The Establishment Success of Native Versus Non-Native Herbaceous Seed Mixes on a Revegetated Roadside in Central Texas

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Abstract: Revegetation is an essential component of roadside and building site construction and improvement. In the southern United States non-native grass species are frequently included in revegetation seed mixes used by highway authorities. Non-native species are frequently selected for aggressive growth characteristics, however these same traits also render them potentially invasive, and subsequently hazardous to, adjacent plant communities. Although the use of pure native seed mixes have been rejected in the past due to perceived inferior establishment characteristics, there have been few comparative quantitative field studies that justify this belief. The establishment characteristics of three seed mixes: one containing non-native species and two with native grass and forb species only, were compared in a randomized-block design along a Texas roadside following spring and summer sowing. After 60 days following the spring sowing, the two native-only seed mixes demonstrated 180% and 560% ($F=10.18$; $P<0.0001$) higher seed densities than the recommended native/non-native mix. The summer sowing results were similar with seedling densities 180% and 330% ($F=9.20$; $P<0.01$) greater than the standard non-native seeding. Although an aggressive colonizer from vegetative tissue such as stolons and rhizomes, the non-native Bermudagrass (Cynodon dactylon) has a lower than expected establishment rate thought to be due to high water demand during the first weeks following sowing. Given the invasive characteristics of this common component of many recommended revegetation seed mixes, these results call into question the widespread recommended use of Bermudagrass for such projects. These data indicate that examination of suites of early- and late-succesional native species can provide a highly effective mix for revegetation projects. Furthermore, this reduces the potential for negative ecological consequences and provides added benefits associated with wholly native plant communities.

Introduction

Revegetation is an essential component of roadside and building site construction and improvement. Successful revegetation requires species that have rapid establishment and growth and minimal input of resources such as water, fertilizer, and pesticides. The final result should be a manageable vegetative cover that fulfils the regional roadside authority's specifications with regard to safety, erosion control, and maintenance. In much of the southern United States non-native grasses such as Bermudagrass (Cynodon dactylon), St. Augustine, (Stenotaphrum secundatum), and Oldworld bluestem (Bothriochloa ischaemum) are frequently included in seed mixes due to their establishment characteristics, low seed cost, and availability (Texas Department of Transport, 1993; Jenkins et al., 2004; Texas Department of Transport, 2004a). Regrettably, these species often spread from their initial locations and become locally or regionally invasive (Jenkins et al., 2004; Diggs et al., 1999), contributing to the 40 million ha. (99 million acres) of already invaded land area in the United States (Babbitt, 1998). This has prompted a call for the decreased use of non-native plants and the subsequent replacement and increased use of native plants in landscaping and revegetation projects. Roadside rights-of-way account for more than 4.9 million hectares (12 million acres) of land in the United States. This land could potentially provide habitat for many native plants and animals (Federal Highway Administration, 1999). Unfortunately, this widespread transportation network often acts as a vector for the spread of ecologically harmful invasive species.

In accordance with this scenario, the Federal Highway Administration issued an Executive Memorandum (November 11, 1995), outlining guidance for landscaping practices on federal lands following the April 1994 Presidential Executive Memorandum on Environmentally Beneficial Landscaping signed into law by President Clinton on April 26, 1994. This included two principles:

1. Use regionally-native plants for landscaping.
2. Design, use or promote construction practices that minimize adverse effects on natural habitat.

Aside from problems associated with non-native plants becoming invasive, the use of native species can also claim other advantages: Regional adaptation can equate to a lower requirement of resources (water and nutrients).They can provide and reinforce habitat for native plants and animals.Many native species provide spectacular seasonal color displays.Native species provide regional character and identity.

