% cover. Kim et al. 1999 compared the rooting depth of 16 cultivars and found that five entries could reach soil depths of 75cm. Dwarf- and turf-type tall fescues do not have reduced rooting depth and rooting extent than intermediate or forage type tall fescue (Kim et al. 1999). Selection for deep root production enhances drought tolerance in cultivars (Bonos et al. 2004, Karcher et al. 2008). A blend of tall fescue cultivars, 'Greenskeeper', 'Coyote II', ' Tarheel II', and 'Fidelity', outperformed other mixtures in trials by Miller et al (2013). The trials were under mow and no mow conditions in low fertility soils. The outcome of the Miller et al 2013 trials showed that blends of cultivars may have a potential broad use under low-maintenance conditions. Recent evidence suggests that the genetic diversity in existing turf-type germplasm is too narrow to promise significant progress in breeding in the future (Baird et al. 2012).

Hybrids: Tall fescue can hybridize with perennial ryegrass and annual ryegrass (Buckner 1960).

Bermudagrass

Cynodon dactylon var. dactylon, Cynodon transvaalensis, Cynodon transvaalensis, Cynodon x magennisii, and Cynodon incompletes var. hirautus

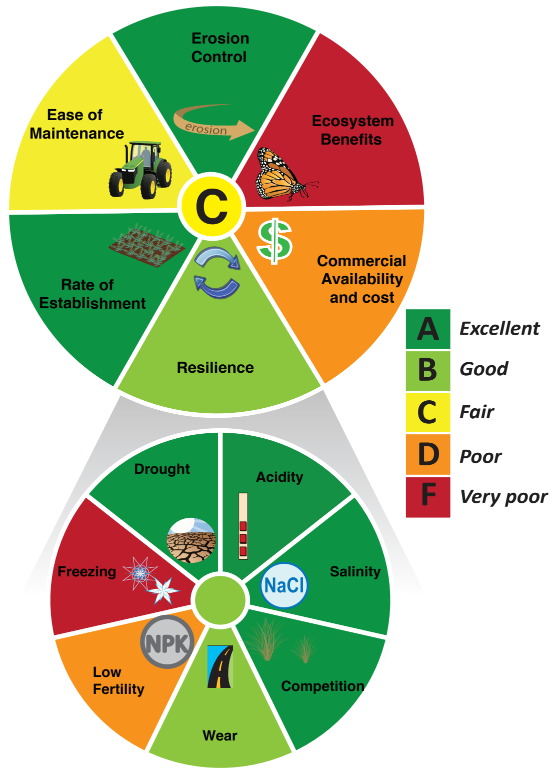
Bermudagrass is a low maintenance grass that establishes quickly and produces a deep and fibrous root system that binds the soil and provides excellent erosion control services. However, the species is rated as Fair (grade= C) owing to several management concerns that decrease the species' overall usefulness for roadside management:

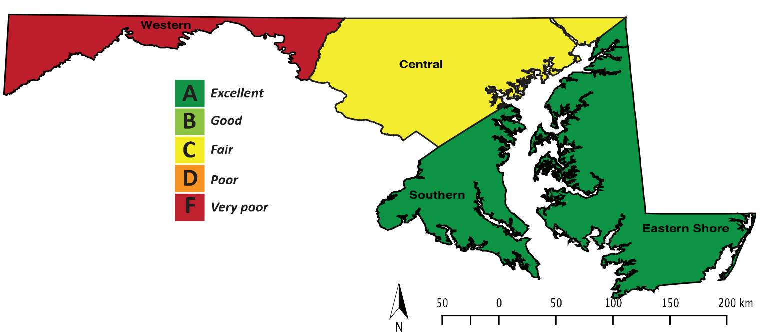
Bermudagrass is an aggressive competitor that can become weedy and invasive. It will enter dormancy in cooler climates, leaving the ground bare and increasing potential for erosion. Ecosystem benefits are therefore rated as very poor.

Costs of acquiring planting material are high.

Bermudagrass needs to be mowed to minimize blooms and avoid scalping. Maintenance requirements are therefore not reduced despite the low stature.

Bermudagrass is intolerant of low fertility soils and has lower tolerance to freezing temperatures than some species. Thus, it is not a resilient species under many of the environmental conditions encountered along Maryland roadsides.





Bermudagrass is adapted to warm climates and is therefore not recommended for Western Maryland. The species may not thrive in Central Maryland but it is well adapted for Southern Maryland and the Eastern Shore.

Vegetative bermudagrass cultivars include Latitude 36, Northbridge, Patriot, and Tifton 10 and new variety Premier.

Bermudagrass (*Cynodon dactylon var. dactylon, Cynodon transvaalensis, Cynodon x magennisii, Cynodon incompletes var. hirautus*)

Biology: Bermudagrass is a complex of nine species and ten varieties within the genus Cynodon that was introduced to Colonial America and spread rapidly with the migration of settlers (Taliaferro 2003). Of all perennial warm season grasses, the Cynodon species that are the most important to turf production are listed above. Several additional Cynodon species are cultivated with minor turf importance (Taliaferro 2003). Bermudagrass is widely distributed throughout humid, tropical, and subtropical regions of the world for use in lawns, parks, sports fields, fairways, cemeteries, and along roadsides and airfields (Beard 1973, Taliaferro 2003). Although adapted to milder climates, bermudagrass may be used in temperate climates or regions of transition between warm and cool season grasses (Taliaferro 2003). Sometimes characterized as a weed in nature (Harlan and de Wet 1969), it only occurs as pure stands under artificial conditions. In natural settings, bermudagrass only thrives in disturbed open areas and will generally not invade natural grasslands or forests (Harlan and de Wet 1969) owing to intolerance to shading and established competitors. However, because bermudagrass can form an aggressive turf with high shoot density and a fibrous and deep root system (Beard 1973) it has the potential to become invasive. Thus, vegetative propagation through sprigs, plugs and sod (Beard 1973) is often recommended to minimize this risk to neighboring ecosystems.

Because bermudagrass can be an aggressive competitors, sodding is the only accepted establishment approach in Maryland.
**Seeds per pound:*725,000 seeds per pound in 'Riviera' bermudagrass.
**Cost per pound:* $15 per pound for 'Yukon' bermudagrass from Chesapeake Valley Seed
**Cost per acre:* $675.00 per acre
**Suggested sowing rate:* 45 pounds per acre (Turner *pers. communication*)
**Sowing depth*: ¼ inch
**Germination time:* 2.5 to 13.5 days (50% germination; Deaton and Williams 2013), 10-30 days (University of California IPM)
Seeding timing: as early as 15 May but later dates have faster germination times (Deaton and Williams 2013). Patton et al. (2004) suggest between June 1 to July 15.
Length of growing season: Spring to fall
Leaf height: Not reported but unmowed height is acceptable for roadsides (Brede 2002).
Height at seed head stage: Not reported because bermudagrass is typically mowed before it blooms.
Shade tolerance: intolerant of shading (Beard 1973, Taliaferro 2003, Jiang et al. 2004, 2005, Wiecko 2008)
Suggested mowing height: 1.5 inch cutting height (Turner pers. communication).
Tolerance of wet conditions: can withstand flooding for extended periods (Beard 1973, Taliaferro 2003)
Humidity tolerance: adapted to humid regions (Beard 1973)
Disease resistance: Susceptible to a variety of diseases including brown patch, *Helminthosporium*, dollar spot, and spring dead spot (Beard 1973). Leaf, stem, and crown rots caused by *Bipolaris cynodontis* are among the more serious diseases in humid climates (Taliaferro 2003). Spring dead spot is a more serious disease in colder climates (Taliaferro 2003). Nematodes and insects such as sod webworms, armyworms, mole crickets, bermudagrass mite, and frit fry are also considered pests (Beard 1973).

Services:

Commercial availability and cost: Bermudagrass is commercially available as seed, sod, sprigs, and plugs. Maryland only allows sod to be planted along roadsides, which increases cost.

Rate of establishment: In Maryland, bermudagrass can only be established via sodding. Establishment of bermudagrass seed, however, is rated as excellent (Beard 1973). Bermudagrass seeded in Indiana reached 95% cover within 30 to 60 days (Patton et al. 2004). Rate of establishment in Turkey was also fast compared to zoysia, buffalograss, and centipedegrass (Severmutlu et al. 2011). However, establishment of bermudagrass along a roadside in Texas was lower than expected due to high water demand during the first week after sowing (Tinsley et al. 2006). Germination rate was highest for cultivar 'Casino Royal' (2.5 to 4.9 days for 50% germination, and 93-100% overall germination) and lowest for cultivar 'Riviera' (6.3 to 13.5 days and 5-52% overall germination; Deaton and Williams 2013). Fall seeding resulted in poor establishment, however (Leinauer et al. 2010). Bermudagrass has the most rapid growth rate of the warm season turfgrasses, has a very rapid establishment rate, and recuperates quickly after disturbance (Beard 1973). Greenhouse experiments observed a growth rate for bermudagrass as high as 9.2% per day which was the highest rate observed among 6 warm season grass species (Busey and Myers 1979).

Ease of maintenance: Bermudagrass is adapted to low maintenance conditions where vegetative cultivars are more sensitive to changes in maintenance than seeded cultivars (Brede 2002). Bermudagrass has a decumbent growth habit, which might suggest that it does not have to be mowed as frequently. However, bermudagrass needs to be mowed to minimize blooms and therefore the risk of invasion into neighboring systems. Blooms are especially frequent under stressful conditions such as roadsides. Frequent mowing is also required to avoid scalping because thatch has a tendency to accumulate (Taliaferro 2003). The cultural requirement of maintaining good quality turf is high for bermudagrass (Taliaferro 2003). Although drought tolerant, bermudagrass requires adequate soil moisture for sustained growth, color and sod density. It also responds well to fertilizer with nitrogen being the most limiting nutrient (Taliaferro 2003).

Erosion control: The root system is fibrous, extensive, and deep (Beard 1973, Wiecko 2008) suggesting that bermudagrass is a good species to use for erosion control. Forty-eight percent of total root length in bermudagrass was located below 30 cm soil depth (Qian et al. 1997), similar to drought resistant buffalograss. However, bermudagrass had significantly lower root length density the next year of the study owing to root disease. 'Tifway' bermudagrass developed the most extensive deep root system within 20-60 cm soil depth in a study comparing seven turfgrass species/cultivars common to the Piedmont region of the southeastern United States (Carrow 1996). Common bermudagrass rooting was less extensive at 20-60 soil depth but equal to Rebel II tall fescue and higher than 'Kentucky 31' tall fescue and zoysia (Carrow 1996). These results, however, were confounded by edaphic stresses that impacted root growth. Nitrogen fertilization and higher cutting height can alleviate some stresses and enhance root extension in bermudagrass (Wherley et al. 2011). For example, in unmowed bermudagrass, roots can extend up to 2.4 m in depth (Burton et al. 1954 in Qian et al. 1997). Cultivar 'La Paloma' had the best root length density and root weight density among 5 bermudagrass and zoysia cultivars whereas cultivar 'Yukon' had the lowest weighted means (Macolino et al. 2012).

Ecosystem benefits: Owing to its aggressive growth, bermudagrass can become a weed and invade neighboring habitats (Beard 1973). In California and Arizona, bermudagrass is considered an invasive weed of cool-season turfgrasses (Cudney et al. 1997) and a serious pest of irrigated alfalfa fields (Taliaferro 2003). In cooler climates, bermudagrass will become dormant, leaving the ground bare and increasing erosion and run-off.

Resilience:

Drought: Bermudagrass has excellent tolerance to drought and heat (Beard 1973, Wallner et al. 1982, Wiecko 2008) owing in part to a deep and extensive root system (Carrow 1996, Qian et al. 1997, Brede 2002). However, substantial variation among cultivars has been documented for dehydration avoidance, drought tolerance, and water use (Taliaferro 2003, Zhou et al. 2013, 2014). Drought resistant genotypes were identified among 460 bermudagrass accessions; however, none of the drought resistant genotypes were commercial cultivars (Zhou et al. 2013) suggesting that collections could be made to increase drought resistance. Drought resistant genotypes had greater soil water extraction and a higher water uptake rate (Zhou et al. 2014). Superior drought resistance was also characterized by a large rhizome network and a higher post-harvest regrowth rate (Zhou et al. 2015). Bermudagrass cultivars selected for use in temperate climates (cold tolerance) were generally ranked lower in drought tolerance (Taliaferro 2003). Bermudagrass has a low evapotranspiration rate (Kim 1983, Feldhake et al. 1984, Kim and Beard 1988, Beard and Kim 1989, Carrow 1995) and had the lowest transpiration rates among 10 warm and cool season turfgrasses (Biran et al. 1981). Bermudagrass required a minimum annual irrigation of 244 mm and maintained acceptable turfgrass quality at 40% actual evapotranspiration rate because it could tolerate lower leaf relative water content and higher levels of electrolyte leakage compared to zoysia, Kentucky bluegrass and tall fescue (Fu et al. 2004). Similarly, in field experiments, bermudagrass cultivar 'Tifway' maintained acceptable turf quality at 35% pan evaporation (Qian and Engelke 1999), which was lower than tall fescue (67%), zoysia (68%), and St. Augustinegrass (44%) but higher than buffalograss (26%). In greenhouse studies (Qian and Fry 1997), bermudagrass had lower osmotic adjustments during dry down (0.60 MPa) than buffalograss (0.84 MPa) and zoysia (0.77 MPa) but greater adjustments than tall fescue (0.34 MPa). Bermudagrass maintained higher quality and equal to higher root density up to 40 cm soil depth than zoysia under non-irrigated conditions (Rimi et al. 2012). Bermudagrass cultivar 'Yukon' maintained the best turf quality whereas cultivar 'La Paloma' developed the best root structure across all soil depths. Root mass density and root length density at 25-40 cm soil depth was positively correlated with turf quality suggesting that those cultivars that can access water resources at lower soil depths are able to avoid drought (Taliaferro 2003).

