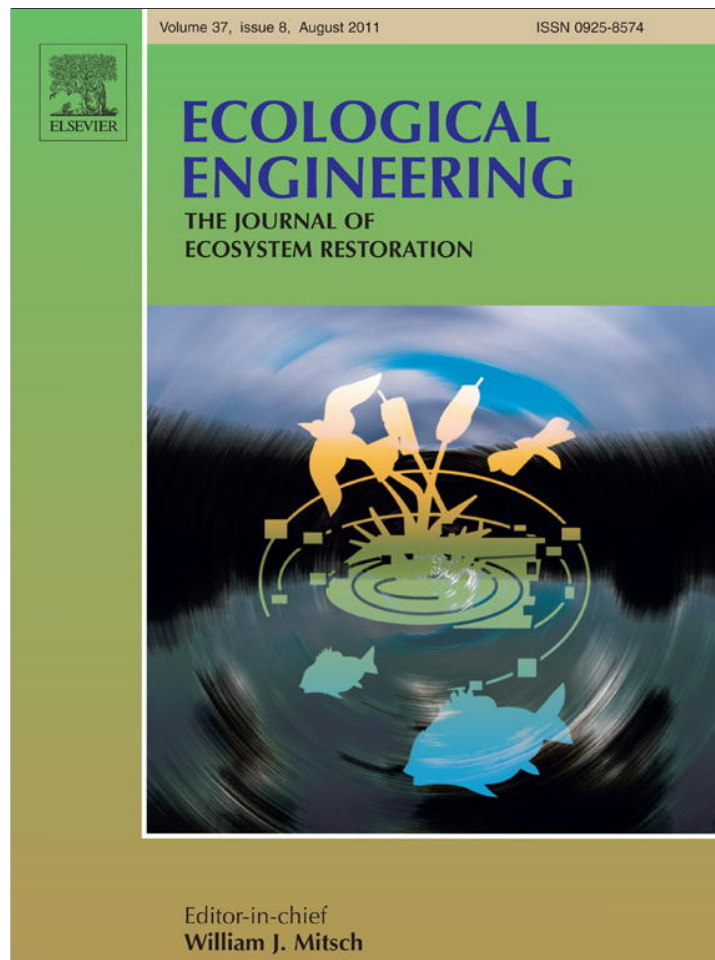


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Review

The performance of native and non-native turfgrass monocultures and native turfgrass polycultures: An ecological approach to sustainable lawns

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ABSTRACT

As environmental impacts and life-cycle costs (water use, water, fertilizer, pesticides and mowing) of the constructed landscape come under increasing scrutiny, the development of methods to reduce resource inputs for managed turf are increasingly important. While the use of a number of native turfgrass species as alternatives to non-natives has been previously examined, only a few are presently commercially available, and many species have been perceived as failing to perform to the level required by industry and consumers. Furthermore, the use of polycultures of native turfgrasses has not been extensively investigated, but could offer an alternative to the conventional lawn. We hypothesize that because native short grass species would be expected to be well-adapted to climate and soil conditions in areas with infrequent and erratic rainfall, their performance in terms of drought resistance, resilience to disturbance, and efficient resource use, will exceed that of a non-native species. Moreover, ecological theory predicts that a polyculture of coexisting native species may exhibit additional performance benefits. One native (*Bouteloua dactyloides*) and one commonly-used, non-native monoculture (*Cynodon dactylon*) and two native polyculture assemblages (two and seven species including *B. dactyloides*, *Bouteloua gracilis*, *Bouteloua rigidisetata*, *Hilaria belangeri*, *Erioneuron pilosum*, *Bouteloua hirsuta*, *Sporobolus vaginiflorus*) were compared for leaf density and weed resistance under two irrigation regimens, traffic regimes and mowing intensities. The native turfgrass and turfgrass assemblages generally had 30% higher leaf densities in the early growing season, and up to 50% lower weed density than the non-native monoculture. There was no difference among species tested in response to traffic or irrigation regimens, suggesting that all assemblages could be subjected to both higher traffic frequencies and reduced water inputs. Even though native species can have slower growth rates compared to the non-native species they maintained a higher or equivalent leaf density than the non-native turfgrass. This is a potentially important finding because of the large impact that mowing has on the total carbon footprint of turfgrass, and the corresponding reduction in that carbon footprint that could be realized through a reduced mowing frequency and corresponding reduction in life-cycle cost. This study suggests that regionally adapted native grass species are worth investigating as mono- and polycultures for performance advantages and lower resource inputs, and consequently may be suitable alternatives to conventional non-native turfgrasses in many applications.

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1. Introduction

Turfgrasses comprise a large portion of residential and commercial landscapes, particularly in the United States, where turfgrasses taken together constitute the largest irrigated crop in America,

covering over 16 million hectares of which 10 million hectares is residential lawn (Bormann et al., 2001; The Lawn Institute, 2010). Historical, horticultural performance expectations of turfgrasses include: ease of propagation and aesthetic qualities such as color, textural density and homogeneity; and depending on application, an ability to cope with foot and/or light vehicular traffic. There has been considerable horticultural research over the last 50 years which has focused on the selection of species to fulfill these demanding performance requirements, through breeding or genetically modifying a single, frequently non-native species, to meet the desired criteria. Recently, the public and many regulatory agencies have expressed concern over the high life-cycle costs of managed turf stemming from high pesticide, fertilizer and water

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use, high mowing rates, and problems with pathogens (Robbins and Birkenholtz, 2003). It is estimated that every year lawns in the United States use between 30% and 60% of municipal potable water, over \$5.2 billion of fossil fuel derived fertilizers, 800 million gallons of gasoline and \$700 million of pesticides (Bormann et al., 2001). Additionally, as more grass species and varieties are tested and marketed for the wide range of turfgrass applications throughout the United States, there is a potential increase in economic and ecological cost associated with the risk that many of these improved grasses could become invasive outside of the lawn environment. For example, bermudagrass (*Cynodon dactylon* (L.) Pers), due to its widespread commercial use and consequent escape, is now considered a problematic weed in Texas and other southern US states (Duble, 1996; Invasive Plant Atlas, 2010), and the USDA lists this species as a noxious weed in Arkansas, California and Utah (USDA, 2010). For these reasons there has been increasing attention toward the selection and propagation of native turfgrasses which have demonstrated a variety of other beneficial traits, including low nutrient requirements and drought tolerance (Bormann et al., 2001; Duble, 1996; McAfee and Leps, 2001; McKernan et al., 2001).