Although several studies have examined establishment characteristics of selected native species (see Bugg et al., 1997 and Jenkins et al., 2004 for review), few compare the establishment characteristics of native versus non-native species. The Texas Department of Transportation (TxDOT) sows more than 13,600 kg (30,000 lb) of native wildflower seed annually, covering over 7,000 ha (17,000 acre) across the state as part of its vegetative management program for 484,000 km (300,000 miles) of state roads and highways (Texas Department of Transport 2004b). Most utilized species are native: green sprangletop (*Leptochloa dubia*); sideoats grama (*Bouteloua curtipendula*); sand lovegrass (*Eragrostis trichodes*); Illinois bundleflower (*Desmanthus illinoensis*); lance-leaf coreopsis (*Coreopsis lanceolata*); and over recent years many non-native species have been removed from recommended seed lists. However, several non-natives including the invasive Bermudagrass and bahiagrass (*Paspalum notatum*) persist in the recommended seed lists. Although there are accepted invasive problems associated with using such non-native grasses, there is no evidence to refute the widely held belief that native species are not as effective at rapid revegetation. Because the

Storm Water Pollution Prevention Plan (SW3P) (40 CFR, Part 122 and Federal Register/Vol. 63, No. 128) requires that adequate stabilization measures (e.g. permanent vegetation) be in place within 21 days after construction activity at a site ceases. Most construction contractors err on the side of caution in using mixes that include species with which they have a greater level of familiarity. This reliance by managers on familiar species however, favors heavy use of non-native species. Existing species recommendations typically include non-native species that have been extensively used historically and therefore have known establishment characteristics. Most of the native species that have been available commercially historically are those that are long-lived perennial species that have value as forage grasses. These late-successional species are often slow to establish, particularly under harsh conditions, and are indeed poor choices for rapid revegetation. In recent years, the commercial seed industry has expanded beyond the agricultural forage production, and has begun to make early-successional species available on the market. We believed that a seed mix that combined both early- and late- successional species would both provide rapid revegetation, and permanent vegetative cover for the long-term.

Therefore the goal of this study was to answer the following questions

1. Is there a significant difference in and rate of coverage after 60 days between existing recommended TxDOT seed mix which contains both native and non-native species, and alternative purely native seed mixes?
2. Is there a single native seed mix that could be used both in spring and summer?

Methods

Site and Experimental Design

A randomized block design (n=6) was established along a one-mile stretch of a rural highway in southern Travis County, Texas (30º 11'N, 97º 52'W; elevation 247 m; mean annual rainfall 810mm). Climate is subhumid, subtropical with a bimodal rainfall pattern peaking in spring and fall. Soils are Speck stony clay loam (USDA, 1974) with a 10% to 30% southeast-facing slope. Three other blocks were located on an adjacent property approximately 500 m away from the highway, giving a total of 9 replicated blocks. Individual experimental units within each block measured 3 m x 3 m with a 1 m buffer around the perimeter. The buffer was created by herbiciding existing vegetation and scraping away as much vegetative debris and roots as possible. Herbicide was reapplied during the course of the study if the integrity of the experimental unit was threatened by outside invasion.

Seed Mix Calculations

The establishment successes of the following three seed mixes were compared:

1. *TxDOT mix:* contains recommended native and non-native seed stipulated by Item 64 –Seeding for Erosion Control; TxDOT Specification Manual (1993/Rev. 2001) (table 1). According to TxDOT recommendations, this seed mix can only be sown in the spring due to a belief that it would have poor success in any other season. For summer sowing these specifications recommend the sowing of foxtail millet (*Setaria italica*) as temporary coverage. Temporary coverage is then to be replaced by the following spring season with the perennial TxDOT seed mix.
2. *Commercial mix:* A mix selected by the authors consisting of commercially available native seed (table 2).
3. Non-commercial mix: a mix of native seed selected by the authors containing commercial and non-commercially available seed (table 3).