Low fertility: Bermudagrass is best adapted to fertile soils (Taliaferro 2003) and requires a higher fertilizer rate (Beard 1973, Booze-Daniels et al. 2000, Brede 2002) to maintain quality (Rimi et al. 2013) and resist disease (Carrow et al. 1987). In comparison with centipedegrass, St. Augustinegrass and zoysia, bermudagrass was very responsive to nitrogen application, exhibiting periods of growth and also deficiency depending on the supply of resources (Bowman et al. 2002). This makes bermudagrass an aggressive grower in nutrient rich environments but a poor performer when nutrients are limited.

Freezing*:* In climatic regions that rarely reach freezing temperatures, bermudagrass will stay green throughout the year and will only show slight discoloration at cooler temperatures. In colder regions, bermudagrass will enter dormancy in the winter months with new growth initiated in the spring from crown buds and rhizomes (Taliaferro 2003). Low temperature tolerance is an important goal in the development of bermudagrass cultivars and genetic gains may be achieved by selecting for color retention, spring green-up and texture (Stefaniak et al. 2009). Stier and Fei (2008) rank the low-temperature tolerance of bermudagrass as ‘medium’, lower than buffalograss, blue grama and zoysia but higher than centipedegrass, seashore paspalum, St. Augustinegrass and bahiagrass. Bhowmik et al. (2008) rank cold hardiness of bermudagrass as poor with turf seriously thinned when exposed to low temperatures (Beard 1973). In Maryland, therefore, use of bermudagrass is restricted to the southern coastal plain region (Bhowmik et al. 2008), although new cultivars show promise in tolerating cooler temperatures. Bermudagrass cultivars vary considerably in freezing tolerance (Taliaferro 2003) with cultivars ‘Arizona Common’ and ‘Tifgreen’ being the least tolerant (mortality at -6.6 to -7.1^{o}C respectively) and cultivars ‘A-12195’, and ‘Midiron’ the most tolerant (-9.9 to -10.5^{o}C) (Anderson and Taliaferro 2002). Plants that are winter hardy may be more susceptible to disease and less tolerant to low pH and fertility (Harlan and de Wet 1969).

NaCl Salinity: Bermudagrass shows high tolerance for salinity (Beard 1973, Harivandi et al. 1992, Marcum 2002, Marcum 2008a,b) and is associated with selective transport of potassium ions versus sodium ions from the roots (Chen et al. 2014) and with sodium-selective secretion via salt glands (Marcum 2002, 2008b, 1999, Marcum and Pessarakli 2006). Saline irrigation water did not affect nitrogen leaching from bermudagrass turf suggesting that bermudagrass is tolerant of saline water (Bowman et al. 2006c). Bermudagrass has greater salinity tolerance than perennial ryegrass (Marcum 2008b), and buffalograss (Marcum (2002, 1999) but less than seashore paspalum (Lee et al. 2004 a,b, Uddin 2009, Gaetani et al. 2013), alkaligrass (Marcum 2008b), seaside bentgrass (Lunt et al. 1964), some dropseed species (Marcum 2008b, 1999, Hameed et al. 2008), desert saltgrass (Marcum 2002, 2008b, 1999, Marcum et al. 2005, Pessarakli and Kopec 2008), and St. Augustinegrass (Uddin et al. 2011). Depending on experimental conditions and cultivars, bermudagrass has greater (Marcum 2008b, Gaetani et al. 2013) or equal (Marcum 1999) salinity tolerance to zoysia. Salinity tolerance, measured as 50% reduction in shoot dry weight, varied from 26 to 40 dS/m among cultivars (Marcum and Pessarakly 2006), highlighting that bermudagrass has wide adaptability to salinity stress (Hameed et al. 2008, Marcum 2008a) with the hybrid line ‘CH048’ (Chen et al. 2014) and cultivar ‘Tifway’ (Nadeem et al. 2012) and ‘Tifgreen’ (Shahba 2010) exhibiting the highest salt tolerance. In contrast, cultivars ‘Satiri’ and ‘Tifdwarf’ are ranked moderately tolerant (6-10 dS/m) and moderately sensitive (3-6 dS/m) of salinity, respectively (Uddin et al. 2011a,b, 2012, Uddin 2013). Further differences were observed in a study comparing six bermudagrass cultivars to six salinity treatments (Peacock et al. 2004). The cultivars with the greatest shoot biomass (‘Quickstand’, ‘Tifton’, and ‘Tifway’) also had the greatest reduction in shoot weight at the highest salinity level (41-43%), but no differences were observed in root or crown weights.

Acidity: Bermudagrass is adapted to a wide range of soil conditions and can tolerate soil pHs between 5.5 to 7.5 (Beard 1973). It has high tolerance to aluminum, and hence acid soils (Liu et al. 2008) similar to Zoysia. In a study of 10 warm season turfgrass species (Baldwin et al. 2005), bermudagrass was less tolerant to aluminum than zoysia and carpetgrass but was less sensitive than seashore paspalum, bahiagrass and buffalograss.

Wear tolerance: Bermudagrass has very good wear tolerance (Wiecko 2008) but lower than the wear tolerance of zoysia (Beard 1973). Bermudagrass had lower stem flexibility than lovegrass, dropseed and perennial ryegrass suggesting that bermudagrass may have lower survival and resistance to trampling than these other species (Sun and Liddle 1993).

Overseeding with perennial ryegrass increased green cover, bulk density, thatch accumulation, and saturated hydraulic conductivity suggesting that the practice of overseeding may protect bermudagrass from wear and compaction (Thoms et al. 2011). Cultivars ‘Tifway’ and ‘Riviera’ were more wear tolerant than cultivar ‘Patriot’ whereas cultivar ‘Mississippi Choice’ ranked intermediate in experiments that manipulated mowing regime (Thoms et al. 2011).

Competition: Bermudagrass was the most efficient grass for nitrogen absorption when compared to 4 other warm season grass species (Bowman et al. 2002) suggesting that it is highly competitive for nitrogen resources. Bermudagrass is an aggressive competitor (Brede 2002) and can displace cool season grasses, such as tall fescue (Cutulle et al. 2014) and Kentucky bluegrass (Davis 1958).

Mixes: Bermudagrass can be overseeded with cool season grasses (Beard 1973, Cockerham et al. 1990, Dunn et al. 1994, Longer 1999, Richardson 2004, Nelson and Crowder 2005, Richardson et al. 2007, Rimi and Macolino 2013, Volterrani et al. 2004, McElroy et al. 2011, Trappe et al. 2012) and clover (Dudeck and Peacock 1983, Han et al. 2012, McCurdy et al. 2013a,b) to maintain a higher quality turfgrass surface in the winter when bermudagrass is dormant.

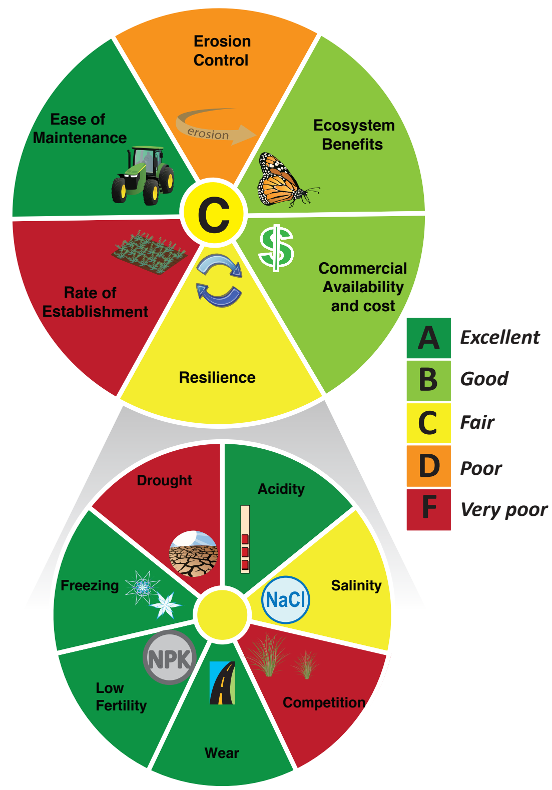
Cultivars: Erosion of natural genetic variability does not appear to be a big concern in most bermudagrass lines (Talioferro 1995). Early cultivars of Bermudagrass were developed in South Africa starting in 1907 (Taliaferro 2003). Cultivars ‘Tifgreen’ and ‘Tifway’ were introduced in the United States in 1956 and 1969, respectively (Taliaferro 2003) and are still the most widely propagated and distributed cultivars today. Cultivars ‘Midlawn’ and ‘Tifsport’ show higher tolerance to freezing (Taliaferro 2003). Cultivar ‘FloraTex’ was developed to be used under low-maintenance conditions (Taliaferro 2003).

Hybrids: Tetraploid *Cynodon dactylon* is often hybridized with diploid *C. transvaalensis* to produce the sterile triploid clonal cultivars ‘Tiffine’, ‘Tifgreen’, and ‘Tifway’ developed in Georgia. Cultivars ‘Midway’, ‘Midiron’, ‘Midlawn’, and ‘Midfield’ are triploid hybrids bred in Kansas. Mutant clones are produced through ionizing radiation.

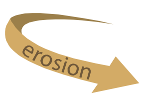
Prairie junegrass

Koeleria macrantha, K. cristata, K. gracilis, K. nitida, K. pyramidata

Prairie junegrass is a native grass that is widely distributed. As a short-statured species, it is an excellent species to plant in areas where less frequent mowing is desired. The species is observed in diverse grass communities and is therefore an excellent biodiversity enhancer. Despite these benefits, prairie junegrass has numerous management concerns that limit its use along roadsides, resulting in a Fair rating (grade = C):

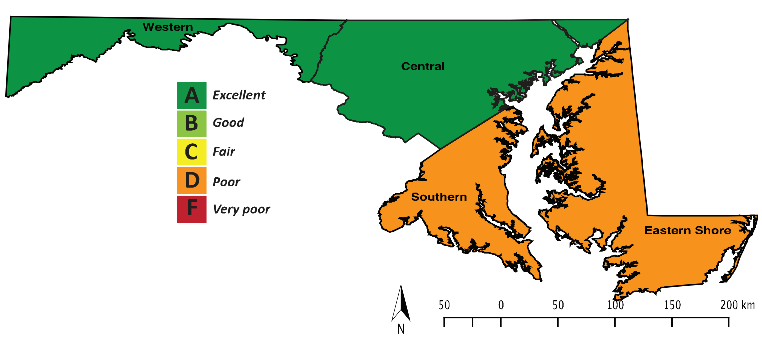


Prairie junegrass is very difficult to establish owing to its slow growth.



Root distribution of prairie junegrass is shallow and therefore not suited for erosion control.

Prairie junegrass is drought sensitive, intolerant of salinity, and a very poor competitor. Thus resilience to roadside conditions is weak.



Because of excellent winter hardiness and tolerance to infertile soils, prairie junegrass is well suited to grow in Western and Central Maryland. Owing to drought sensitivity, planting in Southern Maryland and the Eastern Shore should be avoided.

Prairie junegrass cultivars include Turtle Turf, BarKoel, and Barleria. Native germplasm should be used to increase plant fitness in local environments.

Biology: Prairie junegrass is a cool season perennial bunchgrass that is widely distributed in and native to the United States (Bakker and Wilson 2004). According to USDA, the species is present in Maryland, but it is an uncommon occurrence in the region (Rhoads and Klein 1993). In natural settings, prairie junegrass cover is ~5% (USDA fact sheet) such that in natural settings the species will typically be observed in diverse plant communities. Prairie junegrass was important in the recovery of prairie after the severe drought of the 1930s because it recolonized bare areas rapidly through seed germination and rapid tillering (Albertson and Weaver 1944). Through time, however, other grasses would recolonize and outcompete prairie junegrass. NTEP trials show that prairie junegrass can produce fairly good quality turf (Kevin Morris *pers. communication*). Prairie junegrass is found growing in poor soils and stressful environments and shows the greatest abundance in dry sites of meadows, grasslands, and rocky slopes (Johnson 2008). Owing to its slow growth and short stature (McKernan et al. 2001, Brown et al. 2010), it is considered an excellent candidate for low-input turf areas (Clark and Watkins 2010a) of roadsides, golf courses, and landscaping.

Seeds per pound or gram: Seeds are small. 1,800,000 – 2,300,000 seeds per pound per USDA fact sheet and plant guide
Cost per pound: $65.55 from Ernst Conservation Seed
Cost per acre: $131.10 per acre
Suggested sowing rate: 2 pounds per acre (Chesapeake Valley Seed)
Sowing depth: 0.16 inches
Germination time: 7-10 days
Seeding timing: above 57^{o}F, not recommended for fall or dormant seeding (USDA plant guide)
Length of growing season: Greens up early in the spring when using northern accessions (Clark and Watkins 2010a). The main growth period is from February to May (Dixon 2000).
Leaf height: 1.5 to 5 inches (Simonin 2000)
Height at seed head stage: 4-16 inches (Campbell et al. 1992)
Shade tolerance: Average according to Barenbrug
Suggested mowing height: down to 0.2 inches but mowing needs to be infrequent
Tolerance of wet conditions: requires well drained soil (Simonin 2000)
Humidity tolerance: Does best at 12 to 20 inches annual precipitation (USDA plant guide)
Disease resistance: Susceptible to smut and rust disease, as well as powdery mildew and yellow-leaf spot (Dixon 2000).