Several species native to North America have been examined for turfgrass applications, including warm season grasses such as buffalograss (*Bouteloua dactyloides* (Nutt.)), blue grama (*Bouteloua gracilis* (Kunth.) Lag. Ex Griffiths), sideoats grama (*Bouteloua curtipendula* (Michx.) Torr.), native paspalums (*Paspalum* spp.) and lovegrasses (*Eragrostis* spp.); as well as cool season grasses including red fescue (*Festuca rubra* L.), velvet bentgrass (*Agrostis canina* L.) and native bluegrass species (*Poa* spp.) (Casler, 2006; Frank et al., 2004; Jenkins et al., 2004; Mintenko et al., 2002). These studies demonstrate the potential suitability of the species under examination, but acknowledge (e.g. Jenkins et al., 2004) that significant horticultural development would be necessary before commercial application.

One species in particular, *B. dactyloides*, a short, stoloniferous warm-season grass native to the Great Plains of North America, has been increasingly used for low-traffic turfgrass applications, and has been widely tested in southern states as a potential substitute for the more commonly used non-native warm-season species such as *C. dactylon*, St. Augustine (*Stenotaphrum secundatum* (Walter) Kuntze) and zoysia (*Zoysia japonica* (Steud.)) (Huang, 1999; Mintenko et al., 2002). While the native grass *B. dactyloides* has been demonstrated to have good drought tolerance, slow growth rate and low nutrient requirements (Casler, 2006; Duble, 1996; McAfee and Leps, 2001; Timmons, 1950), it has compared less favorably with non-native counter parts with respect to foot traffic (Duble, 1996), resistance to invasion by unwanted grasses and forbs (Anonymous, 2003; Geren et al., 2009), and, due to its grey-green hue, lower aesthetic appeal (McAfee and Leps, 2001). Consequently, *B. dactyloides* is considered an inferior substitute for most residential and commercial applications despite the conceptual appeal of using a regionally native species. Some negative aspects of this species' performance, however, may have been a result of poor installation and management. Specifically, inadequate soil preparation, over-mowing, and high use of water and fertilizer, which may be appropriate for many commonly used turfgrasses, but can have negative effects on the performance of *B. dactyloides* (Duble, 1996; McAfee and Leps, 2001). Other native grasses have also demonstrated considerable potential as turfgrasses due to high leaf density and drought resistance, and performed as well if not better than some commonly used non-natives (McKernan et al., 2001; Mintenko et al., 2002; Romani et al., 2002) and with further breeding efforts could result in an acceptable monocultural turfgrass.

However, this "horticultural approach" to the selection and creation of turf monocultures from native grassland species presupposes a theoretical method which may need to be questioned.

The horticultural approach focuses on the selection or modification of individual species to fit a wide range of performance requirements which may rely on considerable, potentially unsustainable management inputs to maintain targeted performance characteristics. But as ecological engineering can be defined as the design of sustainable systems consistent with ecological values (Bergen et al., 2001; Gosselin, 2008), we suggest that, following these principles, an alternative "ecological approach" would be more appropriate. Such an approach would take into account multiple biotic and abiotic processes and interactions, of both existing and hypothetical plant communities to address the same targeted performance values. While application of this approach in the constructed landscape has not been empirically tested, it has been widely used in forage science (e.g. Smith and Allcock, 1985) and ecological restoration (e.g. Jackson et al., 1995). Theory suggests ecological design could provide significant value for turfgrass applications through the mimicry or replication of the attributes of native plant communities.

Natural grasslands offer a case in point. Under natural conditions few grasses occur as monocultures. Most occur in assemblages with other grasses and forbs, where their individual performance is affected by coexistence and competition with other species. Indeed, most natural grasslands are species-rich systems maintained in this state by the dynamics of rainfall patterns, pathogens, soil heterogeneity, wildfire, grazing and other ecological inputs and disturbances. Disturbance regimes and the resulting species response and interactions may result in fluctuation over time in frequency of a single species population within the community, but the plant community as a whole is resilient, maintaining a consistent population over time (Begon et al., 1996). As such, plant communities with high species richness tend to exhibit greater stability, both spatially and temporally (Tilman et al., 2006a). McKernan et al. (2001) demonstrated that grass species mixes were better at weed resistance than single species due to a proposed 'synergistic effect'. Addition of species for weed suppression is also employed in agriculture where 'non-crop' species are added to reduce the potential competitive effect of weed on target crop and even erode seed bank over time (Blackshaw et al., 2000; Nice et al., 2001; Roberts et al., 2001; Picasso et al., 2008). This suggests that there may be potential advantages of multi-species mixes of co-occurring native species with similar traits, appearance and habitats to create lawns with greater residence to traffic, drought and weed invasion while requiring fewer maintenance inputs. To some extent this has already been practiced with non-native species. Grass mixes are recommended for specific turfgrass applications: to either maintain a year-round green or shade-sun situation, but these usually comprise one or more non-native species (e.g. rye grass *Lolium perenne* and Kentucky bluegrass *Poa pratensis*). We suggest that this principle should be tested further by examining the relative performance of native and non-native species and as selected multi-species combinations.

This study tests the following hypotheses:

- H1.** Leaf densities, of polycultures of turf grasses are greater than single native or non-native turfgrass species.
- H2.** Weed densities, in polycultures of turf grasses are less than single native or non-native turfgrass species.
- H3.** Leaf densities, of polycultures of turf grasses under high traffic conditions are greater than single native or non-native turfgrass species.