Table 1: Reference seed PLS and density for TxDOT spring seed mix

Common	Species	kg PLS ha^{-1}	seeds $gram^{-1}$	PLS m^{-2}
Sideoats grama	*Bouteloua curtipendula*	2.0	318	64
Buffalograss	*Buchloe dactyloides*	6.0	60	32
Bermudagrass	*Cynodon dactylon*	1.3	4400	592
Green sprangletop	*Leptochloa dubia*	0.7	1196	75
Indiangrass	*Sorghastrum nutans*	1.7	378	64
			TOTAL	827

Table 2: Commercially available perennial native seed mix (spring and summer sowing)

Common	Species	Germination rate (%)	Total seed m^{-2}	Seeds $gram^{-1}$	Seed grams/site	PLS m^{-2}
Purple threeawn	*Aristida purpurea*	93.95	57	300	1.7	54
Sideoats grama	*Bouteloua curtipendula*	72.71	103	318	2.9	75
Silver bluestem	*Bothriochloa laguroides*	50	474	930	4.6	237
Buffalograss	*Buchloe dactyloides*	92.67	58	60	8.7	54
Canadian wildrye	*Elymus canadensis*	90.63	60	205	2.6	54
Engleman's daisy	*Engelmannia pinnatifida*	100	21	105	1.8	21
Green sprangletop	*Leptochloa dubia*	92.7	116	1196	0.9	108
Mexican hat	*Ratibida columnifera*	100	43	950	0.4	43
Little bluestem	*Schizachyrium scoparium*	65.62	114	567	1.8	75
Indiangrass	*Sorghastrum nutans*	60.09	125	378	3.0	75
					TOTAL	796

Table 3: Non-commercially available native seed mix (spring and summer sowing)

Common	Species	Germina-tion rate (%)	Total seed m^{-2}	Seeds $gram^{-1}$	Grams Seed /site	PLS m^{-2}
Purple threeawn	*Aristida purpurea*	93.95	22	300	0.7	21
Sideoats grama	*Bouteloua curtipendula*	72.71	74	318	2.1	54
Hairy grama	*Bouteloua hirsute*	14	228	1666†	1.2	32
Silver bluestem	*Bothriochloa laguroides*	50	64	930	0.6	32
Texas grama	*Bouteloua rigidiseta*	56	384	161	21	215
Buffalograss	*Buchloe dactyloides*	92.67	46	60	7.0	43
Canadian wildrye	*Elymus canadensis*	90.63	23	205	1.0	21
Englemann's daisy	*Engelmannia pinnatifida*	100	21	105	1.8	21
Hairy tridens	*Erioneuron pilosum*	26	165	500†	3.0	43
Indian blanket	*Gaillardia pulchella*	100	21	277	0.7	21
Curly mesquite	*Hilaria belangeri*	5	860	645†	12	43
Standing cypress	*Ipomopsis rubra*	100	21	500	0.4	21
Fall witchgrass	*Digitaria cognatum*	50	128	1400	0.8	64
Green sprangletop	*Leptochloa dubia*	92.7	58	1196	0.4	54
Horsemint	*Monarda citriodora*	100	21	2200	0.08	21
Texas wintergrass	*Nassella leucotricha*	18	178	190*	8.4	32
Hall panicum	*Panicum hallii*	25	44	1000	0.4	11
Mexican hat	*Ratibida columnifera*	100	21	950	0.2	21
Blackeye Susan	*Rudbeckia hirta*	100	21	3500	0.05	21
Little bluestem	*Schizachyrium scoparium*	65.62	49	567	0.8	32
Indiangrass	*Sorghastrum nutans*	60.09	53	378	1.3	32
					Total	855

*Based on number of seeds per gram after treatment with sulfuric acid.
†Seed heads

For the two native seed mixes, species were selected not only based on their potential for rapid establishment (i.e. early successional), but also for longer-term stability. The germination characteristics of many of the locally harvested species were largely unknown, but considered worthy candidates.