Services:

$ *Commercial availability and cost*: While available commercially, the cost of prairie junegrass seed is relatively high owing to low seed yields (Johnson 2008). Prairie junegrass has a low sowing rate per acre which makes planting over a large area affordable.

Rate of establishment: Prairie junegrass is difficult to establish (Johnson 2008) owing to its slow vertical growth rate (Dixon 2000, Doak et al. 2002). Direct seeding and seedling transplants result in poor establishment but, seed stratification increases germination rate (Simonin 2000). Prairie junegrass was seeded on calcareous reclaimed mine soil but plants did not establish (Thorne and Cardina 2011). Likewise, two prairie junegrass cultivars were seeded in a roadside experiment in Minnesota (Friell et al. 2012) that included 14 turfgrass species and 75 entries. Neither of the two prairie junegrass cultivars established at either of the two study sites. Similarly, prairie junegrass plots did not establish in a field experiment that tested the effects of seed coating on germination success (Leinauer et al. 2010) and declined throughout a 3-year study that tested the response of clovers and grasses to management (Lulow 2008). Prairie junegrass also established slowly in a Canadian study (McKernan et al. 2001) and plots received poor weed ratings. Fifty percent of prairie junegrass seeds germinated in control treatments of a salinity experiment in the laboratory (Dudley et al. 2014), which was the third lowest germination rate of 14 species tested. In a study in Canada, prairie junegrass consistently covered >70% of field plots across 3 years after the establishment year (Mintenko et al. 2002). Likewise, prairie junegrass established and persisted for two years at 7 locations that were distributed across 7 midwestern states (Watkins et al. 2011) although turf quality was low at most locations and declined in the second year of the study.

Ease of maintenance: Prairie junegrass is a short-stature plant (Brown et al. 2010; 20 cm long leaves and up to 70 cm with seed head) that grows slowly (Johnson 2008) and therefore has high potential to be a low-maintenance lawn and turf grass (McKernan et al. 2001).

Erosion control: Rooting is dense but shallow (Albertson and Weaver 1944). When Brown et al. (2010) compared 19 grass species in a Rhode Island study, prairie junegrass developed the shallowest roots (11.4 cm mean depth) and produced the least root mass, which does not recommend it for anchoring hillside slopes where slope failure can occur below the shallow root mat (Brown et al. 2010). Root-to-shoot ratios in seedlings of prairie junegrass were lower compared to red fescue and Kentucky bluegrass but similar to tall fescue, perennial ryegrass and tufted hairgrass (Dziamski et al. 2012).

Ecosystem benefits: Prairie junegrass is native to the United States (Bakker and Wilson 2004) but is considered to be non-native to Maryland (Maryland Biodiversity Project). It typically does not cover more than 5-10% in natural or restored communities (Bakker and Wilson 2004, USDA Plant Fact Sheet) unless sowed or planted in high density (Bakker et al. 2003). The species provides forage to livestock and wildlife; however, it provides little coverage for birds and mammals due to its low stature and scattered distribution (Simonin 2000).

Resilience:

Drought: Prairie junegrass exhibits plasticity in its roots (Mueller-Dombois and Sims 1966) and can therefore acclimate to water availability. Still, because roots are generally distributed shallow (<15 cm; Brown et al. 2010), drought tolerance is only moderate, similar to fescues (McKernan et al. 2001, Johnson 2008) but higher than perennial ryegrass and alkaligrass (McKernan et al. 2001). Prairie junegrass abundance was greatly reduced by the 1930's drought, but was able to recover fast from seed in the spring of 1935 with high mortalities after another drought (Albertson and Weaver 1944). Motivated by the 1930s drought, Mueller and Weaver (1942) experimented with drought tolerance of 15 prairie grasses. They found drought tolerance of prairie junegrass seedlings to be poor with high mortality after imposed drought. In a native plant demonstration trial in Blacksburg, Virginia, prairie junegrass appeared to persist across the 6-year study but a drought caused high mortality (Doak et al. 2004). In contrast, after four weeks of drought in New England, prairie junegrass was one of only four species (out of 19 species) that retained >50% cover (Brown et al. 2010). Prairie junegrass recovered to 75% by fall, whereas all other species declined, and remained the highest of all species after the winter (Brown et al. 2010), highlighting the species' potential to withstand and, especially, to recover from drought. Junegrass recovered well after experimental drought conditions (Milnes et al. 1998) suggesting in this study that the species would be well suited to areas where summer rainfall totals are low.

Low fertility: Prairie junegrass grows well in infertile grasslands and rock outcrops (Campbell et al. 1992) suggesting that it is adapted to low fertility environments. 'Barkoel' prairie junegrass had the highest quality in low-input turf compared to 11 other native grass species (Mintenko and Smith 1999). Prairie junegrass had acceptable turf quality at some but not all locations in field studies of 10-12 turfgrass species grown under low-maintenance conditions in 8 states of the North Central Region of the United States (Watkins et al. 2011, 2014). Despite a tolerance of poor soils, prairie junegrass responded to fertilizer with lush spring growth in a Virginia roadside trial (Doak et al. 2004).

Freezing*:* Prairie junegrass is observed to grow between 5,000 – 8,000 feet elevation (1,524-2,438m; Simonin 2000). Winter hardiness is considered to be excellent (Erik Watkins on Golfdom.com). Young plants are subject to frost heaving (USDA plant guide); thus fall seeding is not recommended.

Salinity: Prairie junegrass is advertised as having excellent salt tolerance according to Barenburg. Prairie junegrass is sensitive to salt during germination (Wang et al. 2011, Dudley et al. 2014). Two cultivars of prairie junegrass were as sensitive as Kentucky bluegrass, on average, in a salinity trial that tested the effects of salt exposure (suspension of plants in nutrient-salt solution) on 74 turfgrass cultivars representing 14 species (Friell et al. 2013). However, cultivar 'Barkoel' retained a higher percentage of green tissue than the Minnesota ecotype suggesting cultivars differ in their tolerance to salinity.

Acidity: Prairie junegrass prefers pH 6-8 (Thorne and Cardina 2011, USDA Plant Fact Sheet) but seed company Barenbrug suggests that pH down to 5.5 is acceptable.

Wear tolerance: Prairie junegrass is tolerant of mowing (Johnson 2000) but will be slow to recover from any mowing damage owing to its slow growth (Johnson 2008). The species is well suited for low traffic areas. Willmott et al. (2000) found that prairie junegrass was more wear tolerant than fine fescues, and Newell and Wood (2003) showed that prairie junegrass can tolerate trampling that occurs on paths. Similarly, Mintenko et al. (2002) observed consistently high quality (>70% ground cover, green summer color, fine texture, low disease, and adaptability to mowing stress) in prairie junegrass 'Barkoel' across 3 years after the first establishment year, at three mowing heights and at two study locations in Canada. In a low-input study that compared 12 turfgrass species (Watkins et al. 2011), prairie junegrass performed well under two mowing heights in Iowa and under 10.2 cm mowing height in South Dakota.

Competition: Prairie junegrass is considered to be a subordinate species in grassland communities (Albertson and Weaver 1944) owing to its slow growth and loosely tufted growth habit (Campbell et al. 1992). In an experiment that measured shoot thrust (delay in time to open a window with known resistance), prairie junegrass was the second slowest species (26 days as opposed to 6 days for the two fastest species) in a comparison of 8 species (Campbell et al. 1992). Prairie junegrass also produced second to lowest biomass in mixtures suggesting that its non-aggressive and largely horizontal growth habit is responsible for its weak competitive ability (Campbell et al. 1992). However, the authors note that this growth habit complements the growth habit of more aggressive and taller species by allowing prairie junegrass to forage for light resources rather than competing for it physically at the top of the canopy. Because of prairie junegrass' low density and slow growth, it is vulnerable to weed invasion (McKernan et al. 2001), which may be compensated for somewhat with higher seeding rates (Wilmott et al 2000, Bakker et al. 2003). Slow growth of prairie junegrass allows more vigorous species to out-compete prairie junegrass (Dixon 2000). However, some experiments show that junegrass can establish and survive under pressure from annuals or invasive species (Simonin 2000).

<u>Mixes</u>: Prairie junegrass is considered useful in seed mixes. Minnesota DOT uses prairie junegrass in a prairie seed mix (MN-35-221 Dry Prairie General) with other native species for roadsides and restoration (Agassiz Seed & Supply). In a low-input and low-maintenance experiment in Minnesota, Miller et al (2013) found that a native seed mix consisting of prairie junegrass, little bluestem, side-oats grama, blue grama, poverty oatgrass, and buffalograss performed better under no-mow conditions than mixes consisting of fine fescues and Kentucky bluegrass. Though they were slow to establish, the following years showed high quality ratings and low weed percentages within the native mixes (Miller et al 2013).

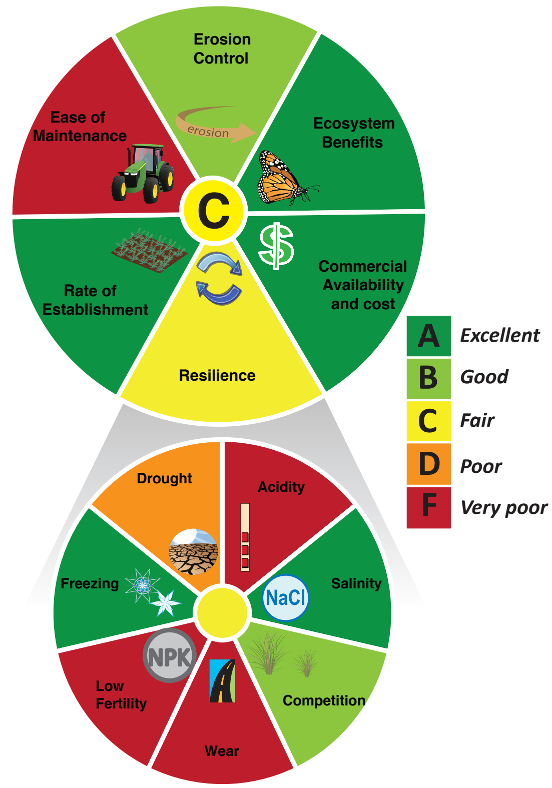
<u>Cultivars</u>: Clark and Watkins (2010a, b, 2012) evaluated seed production and turf quality characteristics for 48 accessions from throughout the world and found high diversity as well as good potential for developing the species as a turf species. However, no individual accession excelled in both seed production and turf quality. Junegrass is marketed by California-based Quality-Turf as 'Turtle Turf'. Dutch turf grass supplier Barenbrug markets prairie junegrass as 'BarKoel' and 'Barleria' with green-up somewhat later than North American genotypes (Johnson 2008). The Elsberry Plant Materials Center in Elsberry, Iowa, released 2 native germplasms to be used in landscaping, prairie restoration, and roadside planting (USDA fact sheet).

Alkaligrass

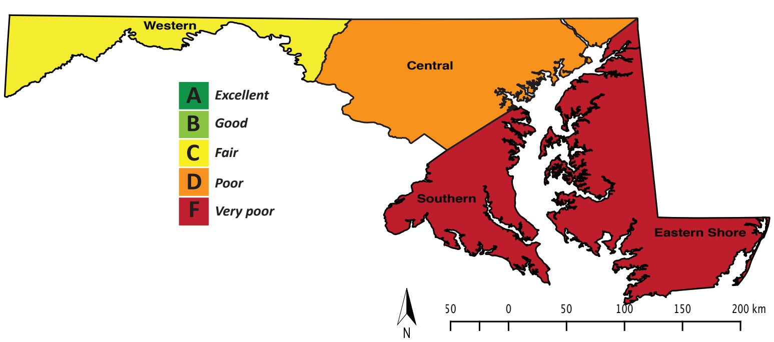
Puccinellia distans and Puccinellia nuttallii

Alkaligrass is a low-stature grass that grows well in saline soils where persistence of other species is low. This places alkaligrass in a unique niche among its peers. Commercial availability and cost of seed is reasonable for wide-spread use. The species has excellent establishment rates and ecosystem benefits through biodiversity enhancement. Two related management concerns, however, limit its use along roadsides, resulting in a Fair rating (grade=C):

Alkaligrass has poor resilience under most roadside conditions with low drought tolerance, high fertility requirements, low tolerance of acid soils, and low wear tolerance.



Although alkaligrass is short in stature and would not need to be mowed frequently, healthy sward is hard to maintain owing to high requirements for irrigation, fertilizer, and liming.



Alkaligrass may be suitable as a roadside grass in some areas of Western Maryland but is not recommended for many parts of Maryland.

Alkaligrass cultivars include Fults, Salty, and Salton Sea.

Biology: Alkaligrasses are low-growing, perennial bunchgrasses that grow in saline and alkaline areas of North America (Butler et al. 1971, Marcum 2008a). The species are adapted to cool climates and are therefore present in higher abundance in the northern United States and Canada. Nuttall's alkaligrass is native to cool semi-arid regions of the western United States; weeping alkaligrass is generally reported as native to Eurasia but seed companies will classify the species as native to the western and northeastern United States. Alkaligrasses are considered invasive weeds in northeastern Oregon where alkaligrass threatens to infest turfgrass farms (Tarasoff et al. 2009, 2010). Nuttall's alkaligrass is a tall erect plant with an open architecture whereas weeping alkaligrass has a short stature with dense plant architecture (Tarasoff et al. 2009). Alkaligrasses were first considered as turfgrass when they were observed to grow along roadsides (e.g., Chicago, Illinois – Hughes et al. 1975; Czech Republic – Sera 2010) where the use of deicing salts in the winter were negatively affecting the growth and survival of other turfgrasses (Marcum 2008a). They are now known as some of the most salt tolerant C_3 grasses in North America. Nuttall's alkaligrass prefers sodic soils whereas weeping alkaligrass does not require saline conditions for survival and actually prefers non-saline soils ('facultative halophyte'; Tarasoff et al. 2009). Alkaligrass is dependent on mycorrhizal associations (Dashtebani et al. 2014).