2. Materials and methods

2.1. Site description

Experimental plots were established in a former pasture in Austin, Texas (30°11'N, 97°52'W; elevation 247 m; mean annual rainfall 810 mm). Climate is subhumid, subtropical with a bimodal rainfall pattern peaking in spring (April–June) and fall (September–October). Soils are highly disturbed, remnant spoil excavated for an adjacent highway derived from clayey, mixed thermic, lithic argiustolls of the Speck series (10–50 cm deep) (USDA, 1974). In March 2007 prior to seed sowing, soil was modified with the addition of a 1.5 cm layer of composted organic matter worked into the top 14 cm of soil. Initial soil tests after compost application and seeding indicated that nitrogen was very low (less than 1 ppm), consequently two fertilizer applications were added to all experimental units during the first year of establishment: July 2007 (0.5% N-NH₃; 0.75% water insoluble nitrogen; 3.75%; 1% phosphoric acid; 1% potassium) at a rate of 35 ml m⁻² and again in August 2007 at a rate of 25 ml m⁻². Composite soil cores (2.5 cm × 7.6 cm) were taken from multiple locations in the experimental units at the end of the growing season and sent to the Soil Testing Laboratory at Texas A&M University College Station, Texas, for analysis. For the first 2 years of establishment (2007 and 2008) all plots were managed to remove grass and forb weeds, and irrigated to maintain consistent growth throughout the growing season (March through November). Irrigation amounts varied during this establishment period depending on rainfall but were as high as 2.5 cm per week during the summer months.

2.2. Experimental design

One commonly used non-native grass and several regionally native species were selected for their aesthetic similarities and turf-like growth patterns (stoloniferous and/or bunch grass), short stature and narrow leaf blades as follows:

1. *Non-native monoculture*. Regional standard, non-native turfgrass, unhulled “common bermudagrass” (*C. dactylon*).
2. *Native monoculture*. Buffalograss (*B. dactyloides*).
3. *Native low-diversity assemblage*. Two regionally native species: 66% buffalograss (*B. dactyloides*) and 34% blue grama (*B. gracilis* Willd. ex Kunth) of Pure Live Seed (PLS) by weight.
4. *High diversity assemblage*. Seven regionally native species, including 99.3% by weight PLS of the two species assemblage described above (*B. dactyloides* and *B. gracilis*) and the remaining 0.7% roughly equal parts of Texas grama (*Bouteloua rigidisetata* (Steud.) Hitchc.), curly mesquite (*Hilaria belangeri* (Steud) Nash), hairy tridens, (*Erioneuron pilosum* (Buckl.) Nash), hairy grama (*Bouteloua hirsuta* Lag.) and poverty drop seed (*Sporobolus vaginiflorus* (Torr. ex A. Gray) Alph. Wood), hand-collected earlier the same season (see Table 1 for species seed rates).

Native species in the high diversity mix were selected based both on appearance – all had similar growth forms, and featured narrow-bladed plants (Table 2), and availability – species had to be either commercially available or harvestable by hand in appropriate quantities for the study. Given the intent of this study to examine and compare general traits of all selected grasses rather than to test a specific cultivar of *C. dactylon*, even though there are many widely available for multiple turfgrass applications, the commonly commercially available non-cultivar “common bermudagrass” which is cultivated and widely sold in Texas and other southern states, for generic turfgrass applications was used for this study. Apart from *B. dactyloides* and *C. dactylon*

there are little data on the turfgrass properties of the other native species. However, available descriptive data on general physiognomic and physiological traits (Table 2) indicates the potential suitability of these species. Proportions of the species within the high diversity assemblage was largely a result of seed availability, hence the heavy bias toward *B. dactyloides* and *B. gracilis* which were commercially available. The other species were hand collected locally. Total seeding rates for all mixes were set at 6700 pure live seed m⁻², and additionally to ensure presence in the mix of the non-commercially available species of which there were limited quantities, pre-grown plugs of all species were added to all plots at the rate of 43 plugs m⁻² (Table 1).

Experimental units ($n=5$), each approximately 3.25 m², were randomly arranged within two independent watering treatment arrays, one to simulate sub-ambient monthly mean rainfall (annual total 70 cm) other to simulate greater than average rainfall (annual total 96 cm). Rainfall data was obtained from NOAA database collected at Camp Mabry in Austin, Texas (1971–2000) (<http://www.ncdc.noaa.gov/oa/ncdc.html>). As the plots were exposed to natural precipitation events, irrigation was initiated every 2 weeks to make up deficits. Actual rainfall was recorded for the site and irrigation amounts were tallied for each experimental unit.

Two mowing frequencies (monthly and twice monthly) were implemented with a gasoline-powered hand mower to a uniform height of 10 cm. Soil compaction was standardized by driving a gasoline-powered utility vehicle (EX-GO ST “work horse” with a curb weight of 590 kg) over one section of all plots at a frequency of 10 times each week for a 12-month period up to July 2009, when final turf measurements were taken. Although not measured repeatedly, this treatment resulted in an average 3 cm depression of all compacted areas. Leaf density (pin-frame interception) was measured with two 20 cm wide point frames for a total of 20 points per experimental unit.

To assess resilience to weed invasion, dandelion (*Taraxacum officinale*) seed was introduced in February 2009. All weed species, both grasses and forbs, were removed during the preceding 2 years of study. Seed viability of *T. officinale* was estimated using seedling germination of 20 seeds on wet filter paper ($n=3$). Each test plot received equivalent of 30 viable seeds (calculated by weight) each in four 100 cm² sub plots. Seeds were hand sown and raked in to maximize contact with soil surface. Seedling emergence was measured in May 2009. Mature weed canopy cover and turfgrass canopy cover were estimated using a centrally placed 1 m quadrat at the end of the spring growing season (June) when forb weeds were fully mature. One-way or two way analysis of variance and Tukey mean comparison ($P=0.05$) test were used for statistical analysis using NCSS Statistical Software, Kaysville, Utah. Data were checked for normality and transformed (arcsine transformation) as necessary.