Seed viability

To fairly test species performance, seeding densities were also corrected for viability. Tetrazolium chloride was used to check for respiratory activity of seed embryos indicating viability (Association of Official Seed Analysts, 1970). Three replicates of approximately 25 random seeds for each hand-collected species were treated. This number is less than the AOSA recommendation, but the supply of seeds from which these samples were drawn was limited. Species tested were hairy grama (*Bouteloua hirsute*), Texas grama (*Bouteloua. rigidiseta*), hairy tridens (*Erioneuron pilosum*), curly mesquite (*Hilaria belangeri*), fall witchgrass (*Digitaria cognatum*), Texas wintergrass (*Nassella leucotricha*), and Hall panicum (*Panicum hallii*).

Each seed was cut to expose the embryo. The seed was placed cut side down in a thin layer of 0.1% tetrazolium chloride solution in a petri dish. All dishes were covered and placed in the dark for at least 2 hours. The seeds were removed and examined for the presence of a red color indicative of viability. Average viability rate was calculated between the three replicates for each species.

Table 4: Seed viability based on Tetrazolium test, for hand-collected species included in non commercial seed mix

Common	Species	Viability
Hairy grama	*Bouteloua hirsute*	60%
Texas grama	*Bouteloua rigidiseta*	56%
Hairy tridens	*Erioneuron pilosum*	50%
Curly mesquite	*Hilaria belangeri*	40%
Fall witchgrass	*Digitaria cognatum*	50%
Texas wintergrass	*Nassella leucotricha*	18%
Hall panicum	*Panicum hallii*	25%.

Percent viability does not necessarily reflect germination percentage (Association of Official Seed Analysts, 1970). Testing for actual germination of these species gave excessively low germination rates. Using those rates in Pure Live Seed (PLS: purity x germination) calculations would have created unrealistically high numbers of seeds needed in the non-commercial mix. For the purposes of this study, we adopted the more conservative approach and the viability percentage was used in the PLS calculation.

Additional procedures were implemented to improve germination rate for both Texas wintergrass and curly mesquite. Research indicates that neither of these species germinates successfully by seeding only (Van Auken, 1997; Cory, 1948). For Texas wintergrass, the awn of each seed was broken off and all the seeds were scarified with concentrated sulfuric acid (White and Van Auken, 1996). Curly mesquite spiklets were soaked in 0.7 mM of gibberellic acid (Ralowicz et al., 1992) for five minutes and dried for 24 hours before planting.

To create a comparable mix of different species based on the number of PLS a reference density (PLS m^{-2}) was computed by determining the number of seeds per gram of each species based on TxDOT specifications. The range of these stipulated densities varied from 753 to 1076 PLS m^{-2}. Therefore, a density of 827 germinating seeds m^{-2} was used to provide a reference PLS density to calculate equivalent densities for the seed mix comparisons. The final species mixes varied only slightly in terms of calculated PLS density compared to the TxDOT mix (+/- 30 seeds m^{-2}). The TxDOT mix contained 5 species with 827 PLS m^2, the commercially available mix contained 10 species with 796 PLS m^{-2} and the non-commercial blend contained 20 species with 855 PLS m^{-2} (tables 1, 2, & 3). Seed mixes were based on germination rating given on purchased seeds and on results of viability testing (table 4) conducted on the hand-collected species.

Planting

Seeds were sown by hand-broadcasting into experimental units. The seed mixes were integrated with damp sand before being broadcast in order to add weight and better adherence to the soil. For the spring sowing, the TxDOT mix and the commercial mix were sown on April 7, 2004; the non-commercial mix was sown April 8, 2004. For the summer sowing, all mixes were sown on August 6 and August 7. Each site was raked, the seeds were spread by hand, and the site was lightly raked again. The back of a cultivator hoe was used to press seeds into the soil.

Watering

The spring planting was immediately followed by 2 significant rain events. The sites received 1.62 cm rain on April 10 followed by 2.42 cm on April 11. Total equivalent water received by each plot was 7.09 cm, 5.81 cm, and 31.85 cm, for April, May, and June, respectively. Summer sowing received 0.20 cm of water immediately upon planting. All blocks received 0.41cm water at least once a week, either in the form of rain or from a sprayer. Total water received by each summer plot was 6.07 cm, 5.38 cm, and 13.63 cm for August, September, and October respectively.