Seeds per pound: 1,200,000 seeds per pound (Ernst Conservation Seed)
Cost per pound: $4.23 per pound (Ernst Conservation Seed)
Cost per acre: $84.60 per acre
Suggested sowing rate: 20 pounds per acre (Chesapeake Valley Seed)
Sowing depth: ½ inch (Pawnee Buttes Seed)
Germination time: fast (a few days)
Seeding timing: spring or fall (Pickseed)
Length of growing season: not reported
Leaf length: weeping alkaligrass: 16 -20 inches; Nuttall's alkaligrass 31-39 inches (Tarasoff et al. 2009)
Height at seed head stage: 24 inches
Shade tolerance: can withstand partial shade
Suggested mowing height: Brede (2000) suggests that alkaligrass can tolerate mowing to 1.5 inches, with 3 inches as ideal. Other studies (see wear tolerance) suggest that alkaligrass is intolerant of mowing.
Tolerance of wet conditions: Alkaligrass is adapted to wetland soils but does not need these conditions to persist.
Humidity tolerance: Alkaligrass is adapted to semi-arid climates; a humid climate may therefore be suboptimal.
Disease resistance: Unknown

Services:

$ *Commercial availability and cost*: Alkaligrasses can be heavy seed producers. Weeping alkaligrass is commercially available from a variety of producers. The cost per pound of alkaligrass is $4.23, which makes it slightly more expensive than sheep fescue. A low sowing rate per acre for alkaligrass makes it very affordable for use over large areas.

Rate of establishment: Alkaligrass can establish rapidly and exhibit fast growth rates (Butler et al. 1971, Tarasoff et al. 2009) when environmental conditions are suitable. However, in many cases alkaligrass does not persist well. Nuttall's alkaligrass and weeping alkaligrass established well in a two-year experiment in Oregon but survival was 60% and 40%, respectively from year 1 to year 2. In contrast, Kentucky bluegrass had 98% survival (Tarasoff et al. 2009). In a Canadian study of 25 species and cultivars (McKernan et al. 2001), alkaligrass established relatively slowly at three locations compared to most other entries and consequently had poor weed density ratings. Nuttall's alkaligrass established poor (60%) cover in the first year and over a 3-year period decreased cover to 20% (Mintenko et al. 2002) in a northern Great Plains study.

Ease of maintenance: Alkaligrass is a short statured species that produced 20-33 cm height growth in lab and field trials (Brown et al. 2010). However, studies consistently show poor performance in the field across a range of environments (McKernan et al. 2001, Brown et al. 2011, Watkins et al. 2011) suggesting that the species needs continued maintenance of environmental conditions (liming, fertilizing, irrigation) to persist.

Erosion control: In three trials comparing 7-19 species, Brown et al (2010) observed 89-91% of alkaligrass root mass to occur within the top 7.5 cm of the soil. Mean rooting depth for alkaligrass in lab and field trials along roadsides was 30.4-58.9 cm, which was relatively shallow and comparable to hard and red fescue. Root mass production was medium.

Ecosystem benefits: Alkaligrass performs well in saline soils where many other species cannot grow well or survive. Weeping alkaligrass is an introduced species from Eurasia. Nuttall's alkaligrass is native to the United States and Canada, where it occurs in the west as well as in the north. In the eastern United States, Nuttall's alkaligrass is present as far south as New York but does not occur naturally in Maryland or surrounding states. When environmental conditions are suitable, alkaligrass persists well within a mix of species.

<u>Resilience</u>:

Drought: Performance was rated poor under conditions of limited water and fertility (Watkins et al. 2011). In a three year study in southern Alberta, alkaligrass had poor to fair drought tolerance (McKernan et al. 2001).

Low fertility: Persistence of alkaligrass was low in a low fertility environment in southern Alberta (McKernan et al. 2001). The species established poorly along roadsides without soil amendments (Brown and Gorres 2011) but persisted well with soil amendments. In a low-maintenance study across 8 states, alkaligrass performed poorly and was therefore not recommended to be used as a turfgrass (Watkins et al. 2011).

Freezing*:* Adapted to northern climates, weeping alkaligrass and Nuttall's alkaligrass have excellent freezing tolerance.

Salinity: Studies comparing different turfgrass species consistently show that alkaligrasses have excellent salinity tolerance (Lunt et al. 1961, 1964, Butler et al. 1971, Hughes et al. 1975, Torello and Symington 1984, Greub et al. 1985, Marcar 1987, Harivandi et al. 1992, Biesboer et al. 1998, Marcum 2008a, b, Brown et al. 2011, Zhang et al. 2011, Uddin and Juraimi 2013) that is higher than seashore paspalum but not as high as saltgrass (Distichlis spicata; Alshammary et al. 2004, Marcum 2008a). Alkaligrass is therefore well adapted to grow along roadsides that receive deicing salts. Alkaligrass have been found growing along roadsides at 20,000 to 30,000 ppm total soluble salts and 4,000 to 10,000 ppm sodium (Butler et al. 1971). Nuttall's alkaligrass is commonly associated with sodic soils suggesting inherent adaptation to saline environments (Tarasoff et al. 2010). In contrast, weeping alkaligrass does not require saline conditions for survival. It responds positively to normal non-saline soil conditions (Tarasoff et al. 2009) and will increase root growth to increase its tolerance to salinity (Alshammary et al. 2004). Germination can be inhibited by osmotic stress (Harivandi et al. 1982, Harivandi et al. 1992) but not more so than other turfgrass species (Marcum 2008a). Germination in control versus saline conditions were 88% versus 81%, respectively, and was only negatively affected by salt application when fertilized with gypsum at high concentrations (Neid and Biesboer et al. 2004). A half concentration sea water solution reduced growth of alkaligrass by 25% and turned leaf color noticeably darker (Lunt et al. 1961). Biomass yield of weeping alkaligrass was reduced by 23% at 20,000 ppm, whereas yield of all other grass species was reduced by at least 40% (Hughes et al. 1975); salt treatment of 30,000 ppm resulted in mortality in all species. In the same study, weeping alkaligrass was 'unusually' tolerant of foliar application of salt. From this and the previous results, Hughes et al. (1975) concluded that weeping alkaligrass is of value for vegetating saline roadsides. Winter survival was good at roadside locations in Minnesota in a comparison of 74 cold-season turfgrass species and cultivars (Friell et al. 2012) but establishment and persistence was found to be unacceptable in a roadside trial in New England (Brown and Gorres 2011). Friell et al. (2013) observed that percent green tissue in alkaligrass cultivars was lower than tall fescue and slender creeping red fescue and equal to most other turfgrass species when exposed to salinity. Similarly, 'Fults' alkaligrass exhibited lower (Torello and Symington 1984) but also higher (Harviandi et al. 1982, Friell et al. 2012) salinity tolerance than 'Dawson' red fescue in salinity experiments. The generally high, but inconsistent, salinity tolerance of alkaligrass suggests that it could be used in mixtures to improve turf quality in areas that receive high concentrations of deicing salts. However, Yuan et al. (2014) observed no improvement in turf quality when alkaligrass was mixed with Kentucky bluegrass and red fescue and subjected to 320 lb/acre of deicing salts in North Dakota. In Minnesota, alkaligrass cultivars 'Fults', 'Salty', 'Oceania', 'Salton Sea' performed well at one road site but not another (Friell et al. 2012). Inoculations of arbuscular mycorrhizal fungi increased tolerance of weeping alkaligrass to salinity by enhancing photosynthesis and ion homeostasis, improving water relations and protecting against oxidative damage in leaves (Dashtebani et al. 2014).

Acidity: Alkaligrass is not adapted to acidic soils. Nuttall's alkaligrass was observed in soils of pH 8.47 and high levels of calcium.

Wear tolerance: In a Minnesota fairway study of 17 species subjected to traffic simulations, Watkins et al. (2010) showed that weeping alkaligrass did not perform well under any mowing regimes with ending stand densities less than 5%. Survival of weeping alkaligrass was 40% and Nuttall's alkaligrass 60% after a July harvest, whereas Kentucky bluegrass had almost 100% survival following the harvest (Tarasoff et al. 2009). Similarly, percent cover of Nuttall's alkaligrass dropped by almost 50% within 15 months when subjected to weekly mowing (Mintenko et al. 2002).

Competition: Tarasoff et al. (2010) suggests that the only factor limiting establishment and abundance of weeping alkaligrass in northeastern Oregon is plant competition. In sodic areas of Kentucky bluegrass fields, alkaligrass is a dominant perennial weedy species (Tarasoff et al. 2009). Weeping alkaligrass was more competitive than Nuttall's alkaligrass and both were more competitive than Kentucky bluegrass in year 1 of a 2-year study (Tarasoff et al. 2009). The authors speculate that alkaligrass grows rapidly and may inhibit slower growing Kentucky bluegrass through shading and soil water depletion. Even though the two alkaligrasses had poor survival (40% and 60%, respectively) and Kentucky bluegrass yield increased in year 2, weeping alkaligrass was still able to decrease Kentucky bluegrass yield by 20%. Observations along Illinois roadsides suggest that Kentucky bluegrass and tall fescue are succeeded by quackgrass that is subsequently invaded and outcompeted by weeping alkaligrass when salt content is high (Butler et al. 1971). Brede (2000) also notes that alkaligrass is persistent and competitive with other species in salty conditions. However, under low salt and neutral or acidic pH conditions, this species is not competitive in a mixture (Brede 2000).

Mixes: Friell et al. 2012 suggests that alkaligrass can be used in seed mixes to establish turf that is better adapted to low-input conditions. Similarly, Brede (2000) suggests that alkaligrass is a useful species to include in any mixes where salt is or may become an issue. However, under low salt and neutral pH conditions, alkaligrass is an inferior competitor to ryegrasses and bluegrasses (Brede 2000). Persistence within the community requires alkaline conditions.

Cultivars: Alkaligrass cultivar 'Fults' was developed in Colorado and is advertised as a versatile grass that can be used in many different landscapes (Simplot.com). It became commercially available in 1979 for use in salty areas of golf courses, then along roadsides in the Midwest where winter deicing is a common occurrence. Density of 'Fults' is positively correlated with salt concentrations in soils. 'Fults' has been found persisting in areas where tall fescue could not survive even after several seedings (Simplot.com). 'Fults' can withstand low- and no-mow conditions, and will readily re-seed itself when left unmowed (Ampac Seed Company). When combined with slender red fescue and Kentucky bluegrass, 'Fults' has the best performance in a mixture (Ampac Seed Company). 'Salty', is a cultivar adapted for use along coastal regions in New England and the Pacific Northwest (AgronoTec Seed Company, Proseeds Marketing). It is well suited for any turf that may be subject to salt sprays during winter deicing (AgronoTec Seed Company, Proseeds Marketing). 'Salton Sea' alkaligrass can also be used for roadsides that are heavily affected by deicing (Turf Merchants, Inc).

Zoysia

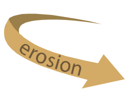
Zoysia japonica, Zoysia matrella, and Zoysia pacifica = Z. tenuifolia

Zoysia is a low-growing turf grass that requires little maintenance once it is established. Resilient to many environment conditions, it is a tough turf grass that can withstand many roadside stressors including salinity, traffic, low fertility, competition, and to some extent drought. However, several management concerns decrease this species' overall usefulness for roadside management resulting in a Poor to Fair (grade = D+):

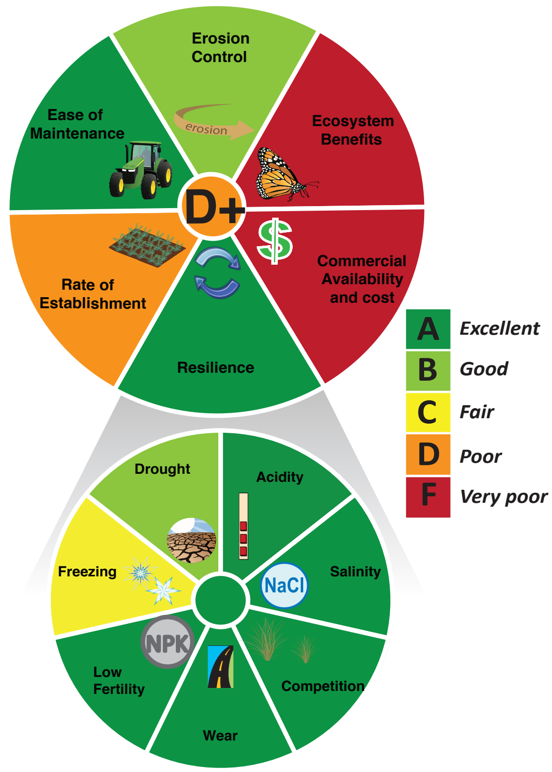
Cost of zoysia seed is high yet affordable. If planted as sod, costs increase significantly.