3. Results

Concentrations of principal plant nutrients following addition of supplemental fertilizer were high and probably not limiting to growth by the end of the season (Table 3). The watering treatments resulted in the higher than average rainfall treatment receiving 12% more than the annual mean with only 1 month (May) showing a total less than the mean (Fig. 1). The below average treatment received 18% less than annual with 3 months exceeding the monthly mean (Fig. 1).

Total weed cover was significantly lower in the native compared to non-native turf plots in April and still evident in July (Figs. 2 and 3). There was no significant difference in the density of *T. officinale* seedlings between the *C. dactylon* and *B. dactyloides* and

Table 1
Sowing and plugging rates for all seed treatments.

Seed assemblage common name	Latin name	Seed rate (pure live seed m ⁻²)	Plug rate (plugs m ⁻²)
Non-native monoculture			
Bermudagrass	<i>Cynodon dactylon</i>	6700	43
Total		6700	43
Native monoculture			
Buffalograss	<i>Bouteloua dactyloides</i>	6700	43
Total		6700	43
Native low-diversity assemblage			
Buffalograss	<i>B. dactyloides</i>	464	7
Blue grama	<i>Bouteloua gracilis</i>	6236	35
Total		6700	42
High diversity assemblage			
Buffalograss	<i>B. dactyloides</i>	470	1.5
Blue grama	<i>B. gracilis</i>	6182	0.5
Hairy grama	<i>Bouteloua hirsuta</i>	10	6
Texas grama	<i>Bouteloua rigidisetata</i>	10	6
Hairy tridens	<i>Erioneuron pilosum</i>	11	9
Curly mesquite	<i>Hilaria belangeri</i>	7	9
Poverty dropseed	<i>Sporobolus vaginiflorus</i>	10	10
Total		6700	42

Table 2
General description of native grasses used in this study after Gould (1975) and Loflin and Loflin (2006).

	Form	Blade width (mm)	Culm or blade length (cm)	US range	Habitat in Texas
<i>B. dactyloides</i>	Perennial, C4 turfgrass	1–2.5	20	MN MT to NV AZ TX	Short grass and/or heavily graxed areas. Full sun
<i>B. gracilis</i>	Perennial, C4 bunchgrass	1–2.5	25–60	WI to MO and CA	Well drained rocky slopes and grassy plains
<i>B. hirsuta</i>	Perennial, C4 bunchgrass	1–2	15–40	WI IL to ND and south to LA and TX	Well drained grassy areas and openings in woodlands
<i>B. rigidisetata</i>	Perennial, C4 bunchgrass	1–2	15–40	OK and TX	Well drained grasslands, rocky areas and openings in forests
<i>E. pilosum</i>	Perennial, C4 bunchgrass	1–2	10–30	KS to NV and south to TX AZ	Open rangelands and pastures in limestone and rocky areas
<i>H. belangeri</i>	Perennial C4 turfgrass	0.5–1	10–30	TX and AZ	Rocky slopes and dry hillsides, swales, and grassy and brushy plains
<i>S. vaginiflorus</i>	Annual C4 bunchgrass	1–2	15–55	Eastern US to MN NE TX AZ	Multiple soil types especially sandy clays and limestone outcrops

B. dactyloides – *B. gracilis* turf. However, the seven species native assemblages had 63% lower weed seedling density than *C. dactylon* turf (Fig. 4).

Neither irrigation (Fig. 5) nor mowing (Fig. 6) had any significant effect on leaf density within or among species assemblages. However, *C. dactylon* canopy height attained over twice the height (over 20 cm) of the native grasses between mowing events. Generally, leaf densities of all species were highest during spring but declined gradually through the growing season (Figs. 5 and 6). Spring leaf densities were highest for the native grasses but *C. dactylon* equaled this growth by the July and November measurements (Figs. 5 and 6). Measurements of leaf density taken the follow-

Table 3
Mean (±s.e.) values for primary soil variables taken at the end of the test period. P, K, Ca, Mg, S and Na analysis by Mehlich II extraction.

Attribute	Unit	Value
pH		7.7 (±0)
Conductivity	μmho/cm	326 (±12)
Nitrate-N	ppm	42.0 (±1.2)
Phosphorus	ppm	53.7 (±2.9)
Potassium	ppm	260 (±15)
Calcium	ppm	15392 (±654)
Magnesium	ppm	452 (±11)
Sulfur	ppm	36.3 (±0.7)
Sodium	ppm	82.3 (±9.4)

ing spring (April 2010) after an unusually cold and late winter revealed that the pattern returned with the natives having on average 30% higher leaf densities ($F=6.10$; $p < 0.01$; data not shown) in the spring. Leaf densities were consistently higher following compaction across all species assemblages, but were only significant under the high frequency mowing regimen (Fig. 7).

Species composition of the turfgrass assemblages after two growing seasons showed some changes from initial (seed and plug) proportions (Fig. 8). The low diversity assemblage that started with higher proportion of *B. gracilis*, was dominated in 2009 by *B. dactyloides* in April and *B. gracilis* in November but this seasonal shift was not significant. In the high diversity assemblage, *E. pilosum* and *S. vaginiflorus* were not detectable in 2009 and *B. hirsuta* and *B. rigidisetata* remained subdominant in the assemblage (Fig. 8). The most marked change was that of *H. belangeri* which was sown at 0.1% of total seed by weight, but was over of 30% total cover by April 2009 and was effectively co-dominant with *B. dactyloides* and *B. gracilis*.

4. Discussion

4.1. Weeds suppression

The most common weeds in turfgrass in Texas are cool and warm season species of grasses (e.g. *Digitaria* sp., *Bromus* spp.)