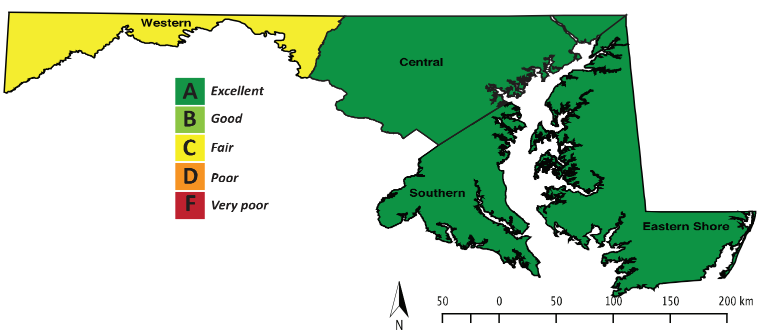
Zoysia establishes slowly when seeded and may require initial herbicide applications for weed suppression. Zoysia requires irrigation during the establishment year.

Zoysia is a non-native species. It is an aggressive competitor that reduces diversity and has the potential to become invasive.



Roots of zoysia are dense and fibrous but tend to be shallow, reducing the species' usefulness in stabilizing soils on steep banks.





A warm season grass that also tolerates cool temperatures, zoysia is well adapted to all regions of Maryland except Western Maryland where cold winters limit its performance.

Zoysia cultivars recommended for Maryland in 2016 include Zenith (seeded), Meyer (vegetative), and Zeon (vegetative). Updates to recommended cultivars in Maryland are published annually in the University of Maryland Turfgrass Technical Update TT77 (Maryland Turfgrass Council).

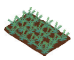
Biology: Named after Austrian botanist Karl von Zois (Richard Duble, Texas Cooperative Extension), zoysia is a complex of 11 recognized perennial warm season grass species that are native to countries of the western Pacific Rim and the Indian Ocean (Engelke and Anderson 2003, Pompeiano et al. 2012). Three zoysia species, as well as their hybrids, have been cultivated and introduced to the United States as turfgrass: *Zoysia japonica*, *Z. matrella*, and *Z. pacifica* (also known as *Z. tenuifolia*) (Beard 1973, Engelke and Anderson 2003, Wiecko 2008, Pompeiano et al. 2012). Most accessions are tropical to southern temperate and therefore adapted to warm climates. However, *Z. japonica* is pre-adapted to cooler climates where summers are too hot and humid for cool season grasses but too cold for Bermudagrass (Duble, Texas Cooperative Extension). Still, Maryland is the northern range limit for zoysia (Duble, Texas Cooperative Extension).

Native habitats of zoysia include coastal foredunes and shorelines of mangroves and estuaries, although zoysia also grows inland within the mountains of Korea and Japan (Engelke and Anderson 2003). Zoysia is a rhizomotous, mat forming perennial (Beard 1973) that forms lumpy swards under ungrazed and unmowed conditions. It can be propagated vegetatively by sprigs, plugs and sod, which is the main form of zoysia turfgrass establishment because seed germination tends to be low for most cultivars (Wiecko 2008). Zoysia grows slowly and therefore establishes slowly. However, once established, zoysia is an excellent low maintenance species owing to its low stature and drought resistance. In North Carolina, for example, zoysia was sodded as a strip below guardrails along Interstate 177. The strips had to be irrigated with watering trucks in the first year. However, once established, maintenance requirements were low (M. Goatley, *pers. communication*).

Seeds per pound: 1,000,000
Cost per pound: $75 per pound from Chesapeake Valley Seed
Cost per acre: $3,375.00 per acre
Suggested sowing rate: 45 pounds per acre (Tuner *pers. communication*)
Sowing depth: 1/8-1/4 inch
Germination time: 7-14 days
Seeding timing: 1-15 June in Indiana/Kentucky (Patton et al. 2004)
Length of growing season: Does not thrive where summers are short and cool (Beard 1973); optimum growth temperature of 80-95^{o}F.
Leaf height: 2-8 inches (estimate)
Height at seed head stage: 2-16 inches (Engelke and Anderson 2003)
Shade tolerance: good when grown in warm humid climates (Beard 1973). *Z. pacifica* > *Z. matrella* = *Z. japonica* for shade tolerance (Beard 1973).
Suggested mowing height: Tolerates low mowing of 0.5 to 1 inch height (Beard 1973). Mowing at 0.75 inches reduces thatch accumulation.
Tolerance of wet conditions: needs well drained conditions (Beard 1973)
Humidity tolerance: Adapted to warm humid climates (Beard 1973) and therefore has high tolerance for humidity.
Disease resistance: Relatively disease resistant (Beard 1973). It is susceptible to brown patch, rust, *Helminthosporium* leaf spot, and dollar spot under certain conditions (Beard 1973). Zoysia is generally more resistant to attack by nematodes and insects than other warm season grasses (Beard 1973).

Services:

Commercial availability and cost: Although zoysia produces many seedheads, seed yield potential is reduced in most cultivars due to small seed size and lower number of spikelets (Meyer and Watkins 2003). Even though *Z. japonica* produces viable seeds, germination is low (Wiecko 2008). Flowering habit, climatic conditions for floral induction, and management for optimum seed production and shattering resistance have been difficult to define such that a viable zoysia seed industry is economically restricted. Being a rhizomatous species, zoysia is therefore typically propagated vegetatively and then sodded, which is expensive (Patton et al. 2004, Wiecko 2008). Cost of zoysia seed per pound is expensive and planting over a large area is cost-prohibitive.



Rate of establishment: Among 6 warm season turfgrasses tested, zoysia had the slowest establishment rate (Severmutlu et al. 2011) over two years when sodded. When seeded, zoysia requires 90-105 days to reach 90% cover, which is 2-3 times longer than bermudagrass establishment (Patton et al. 2004a). Among 5 turfgrass species, zoysia was the slowest to establish after seeding (Patton et al. 2010). Rates of growth differ among zoysia species with *Z. pacifica* < *Z. matrella* < *Z. japonica* (Beard 1973). The slower establishment may initially require the use of herbicides to reduce weed competition (Patton et al. 2004b).

Ease of maintenance: Zoysia is a low growing turf with a slow growth rate (Beard 1973). As such, it is a low maintenance turf that requires less mowing. It is also drought tolerant and therefore requires no irrigation after establishment.

Erosion control: Beard (1973) and Lee et al. (2009) argue that *Zoysia japonica* produces a moderately deep root system relative to other turfgrass species. Other studies suggest that zoysia has a relatively shallow rooting system. Qian et al. (1997) found that 70% of zoysia root mass was located within the top 30 cm with maximum root extension recorded to 62 cm. Huang (1998) measured 62% of root biomass of 'Meyer' zoysiagrass within the top 20 cm of soil, 30% between 20-40 cm and 8% within 40-80 cm. Bowman et al. (2002) found that the roots of zoysia cultivars 'Meyer' and 'Emerald' were concentrated in shallow soils up to 6 cm and very few extended to 44 cm. Similarly, Carrow (1996) found that 'Meyer' zoysiagrass produced few roots and had low root length density below 20 cm. Root length density in 'Companion' zoysiagrass was five times smaller in the 25-40 cm layer compared with the 8-15cm soil layer (Rimi et al. 2012), whereas bermudagrass sustained root length density across soil layers. Considered to be a relatively shallow rooting system compared to bermudagrass, tall fescue, and others (Biran et al. 1981, Qian et al. 1997, Bowman et al. 2002, Macolino et al. 2012), Zoysia's fibrous root system should bind soil adequately and aid in erosion control on shallow slopes. Steep slopes, however should be avoided.

Ecosystem benefits: Zoysia is a non-native species. Its dense growth habit, once established, decreases the potential for colonization by other species. Thus, plant diversity is low in established zoysia sward with potentially negative consequences on ecosystem resilience and functioning. Some studies have found that zoysia leaches more nutrients than other turfgrass species with higher root biomass and deeper root systems (Trenholm et al. 2012, Gonzales et al. 2012, Fan et al. 2014).

Resilience:

Drought: Zoysia is ranked excellent in heat and drought tolerance (Beard 1973) and medium in evapotranspiration rate among cool and warm season turfgrasses (Kim 1983, Kim and Beard 1988, Beard and Kim 1989, Carrow 1995). Species and cultivars of zoysia differ in their drought tolerance mechanisms. For example, *Z. matrella* cell walls are more elastic but *Z. japonica* maintains turgor by accumulating solutes (Engelke and Anderson 2003) and may be better at avoiding drought than *Z. matrella* owing to deeper roots (Marcum et al. 1995). *Z. japonica* 'Meyer' was as drought tolerant as buffalograss and more tolerant than bermudagrass and tall fescue (Qian and Fry 1997). Zoysia was less stressed by drought than Bahiagrass and St. Augustinegrass as reflected in wilting, firing, and visual rating (Cathey et al. 2011). A comparison of 5 warm season turfgrass species observed that zoysia maintained acceptable quality at 40% deficit irrigation through maintaining photosynthesis, internal water holding capacity, and leaf rolling (Lee et al. 2009). Zoysia's drought tolerance was not attributed to rooting depth but to an ability to tolerate internal moisture deficits using osmotic adjustments (Qian et al. 1997, Qian and Fry 1997). Some studies, however, observed lower drought resistance in zoysia. For example, *Z. matrella* ceased water uptake at higher soil water potential and wilted before 10 other turfgrass species or cultivars, which Biran et al. (1981) attributed to its relatively shallow root system. Similarly, 'Meyer' zoysiagrass was ranked as medium to low drought resistance (Carrow 1996) and had lower leaf water potential after drying than buffalograss (Huang 1998) owing to a shallow root system. A comparison with three seeded bermudagrass cultivars showed that 'Companion' zoysiagrass had higher canopy quality in the early and late growing season but poorest quality from June to October (Rimi et al. 2012). This was attributed to lower root length density and root mass density in Zoysia. Using irrigation requirements as a measure of drought resistance, studies showed that Zoysia required as much or higher irrigation levels to maintain turf quality than bermudagrass and tall fescue (Qian and Engelke 1999, Fu et al. 2004).

Low fertility: Zoysia is tolerant of a wide range of soil types (Beard 1973, Wiecko 2008) and has low to medium nutritional requirements (Beard 1973). It thrives on fertile soil (Beard 1973), responding positively to moderate fertilization (Fan et al. 2014). Zoysia turf quality was acceptable even at the lowest fertilizer application (32 kg/ha annual); high application of fertilizer resulted in disease (Trenholm et al. 2012). Zoysia produced higher root biomass at a low nitrogen fertilization rate than a high rate (Wherley et al. 2011). Overall, therefore, zoysia tolerates low fertility environments.

Freezing*:* Zoysia is a tropical grass and is therefore susceptible to cold temperatures. Beard (1973) ranks zoysia's cold temperature tolerance as 'poor to intermediate', with *Z. japonica* as the most cold tolerant (see also Wiecko 2008), *Z. matrella* intermediate, and *Z. pacifica* lowest. Despite the low ranking, zoysia's cold tolerance ranking is the best in a comparison of 6 warm season grasses (Beard 1973). Similarly, Stier and Fei (2008) rank zoysia's low temperature tolerance as 'Good', which is higher than most warm-season grasses except for Bouteloua species. Owing to zoysia's wide latitudinal distribution, cold-hardiness is likely to be under genetic control and can therefore be selected for. The commercially available cultivars 'Meyer' and 'Midwest' are reported to be the most cold-hardy, whereas cultivars 'Zorro' and 'Emerald' have poor cold-hardiness (Peterson et al. 2014). Nonstructural carbohydrates in stolons and rhizomes increased freezing tolerance of 'Meyer' *Z. japonica* in the fall and winter months (Rogers et al. 1975).

Salinity: Zoysia is indigenous to coastal salt marshes and is therefore naturally adapted to higher salinity environments of 6-10dS/m (Harivandi et al. 1992, Marcum 2008a) or higher (Uddin and Juraimi 2013). Salinity trials have found a range of salinity tolerances within the genus zoysia with *Z. matrella* having higher tolerance than *Z. japonica* in some studies (Lee et al. 1994, Marcum et al. 1998, Qian et al. 2000) and lower in other studies (Uddin et al. 2011b and Uddin and Juraimi 2013). *Z. japonica* ('Meyer') had similar salinity tolerance than bermudagrass (*Cynodon dactylon*) but higher tolerance than Bouteloua species (buffalograss and blue grama) (Marcum 1999). Similarly, *Z. japonica* had the highest salinity of 8 warm season turfgrass species tested based on leaf firing (Uddin et al. 2011a), and *Z. japonica* and *Z. matrella* had lower salinity tolerance compared to Seashore paspalum but higher tolerance to bermudagrass (Uddin et al. 2012), and 13 other turfgrass species (Uddin et al. 2011b). Similarly, *Z. matrella* had lower tolerance to seashore paspalum (Gaetani et al. 2013) but higher tolerance compared to four other tropical turfgrasses (Uddin et al. 2009). Owing to the presence of leaf salt glands (Marcum 2008b), *Z. matrella* had one of the highest salinity tolerances of six C_4 turfgrass species tested (Marcum and Murdoch 1994) with shoot growth being reduced by 50% at 400mM salinity.

Acidity: Zoysia is best adapted to soils with pH between 6 and 7 (Beard 1973). Liu et al. (2008) report zoysia as being tolerant of aluminum and therefore acidic soils. Cultivars differ in their tolerance (Duncan and Shuman 1993, Baldwin et al. 2005) providing high potential for further acid tolerance improvements. The hybrid 'Emerald' is particularly well adapted to acidic soils (Pompeiano et al. 2012).

Wear tolerance: Because the stems and leaves are tough and stiff, zoysia has excellent wear tolerance (Pompeiano et al. 2012) when actively growing (Beard 1973). However, it is not wear tolerant during winter dormancy (Beard 1973).

Competition: Zoysia produces a high-density sward once established. Thus, a mature sward is resistant to invasion by weeds (Beard 1973, Pompeiano et al. 2012). In a 5-year study, a zoysia – 'Merion' bluegrass mixture had high resistance to invasion and attained 80% ground cover of planted species (Davis 1958). During establishment, however, zoysia is vulnerable to weed invasion owing to its slow establishment.

<u>Mixes</u>: In transition zones, cool season grasses are commonly overseeded with warm season grasses to help retain visual quality (Yin et al 2014). In some cases it may be beneficial to plant the warm season grass at its optimal seeding date and overseeding with a cool season grass in the fall. Trials by Murray (1985) concluded that zoysia could be mixed with tall fescue as long as both of the grasses were sowed in their most optimal season. The seeding rate used was two pounds of tall fescue for every one pound of zoysia per 1,000 / ft^2 (Murray 1985). The results from these trials also showed that zoysia could be established with perennial ryegrass and Kentucky bluegrass, but establishment with tall fescue was the most successful. A perennial ryegrass and zoysia mixture led to the reduction of zoysia, due to the aggressiveness of perennial ryegrass (Murray 1985). In 1995, Morris continued work on a zoysia/tall fescue mix; the results concluded that while this mix was successful, it had poor wear tolerance performance. In a 2-year study by Rimi and Macolino (2014), a mature stand of zoysia was overseeded with red fescue. They found a decrease in red fescue cover each year because of the aggressiveness of zoysia (Rimi and Macolino 2014).

Cultivars: *Zoysia japonica* and *Z. matrella* have been cultivated in Asia for centuries and were introduced from Japan to the United States in 1902 (Engelke and Anderson 2003). The earliest herbarium collection comes from Washington DC in 1907. Most cultivars that are commercially available in the U.S. today are hybrids across species. Cultivars ‘Emerald’, ‘Meyer’ and ‘HT210’ had low growth rates whereas cultivars ‘Zenith’ and ‘DALZ0101’ had higher growth rates (Pompeiano et al. 2012). Cultivar ‘Meyer’ has excellent cold hardiness and has therefore been used as the principal cultivar in the United States (Murray 1985). However, ‘Meyer’ was not at shade tolerant as some other zoysia cultivars. In contrast, shade tolerant cultivars ‘Emerald’ and ‘Zorro’ were not cold-hardy (Peterson et al. 2014).

Hybrids: *Zoysia japonica*, *Z. matrella*, and *Z. pacifica* all form hybrids with each other.

Kentucky bluegrass

Poa pratensis

Kentucky bluegrass is often used in roadside mixes because it is widely available commercially and produces dense sod that is good at stabilizing soil. The species has excellent freezing tolerance and is an aggressive competitor such that it will persist in cool climates. However, Kentucky bluegrass receives a Poor to Good rating (grade = D+) as a turfgrass for roadside management owing to a variety of management concerns:

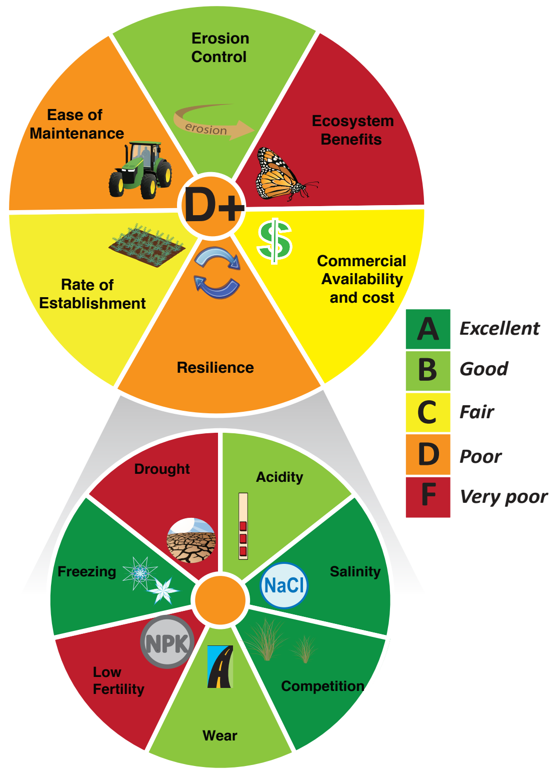
Kentucky bluegrass provides very poor ecosystem benefits. It is a non-native species that may become invasive in some areas outside of Maryland. It also has high nutrient leaching potential.

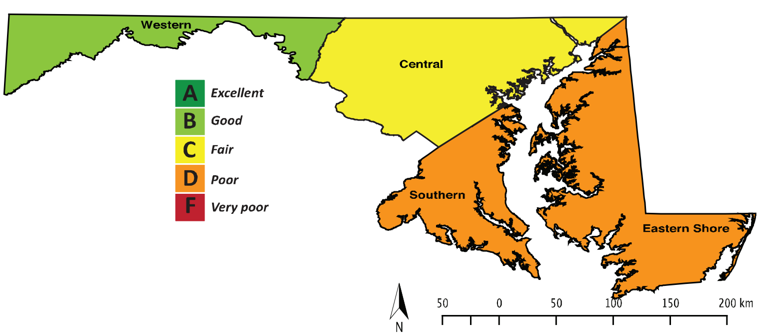
Kentucky bluegrass is moderatly expensive when seeded in a large area.

Although a low-stature plant, Kentucky bluegrass requires fertilization and irrigation to maintain turf quality.

Kentucky bluegrass germinates slowly and has a long juvenile stage. It is therefore slow to establish.

Kentucky bluegrass has poor resilience because it is sensitive to drought, low fertility, and salinity, allof which are conditions frequently encountered along roadsides.





Owing to its freezing tolerance, it is most adapted to Western Maryland and somewhat Central Maryland but is likely to perform poorly in Southern Maryland and the Eastern Shore due to drought susceptibility. For these reasons, Kentucky bluegrass is not recommended for planting along Maryland roadsides.

Proven and promising Kentucky bluegrass cultivars for Maryland include Aries, Barvette HGT, Beyond, Bluebank, Blue Coat, Blue Note, Cabernet, Diva, Endurance, Everglade, Full Back, Granite, Hampton, Impct, Keenland, Legend, Midnight, Noble, NuChicago, NuGlade, Oasis, Skye, Solar Eclipse, Sudden Impact, and Touche.

Biology: Kentucky bluegrass is a perennial cool-season turfgrass species that is native to Eurasia (Beard 1973) and was introduced as an agronomic crop to the United States with the early settlers (Huff 2003). It is now the most widely cultivated cool season turfgrass worldwide and is used as a lawn grass as well as a forage grass and for conservation purposes (Huff 2003). Its vigorous and dense root and rhizome system allows the species to recuperate from stress (Beard 1973) and to stabilize soil (Huff 2003). Under proper culture (irrigation, fertilization), it forms a high quality turf (Beard 1973). Vegetative expansion is very high in Kentucky bluegrass, where one shoot can produce 20-60 ft of rhizomes within one growing season (Beard 1973). Kentucky bluegrass is often used in large proportions is roadside mixes because it a good sod producer; however, it establishes slowly and over-winter survival is low (Friell et al. 2012). It is therefore not recommended for use along roadsides in Maryland (Turner *pers. communication*).

Seeds per pound: 2,200,000 (University of Tennessee extension)
Cost per pound: $2.95 per pound from Chesapeake Valley Seed
Cost per acre: $256.65 per acre
Suggested sowing rate: 87 pounds per acre (Tuner *pers. communication*)
Sowing depth: ¼ inch
Germination time: 14 days minimum
Seeding timing: spring or fall
Length of growing season: early spring to fall
Leaf length: 2-16 inches (Huff 2003)
Height at seed head stage: 12-47 inches (Huff 2003)
Shade tolerance: Full sunlight or only slight shading are preferred. Kentucky bluegrass will not persist under shaded conditions in cool climates (Beard 1973).
Suggested mowing height: should not be cut lower than 1.5 to 2 inches (Center for Turfgrass Science, Pennsylvania State University)
Tolerance of wet conditions: may cause leaf spot
Humidity tolerance: Kentucky bluegrass is adapted to cool humid climates (Beard 1973) and is therefore tolerant of humid conditions. However, humid conditions may cause leaf spot (Turf Care Omaha)
Disease resistance: Cultivars of Kentucky bluegrass differ in their resistance to diseases. Diseases are numerous and include *Helminthoporium*, rust, stripe smut, *Fusarium* blight, powdery mildew, *Fusarium* patch, *Pythium* blight, dollar spot, brown patch, *Ophiobolus* patch, and *Typhula* blight (Beard 1973).

Services:

Commercial availability and cost: Kentucky bluegrass is commercially available. Seeds cost only slightly more than tall fescue, perennial ryegrass, and fine fescues. Over a large area the cost of seeding Kentucky bluegrass is similar to the fine fescues.

Rate of establishment: Kentucky bluegrass takes relatively long to establish compared to other cool season grasses (Erdmann and Harrison 1947, Huff 2003, Friell et al. 2012). It germinates relatively slowly (14 to 28 days) and has a long juvenile stage (Huff 2003), which increases susceptible to drought conditions during establishment.

Ease of maintenance: Kentucky bluegrass is a low stature plant but requires fertilizer and irrigation to maintain acceptable turf quality and survival.

Erosion control: Kentucky bluegrass produces a dense sod and has a high root-to-shoot ratio (Dziamski et al. 2012; but Sprague (1933) observed a low root-to-shoot ratio owing to vigorous top growth). It has a well-developed root system with most roots within the top 1.5 to 2 feet of soil but some roots reaching to 3 ft (Weaver 1958). Beard (1973) reported a higher concentration of roots within the top 6-10 inches of soil with some roots penetrating up to 25 inches. Kentucky bluegrass can start root growth early in the growing season, reaching 9 inches soil depth in April whereas colonial bentgrass reached the same soil depth 1 month later in New Jersey (Sprague 1933). Sprague (1933) concludes that Kentucky bluegrass is an excellent species to use as an agricultural crop owing to the combination of early root growth and high root biomass that supports a high above-ground biomass. However, on poor soils where survival is more important than biomass yield, hard fescue is superior to Kentucky bluegrass owing to higher root growth and better root-to-shoot ratio (Sprague 1933). Despite a dense root system, water retention in the soil cultivated with Kentucky bluegrass was not as high as tall fescue and perennial ryegrass owing to differences in root morphology among species (Glab and Szewcyk 2014). Thus, Kentucky bluegrass is not as effective as other cool season species in increasing infiltration capacity of trafficked soils.

Ecosystem benefits: Cultivars that are grown for turfgrass originated from European sources (Huff 2003) with the center of origin in Eurasia; however, some evidence exists that some Kentucky bluegrass may be native to North America prior to European settlement (Johnson 2008). Kentucky bluegrass is first mentioned as growing in the United States in 1685 (Johnson 2008). Therefore, Kentucky bluegrass can be considered native or non-native and naturalized irrespective of origin with intercrossing and hybridization likely. Kentucky bluegrass can be competitive in some situations and it has been observed to compete with native species in national parks and national forests. It has been listed as invasive species, or potentially invasive species, in some areas but not in Maryland (Johnson 2008, Turner *pers. communication)*. An estimated 90% of Kentucky bluegrass growing in pastures and along roadsides (Huff 2003) and at least 8-11% of Kentucky bluegrass established on reclaimed mine sites planted with native grasses (Thorne and Cardina 2011) were established without being intentionally planted highlighting the species' ability to disperse and establish in new potentially unintended areas. Soil nitrate concentrations are higher under Kentucky bluegrass plots than under tall fescue or perennial ryegrass plots with concentrations approaching drinking water standards in the non-growing season (Liu et al. 1997). Cultivar 'Liberty' had soil nitrate concentrations consistently over the drinking water standard, and other cultivars exceeded the standard intermittently. In contrast, other cultivars such as 'Eclipse', 'Able', 'Midnight', and 'Joy', never exceeded the drinking water standard. This suggests that leaching potential may be higher from turf that it composed of Kentucky bluegrass but cultivars differ in nitrate removal from soil. Kentucky bluegrass is a host plant for moths such as the pepper and salt skipper and Peck's skipper. It is considered a valued forage plant for herbivores.

<u>Resilience</u>:

Drought: Kentucky bluegrass prefers moist, well-drained sites (Beard 1973, Wakefield et al. 1974) and will only persist in semi-arid or arid regions when irrigated (Beard 1973). It is not considered to be tolerant of drought or heat stress (Beard 1973, Brown et al. 2011). The species has a high evapotranspiration rate (Feldhake et al. 1984, Beard and Kim 1989) and therefore requires more water than fine fescues (Johnson 2008), zoysia, bermudagrass and tall fescue (Fu et al. 2004) to maintain acceptable turf quality when water is limited. Under rain-fed conditions in Wyoming (Islam et al. 2013), Kentucky bluegrass and tall fescue turf quality were inferior to buffalograss and blue grama. Kentucky bluegrass declined rapidly when soil water potential reached -50 to -80 kPa as opposed to hard and chewings fescue, which demonstrated a greater ability to thrive under limited soil moisture (Aronson et al. 1987). Similarly, Kentucky bluegrass showed a fast killing time and high electrolyte leakage when subjected to heat stress (Wallner et al. 1982). These results however contrast with McKernan et al. (2001) who observed that Kentucky bluegrass cultivar 'Washington' had excellent drought tolerance. The excellent drought tolerance was only specific to this one cultivar of Kentucky bluegrass and was attributed to the plants reestablishing after a drought from their extensive rhizomes. In fact, Johnson (2008) suggests that Kentucky bluegrass can withstand extended periods of drought through dormancy. Tests in Utah showed that Kentucky bluegrass survived 120 days of drought, which was longer than perennial ryegrass, creeping red fescue and prairie junegrass. An early British study (Carroll 1943) showed Kentucky bluegrass had high drought endurance and was the most resistant among 15 grass species to drawdown of soil moisture from 5% to 3%. Kentucky bluegrass had low tolerance to increased soil temperatures but high tolerance to increased air temperatures. Cultivars of Kentucky bluegrass can vary greatly in drought tolerance (Wallner et al. 1982); drought resistant include 'Unique', 'Apollo', 'Brilliant', and 'Showcase' (McCann and Huang 2008).