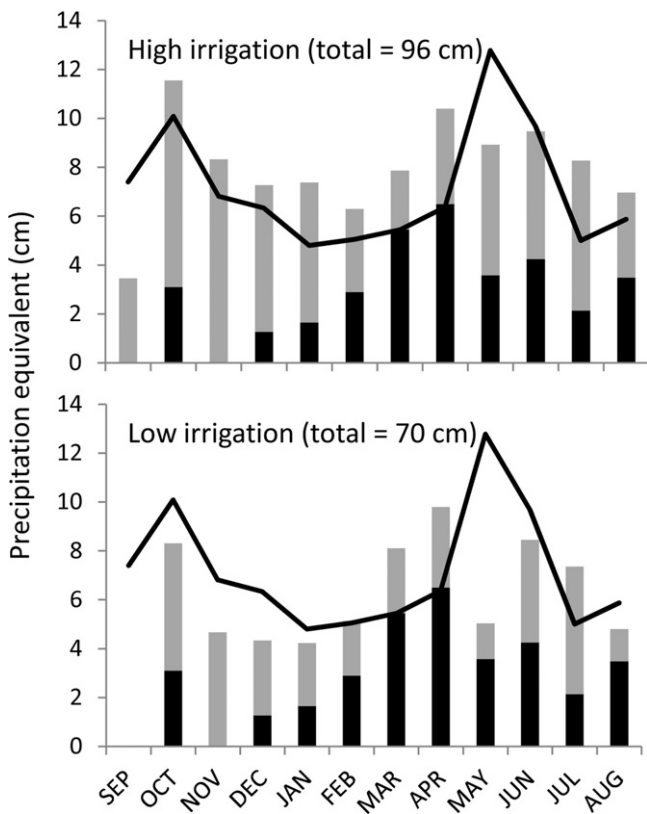


Fig. 1. Mean monthly precipitation (solid line, mean total = 86 cm), actual precipitation (black bar) and supplementary irrigation (grey bar) for above and below average irrigation treatments.

and forbs (e.g. *T. officinale*, *Dichondra* spp.) and mainly occur in the wetter, cooler months of spring and early summer. This trial demonstrated that turf leaf densities were highest in the spring for the native species but *C. dactylon* density peaked in July. If weed suppression is a function of leaf density then this would explain the greater weed resistance of the native species assemblages over *C. dactylon* in the spring. The reduction in leaf density for all species in all treatments later in the season is likely a result of warmer temperatures negatively affecting growth performance (Stanford et al., 2005), although this could have also been attributed to other mechanisms such as nutrient depletion. The general pattern of

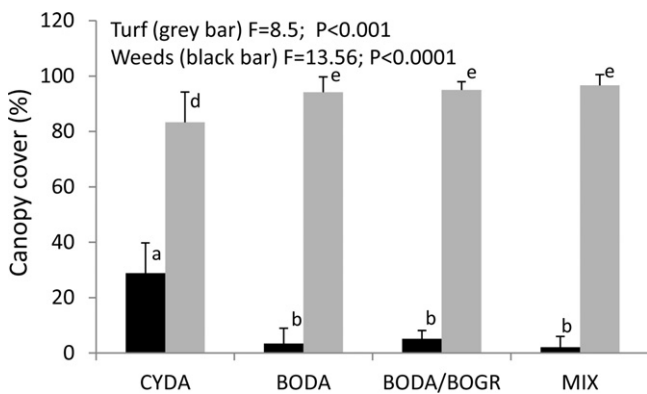


Fig. 2. The effect of seed assemblage on turf and total weed (all species) canopy cover in April 2009. Error bars represent standard deviation. Bars with different letters are statistically different Tukey test alpha = 0.05.

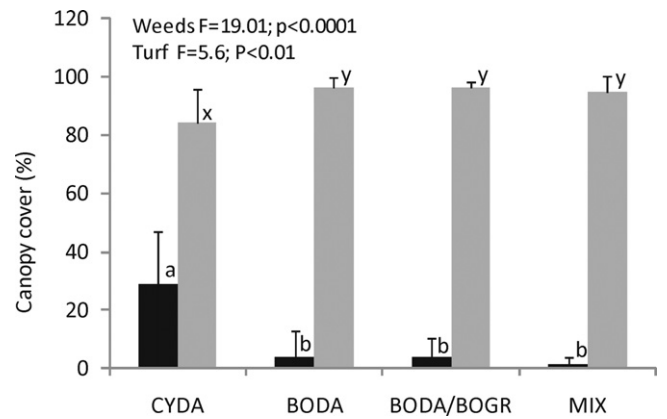


Fig. 3. The effect of seed assemblage on turf and total weed (all species) canopy cover in July 2009. Error bars represent standard deviation. Bars with different letters are statistically different Tukey test alpha = 0.05.

the negative relationship between the total cover of weed density and turfgrass leaf density and/or number of species concurs with studies elsewhere (McKernan et al., 2001; Timmons, 1950), and the return of the higher density of native species the following year suggesting this may be a predictable growth trait. The precise mechanisms of suppression of establishment of weed species were not examined here, but could be attributed to multiple ecological processes including above- and belowground competition and modification of the soil surface light environment related to increased turf canopy density.

4.2. Growth and architecture of *C. dactylon*

Johnson et al. (2000) noted that it was evident that *B. dactyloides* has a slower growth rate than many other commercially available non-native turfgrasses. *Bouteloua dactyloides* has been demonstrated to have lower evapotranspiration (Beard and Kim, 1989; Kim, 1983) and slower growth rates than *C. dactylon* (Common bermudagrass) under uniform and optimum cultural growing conditions (Beard and Kim, 1989; Kim, 1983). This finding was confirmed in this study where all the native species put on significantly less growth between mowing events than *C. dactylon* under both water regimens (Duble, 1996). Furthermore, there was significant canopy scalping of the faster growing *C. dactylon* canopy plots following mowing events, resulting in exposure of the lower, non-photosynthetic portion of the tillers. This phe-

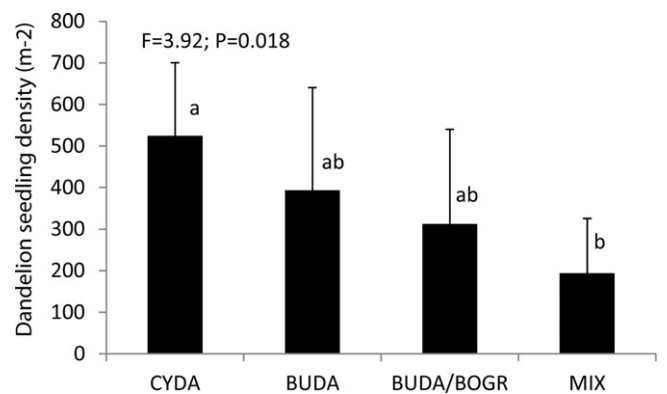


Fig. 4. The effect of seed assemblage on weed (*T. officinale*) seedling density in May. Error bars represent standard deviation. Bars with different letters are statistically different Tukey test alpha = 0.05.