Low fertility: Kentucky bluegrass prefers fertile sites (Beard 1973, Wakefield et al. 1974, Brown et al. 2011) and responds well to fertilizer applications (DeBels et al. 2012). In a low input study in Maryalnd, Kentucky bluegrass performed well for the first 4 summers but quality declined during a severe summer drought in the 5th summer (Turner *pers. communication*). Of 15 monoculture and polyculture treatments, Kentucky bluegrass had the worst quality ratings under low fertilizer use (Horgan et al. 2007). In a low-input fairway study in Minnesota (Watkins et al. 2010), Kentucky bluegrass turf quality was acceptable in the first year of the study and only surpassed by bentgrasses, but turf quality declined to unacceptable quality in the second year. In a low-maintenance study in Minnesota, Kentucky bluegrass had acceptable summer performance in only 3 of 8 locations (Watkins et al. 2014). In an early British study that compared 15 turfgrass species, Carroll (1943) found that Kentucky bluegrass had the highest survival rates under low and high-N conditions.

Freezing*:* Kentucky bluegrass has good freezing tolerance (Beard 1973, Bhowmik et al. 2008, Stier and Fei 2008) and can grow from sea level to 4000 m (Huff 2003). Survival of Kentucky bluegrass was the highest observed among 15 grass species in a British study (Carroll 1943). While -15^{o}C was the killing temperature for most of the other species, Kentucky bluegrass survival was 25% at -15^{o}C and 20% at -20^{o}C under low-N conditions.

Salinity: Kentucky bluegrass is sensitive to salinity (Lunt et al. 1961, 1964, Hughes et al. 1975, Harivandi et al. 1992, Alshammary et al. 2004, Marcum 2008a, Brown et al. 2011, Uddin and Juraimi 2013, Kazlauskiene and Brukstute 2015). Biesboer et al. (1998) suggest that Kentucky bluegrass should never be used along roadsides that are heavily salted in the winter. Observations along Illinois roadsides suggest that planted Kentucky bluegrass does not last along roadsides that receive deicing salts in the winter. Rather, Kentucky bluegrass is succeeded by quackgrass that is invaded and outcompeted by weeping alkaligrass (Butler et al. 1971). Germination of Kentucky bluegrass decreased from 85% to 54% when subjected to NaCl during emergence but was alleviated by gypsum, KCl, and KNO_3 (Neid and Biesboer 2004). Similarly, Kentucky bluegrass had the lowest germination percentage under salinity treatments among 6 turfgrasses tested (Harivandi et al. 1982); the greatest yield reduction among 5 (Hughes et al. 1975) and 4 (Alshammary et al. 2004) grass species; the greatest dry matter yield reductions and most severe foliage injury when treated with salt among 40 grass and legume species and cultivars (Greub et al. 1985); and the lowest survival in Minnesota roadside trials among 74 cool-season species and cultivars (Friell et al. 2012). However, differences in salt tolerance among cultivars are observed (Rose-Fricker and Wipff 2001, Koch et al. 2011) and vary by location (Brown et al. 2011, Koch et al. 2011, Friell et al. 2012, 2013) with cultivar 'Diva' performing well in many (Brown and Gorres 2011, Koch et al. 2011) but not all locations (Friell et al. 2012). Among 26 Kentucky bluegrass cultivars tested in salt baths, cultivars 'North Star', 'Ascot' and 'Moonlight' showed the best tolerance based on percent survival and leaf firing (Rose-Fricker and Wipff 2001). Koch et al (2011) showed that cultivars 'Eagleton', 'Moonshadow, 'Fairfax', 'Cabernet', and 'Liberator' were the most tolerant to saline irrigation. However, Marcum (2008a) highlights inconsistencies among studies in ranking of Kentucky bluegrass cultivars for salt tolerance and suggests that conflicting trends may be due to a narrow range of salt tolerance within the species. Salinity tolerance is also influenced by deicer products where injury to Kentucky bluegrass was highest for rock salt and urea sprayed on turf (Minner and Bingaman 1998).

Acidity: Kentucky bluegrass is adapted to soil pH between 6 and 7 and does not tolerate extremes in acidity or alkalinity (Beard 1973). Liu et al. (2008) suggest that cultivars differ in aluminum resistance and that Kentucky bluegrass was the least aluminum resistant among three Poa species.

Wear tolerance: Kentucky bluegrass is ranked as having medium to good wear tolerance (Beard 1973, Canaway 1981, Dunn et al. 1994) with cultivars showing a range of tolerances (Brosnan et al. 2005, Park et al. 2010). In a study of 7 turfgrasses and 37 cultivars, Kentucky bluegrass ranked slightly lower in wear tolerance than perennial ryegrass and tall fescue (Glab et al. 2015). In a low-input fairway study in Minnesota, Kentucky bluegrass turf quality in the first year after establishment declined under different traffic treatments and declined to unacceptable quality in the second year (Watkins et al. 2010). Kentucky bluegrass recovers well from traffic and wear through its extensive rhizomatous growth (Johnson 2008).

Competition: Kentucky bluegrass is competitive under moist and fertile conditions (Beard 1973) and may outcompete native species under some environmental conditions (Johnson 2008). In some areas it is even considered invasive or potentially invasive (Johnson 2008). Kentucky bluegrasss is often mixed with tall fescue (Beard 1973) to increase sod strength especially under extreme wear conditions (Gibeault et al. 1993, Hunt and Dunn 1993). Rhizomotous lines of tall fescue were more competitive with Kentucky bluegrass, which can dominate mixtures with tall fescue and decrease turf quality (Macolino et al. 2014). A 95/5 percent by weight tall fescue to Kentucky bluegrass mixture produces a stand with approximately equal number of both species; however, composition of the mixture can gradually shift to Kentucky bluegrass at lower mowing heights, greater nitrogen fertility and more frequent irrigation which are conditions that favor Kentucky bluegrass (Dunn et al. 2002). Kentucky bluegrass is similar in competitive ability to chewings fescue and the species can therefore be used in mixture without significant changes in yield in either species. Kentucky bluegrass is susceptible to competition with perennial and annual ryegrass (Erdmann and Harrison 1947, Dunn et al. 2002) owing to the rapid establishment of ryegrass; however a high Kentucky bluegrass to perennial ryegrass ratio can yield a high performing sward (Brede and Duich 1984). Kentucky bluegrass is an inferior competitor to alkaligrass (Tarasoff et al. 2009), which the authors hypothesize is due to alkaligrass' rapid establishment and growth, and inferior to Canada thistle (Gabruck et al. 2013). In areas that are eroded and have low fertility soils, Kentucky bluegrass high fertilizer inputs to resist weed invasion and maintain quality (DeBels et al. 2012).

Mixes: Kentucky bluegrass is frequently used in mixture with red fescue (Davis 1958, Juska and Hanson 1959, Beard 1973, Ebdon and Skogley 1985) and chewings fescue (Erdmann and Harrison 1947, Beard 1973, Ruemmele et al. 2003). Seed mixtures containing at least 50% red fescue were able to maintain the desired species composition (Juska and Hanson 1959). An initial seed mixture of 48% Kentucky bluegrass and 52% creeping red fescue maximized turf quality that was acceptable when lawns received 150 and 300 lb/acre deicing salts (Butler et al. 1971). Under high intensity culture, Kentucky bluegrass will dominate (Davis 1958), but under droughty, low-input environments, red fescue will dominate (Beard 1973, Ebdon and Skogley 1985). In a New Mexico field study, a mix of 70% hard fescue, 25% sheep fescue, and 5% Kentucky bluegrass showed good germination, excellent turfgrass coverage, and was fastest in achieving 50% coverage at normal and reduced seeding rate and at lower irrigation (Leinauer et al. 2010). Beyond fine fescue, a ratio of 70-95% Kentucky bluegrass to 5-30% perennial ryegrass providing the best compromise for fast establishment and an even sward (Brede and Duich 1984), as did a mix of Kentucky bluegrass with rhizomatous tall fescue lines (Macolino et al. 2014). The mix outperformed the respective monocultures. However, in a low-maintenance study, a Kentucky bluegrass blend of 3 cultivars had unacceptable quality ratings and was not competitive with weeds compared to fine fescue, tall fescue, and native grass mixes (Miller et al. 2013).

Cultivars: Considerable variable exists among cultivars in turf quality, stress tolerance, cultural requirements, and disease resistance (Beard 1973). Common type cultivars collected from old pastures and high-cut turfs often outperform improved cultivars under low maintenance conditions (Huff 2003). Cultivar 'Merion' was the first turf-type cultivar that was low-growing and had higher disease resistance (Huff 2003).

Hybrids: Kentucky bluegrass has the most shared genomes with other bluegrasses due to interspecific hybridization and may be one reason for why the species is so widely adapted (Huff 2003, Johnson 2008). Breeding efforts work on enhancing drought tolerance of Kentucky bluegrass through hybridization with native bluegrasses, such as with Texas bluegrass (*Poa arachnifera*; Johnson 2008, Su et al. 2007). However, in an eight-state low-maintenance study, Watkins et al. (2014) found that *Poa arachnifera* did not perform at a level that showed any adaptability to the North Central US region.

Perennial ryegrass

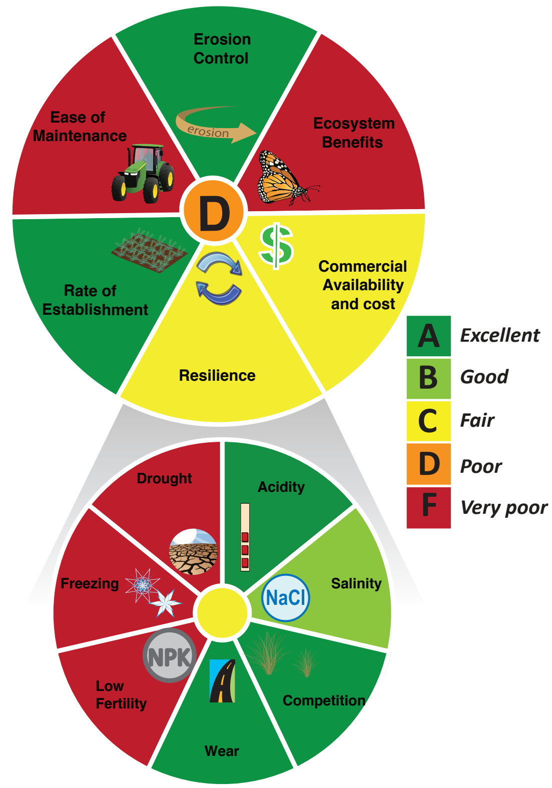
Lolium perenne

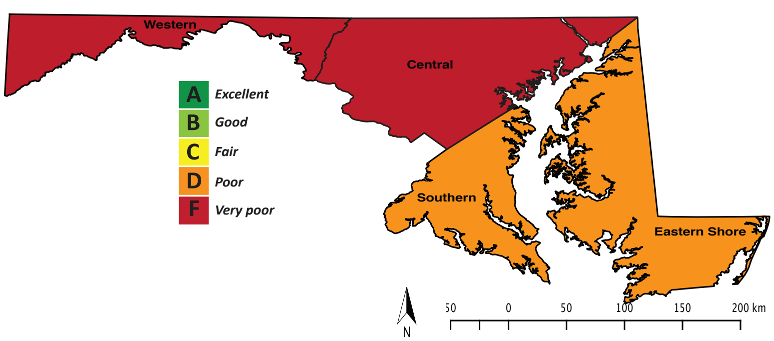
Owing to its high commercial availability, fast establishment rate, and deep and fibrous root system that reduces erosion, perennial ryegrass is used extensively as a nurse grass in establishing grass mixtures. It is therefore often incorporated into roadside grass mixtures. Despite these excellent attributes, perennial ryegrass receives one of the poorest ratings (Poor = D) as a turfgrass for roadside management owing to a variety of management concerns:

Perennial ryegrass is exceptionally poor in providing ecosystem benefits. The species is non-native and non-persistent with some cultivars exhibiting high leaching potential. Perennial ryegrass is also an aggressive competitor and hence a biodiversity reducer.

Mowing requirements for perennial ryegrass can be substantial. The species requires fertilization and irrigation to maintain turf quality beyond the first year of growth.

Perennial ryegrass has very poor freezing and drought tolerances and requires fertile soils to persist. It is highly disease prone. Hence, resilience of perennial ryegrass along roadsides is only fair.





Perennial ryegrass is not recommended for use along roadsides in any part of Maryland owing to its sensitivity to freezing as well as drought.

Proven perennial ryegrass cultivars for Maryland in 2016 include Apple GL, Apple SGL, ASP6004, Banfield, Charismatic II GLSR, Fiesta 4, Grandslam GLD, Homerun, Line Drive GLS, Octane, Palmer V, Paragon GLR, Rio Vista, Soprano, Stellar GL, Stellar 3GL, and Uno. Updates to recommended cultivars in Maryland are published annual in the University of Maryland Turfgrass Technical Update TT77 (Maryland Turfgrass Council).

Biology: Perennial ryegrass is a short-lived noncreeping bunch-type grass native to temperate regions of Asia and North Africa (Beard 1973). It is adapted to cool moist climates with mild winters and cool moist summers. Thus, it does not persist if not subjected to extremes in temperatures (Beard 1973). It is used extensively for forage and turf purposes but also along roadsides and for general landscaping (Thorogood 2003).

Seeds per pound: 230,000 (USDA Fact Sheet)
Cost per pound: $1.85 per pound from Chesapeake Valley Seed
Cost per acre: $240.50 per acre
Suggested sowing rate: 130 pounds per acre (Turner *pers. communication*)
Sowing depth: ½ inch or less
Germination time: 5-10 days
Seeding timing: March through May or mid-August through early September (USDA Fact Sheet) with fall Seedings under irrigated conditions (USDA Plant Guide).
Length of growing season: May through June with a possible second growth season in the fall (USDA Plant Guide)
Leaf length: 2-6 inches
Height at seed head stage: 3.9-35.4 inches (Thorogood 2003)
Shade tolerance: adaptation to partial shading is good (Beard 1973)
Suggested mowing height: 1.5 to 2 inches is preferred.
Tolerance of wet conditions: tolerates extended periods of flooding (up to 25 days; Thorogood 2003) and wet soil conditions as long as drainage is adequate (Beard 1973).
Humidity tolerance: tolerant of humid climates.
Disease resistance: susceptible to *Pythium* blight, ruse, *Fusarium* patch, brown patch, red thread, stripe smut, *Typhula* blight and *Helminthosporium* (Beard 1973, Thorogood 2003, Brede 2000). Seeds and plants are infected by the endophytic fungus *Neotyphodium lolii*, which deters a range of insect pests (Thorogood 2003, Brede 2000).

Services:

$ *Commercial availability and cost*: Perennial and annual ryegrass seed is commercially available and affordable, even over large areas.

Rate of establishment: Perennial ryegrass, and its close relative Italian ryegrass (*Lolium multiflorum*) have a rapid germination rate, fast establishment rate (Beard 1973, Erdman and Harrison 1947, Brede 2000), and a fast growth rate (VanHuylenbroeck and VanBockstaele 1999) compared to other cool season grasses. Percent germination is high (85-95%; Wrochna et al. 2010), and establishment is quick even in low-input environments (McKernan et al. 2001, Watkins et al. 2010, Brown et al. 2011, Friell et al. 2012). The rapid establishment allows Perennial ryegrass to be used for turf repairs by managers, even under adverse conditions (Brede 2000).

Ease of maintenance: Perennial ryegrass is a relatively short statured plant growing between 10 and 90 cm tall (Thorogood 2003). Perennial ryegrass cultivar ‘Fiesta’ had a low stature in a study comparing 25 turfgrass cultivars and species (McKernan et al. 2001) suggesting that cultivars could be selected that would decrease the need for mowing. A study comparing natural populations of perennial ryegrass to forage-type cultivars and turf-type cultivars (Sampoux et al.

2013) observed that breeding has decreased the turf height increase rate. Perennial ryegrass produced better quality turf at reduced irrigation rates and recovered from stress better than tall fescue (Barnes et al. 2014). It produced good turf quality in the first year of a low-input fairway study in Minnesota (Watkins et al. 2010); however, quality could not be maintained beyond the first year and especially when subjected to traffic in the second year. Thus, perennial ryegrass requires continued fertilizer applications and irrigation to maintain a presence in turf beyond the first year.

Erosion control: Perennial ryegrass effectively controls erosion by germinating quickly (Thorogood 2001, Brown et al. 2011) and thereby establishing ground cover quickly. The roots are fibrous but the root system is annual (Beard 1973) and therefore not suited for erosion control when grown alone. Brown et al. (2010) observed the root system of perennial ryegrass to relatively evenly distributed in the soil column with roots penetrating the soil column to the lowest depth measured at 76 cm and a mean rooting depth of 75 cm. This root system is probably explains why perennial ryegrass turf that was trafficked was able to maintain water retention as high as tall fescue but significantly higher than fine fescue turf (Glab and Szewcyk 2014). Thus, perennial ryegrass can increase infiltration capacity of trafficked soils which enhances erosion control by decreasing overland flow.

Ecosystem benefits: Perennial ryegrass is non-native and non-persistent and therefore does not provide significant and sustainable ecosystem benefits. In a study examining soil nitrate levels associated with perennial ryegrass, Kentucky bluegrass, and tall fescue, Liu et al. (1997) measured soil nitrate levels to be lower than Kentucky bluegrass but higher than tall fescue. A 5 to 10-fold range in nitrate concentrations was observed among cultivars with none exceeding drinking water standards. Nitrate loss by leaching also differed among cultivars with cultivars 'J208', 'Manhattan', and 'J207' exhibiting high leaching potential and cultivar 'Linn' showing the least leaching potential.

Resilience:

Drought: Perennial ryegrass has little tolerance to drought (Carroll 1943, Beard 1973, McKernan et al. 2001, Thorogood 2003) and therefore tends to be a short-lived species along no-input roadsides. It has a high (8.5-10 mm/day) evapotranspiration rate (Beard and Kim 1989) and therefore requires more water than fine fescues and warm season grasses. Perennial ryegrass declined rapidly when soil water potential reached -50 to -80 kPa as opposed to hard and chewings fescue, which demonstrated a greater ability to thrive under limited soil moisture (Aronson et al. 1987). In contrast, killing time was long and electrolyte leakage relatively low in perennial ryegrass compared to 5 other turfgrass species (Wallner et al. 1982) suggesting that other traits are responsible for the low drought tolerance in perennial ryegrass. Perennial ryegrass exhibited higher tolerance to drought than Kentucky bluegrass but lower tolerance than creeping bentgrass and tall fescue (Pessarakli and Kopec 2008, Brede 2000). Perennial ryegrass was more heat tolerant than its close cousin annual ryegrass (Yang et al. 2014). Perennial ryegrass can go dormant if drought persists in the summer (Brede 2000). Cultivars of Perennial ryegrass that are considered to be most drought resistant include 'Passport', 'Affinity', 'Calypso II', and 'Edge' (McCann and Huang 2008). Yet, NTEP trials have observed no significant improvement in drought tolerance among new cultivars compared to old standards (Thorogood 2003).

Low fertility: Perennial ryegrass requires medium to high soil fertility (Beard 1973, Thorogood 2003). Perennial ryegrass cultivar persistence was low in low fertility environments (McKernan et al. 2001).

Freezing*:* Perennial ryegrass has poor low-temperature tolerance (Carroll 1943, Beard 1973, Stier and Fei 2001) and therefore suffers serious winter injury (Stier and Fei 2008, Friell et al. 2012). Its roadside performance in areas with cold winters is therefore poor (Brown and Gorres 2011, Friell et al. 2012), suggesting that its usefulness beyond serving as a cover crop is limited along roadsides (Brown and Gorres 2011, Friell et al. 2012). No improvements in winter hardiness have been achieved by breeders (Thorogood 2003). Perennial ryegrass can be considered a short-lived perennial because of its poor freezing tolerance, which leads to winterkill (Iraba et al 2013).

Salinity: Marcum (1999, 2008a), Beard (1973), and Marcar (1987) rate perennial and annual ryegrass as moderate in salinity tolerance at 4-8 dS/m with salt tolerance conferred through its ability to exclude $Na+$ (Krishnan 2010). Percent germination decreased from 95% to 85% at higher salinity levels and germination was delayed by up to 3 days. Root length and seedling growth also decreased at higher concentrations of deicers (Wrochna et al. 2010). Biomass yield decreased 5%, 17%, to 44% with salt additions of 5,000, 10,000, and 20,000 ppm respectively (Hughes et al. 1975). Dry matter yield of perennial ryegrass did not differ under salt and no-salt treatments but foliar injury was significant (Greub et al. 1985) with low percent green tissue (Friell et al. 2013). Experiments by Balterenas et al (2006) as well as Kazlauskiene and Brukstute (2105) found that Perennial ryegrass established and grew quickly but the above ground phytomass were reduced when compared to a control stand. Perennial ryegrass can exhibit salt tolerance as high as tall fescue (Wang et al. 2011, Zhang et al. 2013) and red fescue (Zhang et al. 2013) in germination trials. In a hydroponics system, perennial ryegrass exhibited higher tolerance to salinity than Kentucky bluegrass but lower tolerance than creeping bentgrass (Pessarakli and Kopec 2008). However, during vegetative growth, perennial ryegrass was only as salt tolerant as salt-sensitive Kentucky bluegrass (Wang et al. 2011), contradicting earlier observations (Harivandi et al. 1992, Marcum 2007). Similarly, perennial ryegrass was less salt tolerant than annual ryegrass during germination but more tolerant during vegetative growth (Marcar 1987). Different cultivars of perennial ryegrass showed a range of tolerances to salinities (Marcar 1987, Krishnan 2010) with higher salt tolerance linked to lower relative growth rate and competitive ability (Humphreys 1981). Large variations in salinity tolerance are observed in perennial ryegrass cultivars (Marcum 2007, 2008a, Rose-Fricker and Wipff 2001) with perennial ryegrass cultivars Brightstar SLT, PST-2SLW, B-2, Manhattan 3, PST-216, Catalina, and Fiesta III being the most salt tolerant (Rose-Fricker and Wipff 2001, Marcum 2008a, Krishnan 2010). Cultivars 'Paragon', 'Divine'. And 'Williamsburg' were the most salt tolerant cultivar among 32 perennial ryegrass turf cultivars (Marcum and Pessarakli 2010) as assessed using leaf clipping dry weight, root weight, rooting depth, and percent green leaf canopy area relative to a control.

Acidity: Perennial ryegrass prefers neutral to slightly acidic soils with an optimim pH of 6.5 (Beard 1973), however alkaline soils to pH 8.4 are tolerated (Thorogood 2003). Liu et al. (2008) suggests that cultivars of perennial ryegrass differ in their resistance to aluminum and rank overall acid tolerance and aluminum resistance as medium.

Wear tolerance: Perennial ryegrass is highly tolerant of traffic (Beard 1973, Canaway 1981, Cockerham et al. 1990, Dunnet al. 1994, Thorogood 2003, Krishnan 2010). It was ranked highest in wear tolerance among 7 species (Glab et al. 2015). Perennial was highly wear tolerant the first year of establishment, but turf quality seriously declined in the second year of a low-input fairway study in Minnesota, which affected species tolerance to imposed traffic (Watkins et al. 2010). Brede (2000) found that Perennial ryegrass has limited ability to refill bare spots that resulted from wear. Improvement among cultivars in wear tolerance has been observed (Sampoux et al. 2013).

Competition: Perennial ryegrass should not compose more than 20-25% of the seed mixture on a seed number basis (Beard 1973) and should be kept to a minimum if used at all (Erdmann and Harrison 1947). Higher levels of perennial ryegrass in seed mixtures would lead to excessive competition. Ryegrass negatively affected the growth of Kentucky bluegrass, chewings fescue, and redtop bentgrass in polyculture owing to the initial rapid growth of ryegrass (Erdmann and Harrison 1947). Interseeding zoysia into existing perennial ryegrass resulted in only 2% zoysia cover after 120 days (Patton and Williams 2004b).

<u>Mixes</u>: Perennial ryegrass is often used as a nurse grass in seed mixtures (Erdmann and Harrison 1947, Meyer and Pederson 1999) when rapid establishment of turf and rapid soil stabilization is desired. In North America it is often mixed with Kentucky bluegrass for lawns and sports pitches and is seldom planted alone (Thorogood 2003). Blending perennial ryegrass with Kentucky bluegrass, tall fescue and fine fescues can lead to a nice mixture (Brede 2000). After a five-year experiment, Hunt and Dunn (1993) found that perennial ryegrass began to dominate swards where it was planted with tall fescue and Kentucky bluegrass after two years. Perennial ryegrass is used for winter overseeding of dormant grasses (Beard 1973, Thorogood 2003, Nelson et al. 2005, Richardson et al. 2007, Thoms et al. 2011, Trappe et al. 2012) to provide adequate winter color. In grassland settings, perennial ryegrass is frequently mixed with clover for better pasture yield (Elgersma and Hassink 1997, Eriksen et al 2014, Gibb et al 1989, Hay and Hunt 1989).

The use of perennial ryegrass should be avoided unless rapid establishment is essential for erosion control (Erdmann and Harrison 1947). Brede (2000) mentions that the explosive seed growth can overwhelm other species in a mixture and wipe them out. When added to a mixture of tall fescue and Kentucky bluegrass, Perennial ryegrass dominated the mixture regardless of manager intervention (Dunn et al 2002). By frequently overseeding Perennial ryegrass, Elford et al. (2008) hoped to suppress weeds in established grass swards on sports fields. They found that this provided adequate weed competition and should be considered part of a non-pesticide weed management program (Elford et al 2008).

<u>Cultivars</u>: A number of cultivars were developed in the United States in the 1960's including 'Linn', 'NK100', 'Manhattan', and 'Pennfire' (Thorogood 2003, Brede 2000). Bonos et al. 2004 used selection experiments to increase root mass by 130% in turf type and 367% in forage type perennial ryegrass.

<u>Hybrids</u>: Perennial ryegrass shows degrees of fertility with species of the genus *Festuca* and other genera (Thorogood 2003). The deep root system of fescue is a desirable trait to increase drought and heat resistance and has therefore been used to introgress increased drought tolerance into *Lolium* backgrounds (Barnes et al. 2014), producing the hybrid *Festulolium*.

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