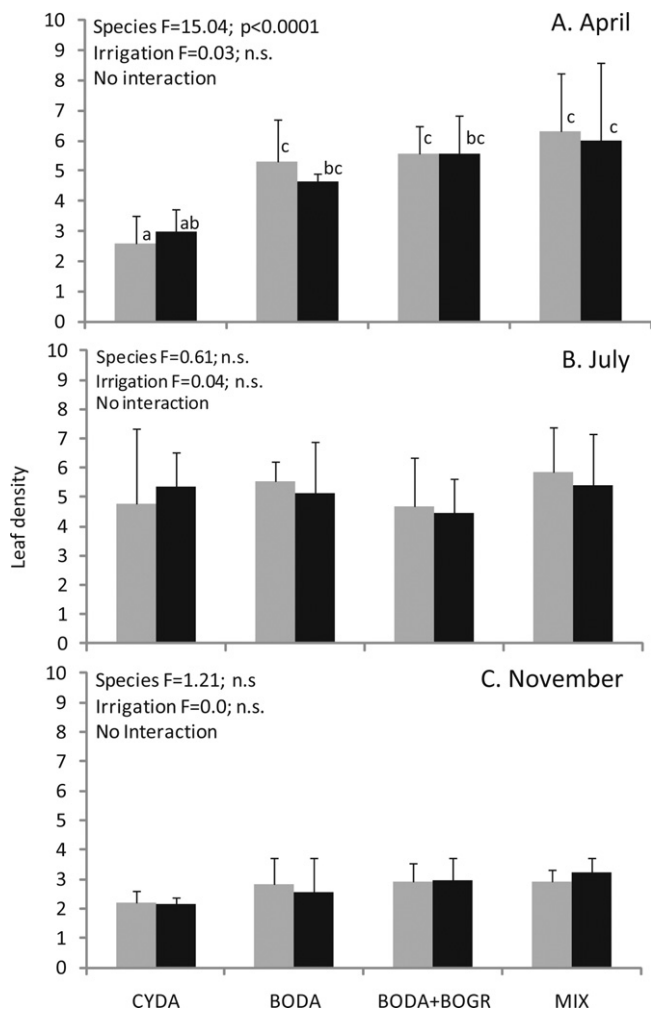


Fig. 5. Mean leaf density (leaf area index) of native and non-native monocultures in April (A), July (B) and November (C) 2009 and assemblages in under low (grey bar) and high (black bar) irrigation. Error bars represent standard deviation. Bars with different letters are statistically different, Tukey test alpha = 0.05.

nomenon is likely a result of the combination of *C. dactylon*'s unique architecture where by aerially branch stolons of *C. dactylon* result in a somewhat arborescent, branched, grass canopy (Dong and Kroon, 1994), which was removed at a mowing frequency of 2 weeks. *C. dactylon* (common bermudagrass) was selected as it is known regionally as the most commonly used turfgrass for commercial and residential applications mainly due to its visual appeal, and excellent drought and traffic resistance. This species, including its cultivars, developed for turfgrass applications, is commonly mowed at lower heights (2–8 cm) and at higher frequencies (weekly during the growing season) to increase density and maintain its performance characteristics (Duble, 1996). It is predicted that under more aggressive mowing frequency and lower height, the leaf density of this species would be higher and likely exhibit better weed suppression than demonstrated in this study, but this remains to be tested. An intensive management, particularly mowing, of this variety of *C. dactylon* would be needed to maintain a good quality turf, and this indicates that it may not be the optimal choice for some applications, particularly those designed to reduce the costs and emissions associated with mowing and other management activities and reduce the chance of on-site encroachment or regional invasion by this species.

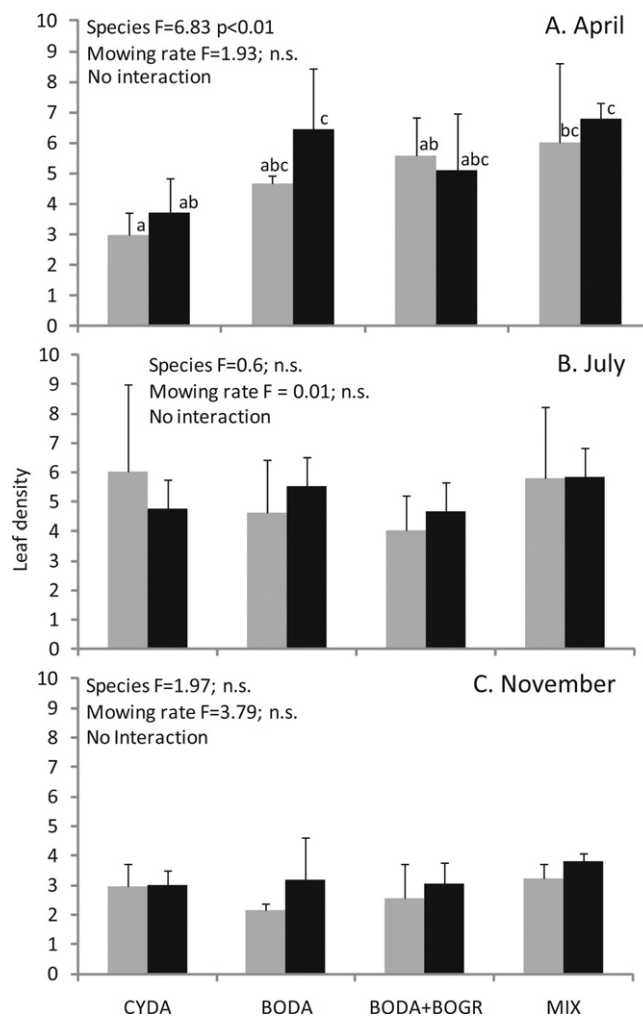


Fig. 6. Mean leaf density (leaf area index) of native and non-native monocultures and assemblages in April (A), July (B) and November (C) 2009 under low (4 weeks frequency; grey bar) and high (2 week frequency black bar) mowing rates. Error bars represent standard deviation. Bars with different letters are statistically different, Tukey test alpha = 0.05.

4.3. Resistance to traffic

The indication that all these species assemblages had similar traffic resistance may be simply a result of too low a disturbance frequency or impact pressure as well as initial soil bulk density which may have also been too low (not measured). Although most of the native species used in this trial have not been tested, other research has shown *B. dactyloides* to have low tolerance to traffic (Duble, 1996), but this clearly requires more investigation.

4.4. Turfgrass composition

All the assemblages maintained an overall homogenous appearance that is important to the aesthetic of the American lawn. This seemingly homogenous assemblage however, was maintained by several species which had similar leaf blade characteristics. Compositionally, the high diversity assemblage in this trial ended the trial period with three co-dominants (>25% each) *B. dactyloides*, *B. gracilis*, and *H. belangeri* with *B. hirsuta* and *B. rigidiseta* subdominant (<5% each). This final species composition is notable given the very low densities at which *H. belangeri*, *B. hirsuta* and *B. rigidiseta* were sown. The remaining species (*E. pilosum* and *S. vaginiflorus*) disap-

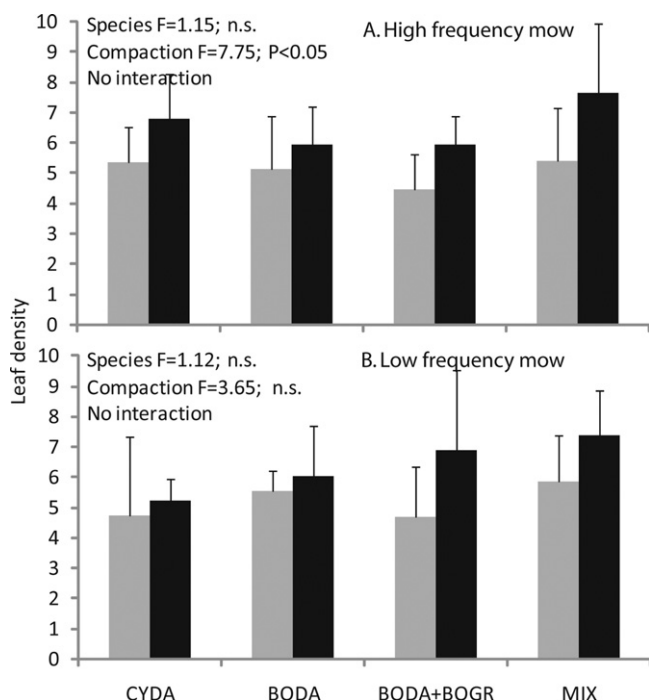


Fig. 7. Effect of soil compaction on mean leaf density (leaf area index) of native and non-native monocultures and assemblages in July 2009 under low high (every 2 weeks) frequency (A) and low (every 4 weeks) frequency mowing regimen. Grey bar represent sun compacted soil, black bar represents compacted soil. Error bars represent standard deviation.

peared from the assemblage. *E. pilosum* is usually found in disturbed sites (Gould, 1975) and although stoloniferous, may be unable to compete in more productive environments. *S. vaginiflorus* is an early-seral annual also found in highly disturbed sites and may also only emerge under increased disturbance. Although neither

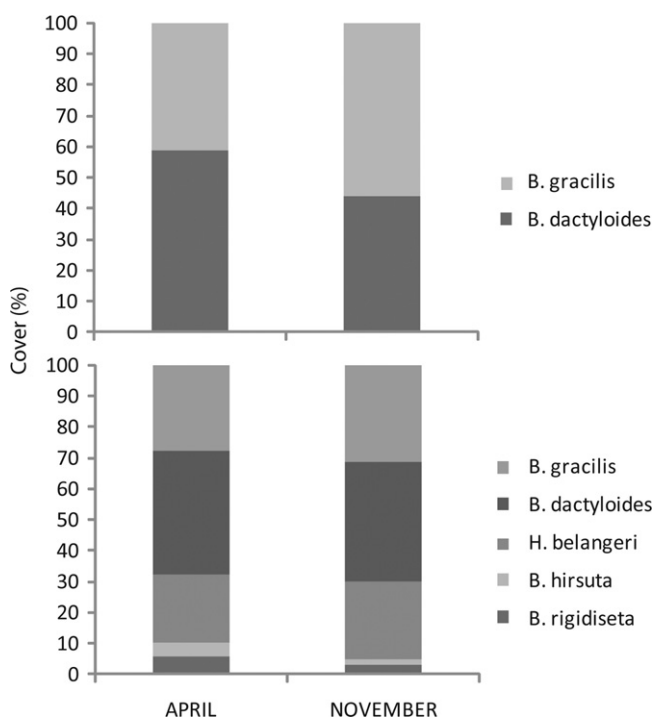


Fig. 8. Species composition in April and November 2009 of *B. gracilis* and *B. dactyloides* assemblage (upper graph) and high diversity assemblage (lower).

species formed a large component of the assemblages in this study, either of these infrequently occurring species could contribute to overall species composition in trials which focus on more stressed or rigorously disturbed conditions and may be useful in obtaining adequate coverage when lawns are being started from seed. But this remains to be tested.

4.5. The disadvantages and advantages of native turf species

Although the dominant native grasses as a monoculture or polyculture demonstrated some performance benefits and created a fine-leaved turf, there are some clear potential problems for their commercial use. Most notably is the issue of blue-green coloration of the leaves of *B. dactyloides*, *B. gracilis*, and *H. belangeri* (Duble, 1996) which may or may not be considered acceptable for some turf applications in the southern US where they might be considered substitutes for the more verdant *S. secundatum* and *C. dactylon*. The prominence of inflorescences at different times of year throughout the growing season may also present aesthetic disadvantages. While these specific appearance issues may be overcome, perhaps the greatest educational challenge if landscape sustainability is a priority, would be the acceptance of drought or cool-season dormant, brown, turf. In a non-irrigated study of native and non-native grasses in Texas (McAfee and Leps, 2001) *B. dactyloides* demonstrated higher survivability (85–98%) than *C. dactylon* (5–35%) after a 3-year study. It is possible in regions of enforced water restrictions where non-turf xeriscapes are not desirable, turfgrass species which exhibit good drought dormancy traits may become more visually acceptable. Grasses with slower growth rates and as exhibited by some native grasses and reduced resource inputs may also have dramatic effects on carbon balance. Townsend-Small and Cziczik (2010) indicated in a study of CO₂ footprint of urban turf in California that the net emission of CO₂ from turfgrass was largely due gasoline-powered maintenance equipment. Any turf characteristics that reduces operations such as mowing and water, fertilizer and pesticide application could have a significant positive impact on the carbon balance.

4.6. The ecological approach: the advantages of polyculture vs. monoculture

The ability to function under a broad range of growing conditions which might change through the year is one of the potential strengths of a multi-species turfgrass assemblage. Ecological theory suggests that there may be advantages of polyculture over a monoculture. Plant species with similar environmental demands coexist, facilitated by several mechanisms including temporal, spatial and functional niche differentiation and occasional disturbance (Wilson, 1990), and this has been demonstrated in both natural grasslands and lawns (Mason and Wilson, 2006). Events such as severe drought have been shown to cause local species extinctions in natural grasslands (Tilman and El Haddi, 1992). This suggests that a plant community comprising high species diversity with a broad range of ecological niche space is likely to be more resistant to environmental perturbations (Loreau, 1994). One obvious example of this adaptation might occur if differential preference among co-existing species for a wet or dryer growing season was seen, but might also be evidenced as tolerance for varying levels of shade, traffic, or soil variation. Studies of complex natural grassland and lawn systems have shown that species composition is dynamic and can change over the short term (within a growing season) due to hierarchies of competitive abilities among species responding to resource availability and disturbance (Collins, 2000; Fowler, 1982; Roxburgh and Wilson, 2000). Alternatively, short-term fluctuations in species abundances may average in the long term,

forming a loose equilibrium (Whittaker and Levin, 1977). Theory also predicts that the stability of polycultures may be due to the negative relationship between diversity and invasibility (Tilman, 1997). However, some empirical studies have shown that in natural diverse plant communities with heterogeneous environments (Levine and D'Antonio, 1999), or high dominance (Smith et al., 2004) may be actually be more invasible. Overall, contemporary ecological theory argues that more diverse plant communities may exhibit advantageous characteristics compared to a monoculture. This would have desirable benefits for many turfgrass applications including:

1. More efficient use of resources (Loreau, 2000): the array of species' ecological niches increases nutrient and water uptake and retention which could mean not only lower inputs but decreased waste such as nutrient leaching.
2. Greater plant community stability: more resistance and resilience to seasonal climatic fluctuation and disturbance (Loreau, 2000): stochastic climatic events such as drought are less likely to have a chronic effect on the plant community.
3. More resistance to weed invasion (Tilman, 1997) but see (Smith et al., 2004) and (Levine and D'Antonio, 1999) for review: reduced herbicide application.
4. More resistance to pathogens (Elton, 1958): reduce pesticide application.

Additionally, if biological diversity is linked to multiple ecological functions and ecosystem services (Diaz and Cabido, 2001; Loreau, 2000), then there may be advantages in increasing turfgrass diversity to improve biological traits associated with sustainability and specific ecosystem services, such as:

1. Efficient exploitation of resources above and below ground (Grime, 1977; Spehn et al., 2000; Tilman, 1982).
2. Increased below-ground carbon sequestration (Tilman et al., 2006b).
3. Increased absorption of atmospheric pollution (Spehn et al., 2000).

5. Conclusion

The concept of the evenly-green, close-cropped, landscaped lawn is a highly desirable and entrenched part of the modern constructed landscape, but its design origins are from the native temperate grasslands of Europe. There, intense grazing pressure from livestock and other herbivores created an herbaceous layer comprising low growth-form, but highly diverse, grasses and forbs. Such a complex of plant species features an assortment of life histories which occupy a range of ecological niches. As such, this represented an ecologically stable climax plant community whose overall physiognomy resulted in plant assemblages not only adapted to soil and climate, but also capable of tolerating different biological (weeds) and physical (foot traffic) disturbance as well as year-to-year climatic fluctuations. More recently, however, the horticultural adaptation of this landscape has focused on the development of single species for specific, high-demanding applications, and in the process desirable, more environmentally sustainable attributes of this landscape type may have been lost.

Further study and development of the native species examined in this research and other species appropriate for regions around the country is clearly needed. Nonetheless, polycultures of grasses and particularly native plant species and communities represent a relative untapped resource for constructed landscape applications. In Texas alone there is a vascular flora of approxi-

mately 5000 species, but presently less than 200 are commercially available. As we have noted elsewhere (Simmons et al., 2007), there is a significant opportunity to use native plants to resolve design challenges. Also, we suggest that an ecological approach for the selection of appropriate plant species for the urban environment may have advantages over a more horticultural approach, particularly when resource conservation and the provisioning of ecosystem services are an issue of concern. Examination of regional genotypes of native species, regional natural grassland plant communities and the ecological mechanisms that maintain them may help to optimize function of turfgrass landscapes and simultaneously minimize environmental impact.

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