Climate

The 2003 spring growing season provided typical temperatures and precipitation for the central Texas region. The months of April and May had a range of temperatures from 6.1°C to 32.2°C averaging 21.5°C. Rainfall totals for this area during these two months were 93.98 mm and 45.72 mm respectively.

Summer climate was atypical for the area. June experienced an exceptionally high amount of precipitation of approximately 317.25 mm. Temperatures in June ranged from 33.2°C to 11.8°C with an average of 24.8°C. July and August had relatively mild temperatures for the summer season with a range from 37.3°C to 18.2°C with an average of 27.5°C. July precipitation totaled 26.16 mm. and August totaled 34.8 mm. September temperature averaged 25.7°C, and the amount of precipitation was 29.5 mm. October was another record setting month for precipitation with a total of 153.03 mm. Temperatures were within the range of 32.1°C and 11.4°C with the average temperature of 23.3°C.

Surveying

All germinated seed within each experimental unit were counted at 21, 30 and 60-day intervals. Clearly identifiable resprouting tillers of weed species not killed by the herbicide application were ignored. Seedling counts were conducted in two groups: those that could be positively identified as species planted, and unidentified species (possibly volunteers). For 21- and 30-day counts both groups of seedlings were included in the count. However, by 60 days positive identification was possible. Due to increased seedling densities by the 60-day survey date, total counts were estimated from 2 subsamples (2 x 1m^2 quadrats) arranged randomly in each experimental unit.

Data Analysis

Seedling density data were analyzed using repeated-measures ANOVA with treatment as main factor, and the 60-day count of positively identified species was analyzed with one-way ANOVA. Tukey MSD test was used throughout ($P \leq 0.05$).

Plant species nomenclature follows (Kartesz, 1999).

Results

Seedling Establishment - Spring Sowing

Total (identified and unidentified) seedling counts after 14 days revealed no difference between treatments. However, after 30 days, the non-commercial mix had significantly higher total seedling density than the TxDOT, and by 60 days the commercial mix and non-commercial mix densities were respectively 180% and 560% higher than the TxDOT mix ($F=20.18$; $P<0.001$; fig. 1), with a significant seed mix x time interaction ($F=15.38$; $P<0.001$) indicting the increase of the magnitude of the seed mix density effect over the monitoring period. Total identified seedling density revealed a similar pattern with non-commercial mix significantly greater (490%) than TxDOT mix (fig. 2). Sideoats grama, buffalograss/curly mesquite constituted the bulk of the seedlings across all seed mixes. Non-commercial mix also had significant contributions (>5% composition) from hairy tridens (12%), Texas wintergrass (9%), and Indian blanket/Englemann's daisy (7%) (table 5) and this pattern similarly reflected in relative establishment success (table 6).

Seedling Establishment - Summer Sowing

Both the commercial and non-commercial seed mixes out-performed the TxDOT seed mix at 14 and 21 days, and at the end of 60 days exhibited seedling densities of 180% and 330% greater than the TxDOT seed mix ($F=9.20$; $P<0.01$, fig 1). Examination of 60-day spring-sown species composition expressed as proportion of total identifiable seedlings, showed that all but one species (Indian grass) exhibited some measurable germination. Purple three-awn, sideoats/hairy/Texas grama, buffalograss/curly mesquite, and green sprangletop contributed most to all mixes, with the addition of Texas wintergrass and hairy tridens in the non-commercial mix, and significant contributions from Bermudagrass in the TxDOT mix (table 5). This was reflected in the relative germination success, although the few forbs on average performed better than grasses overall (table 6). For the summer sowing, purple three-awn, sideoats/hairy/Texas grama, buffalograss/curly mesquite, hairy tridens, green sprangletop and hall panicum had the greatest germination success and dominated the composition of the two native seed mixes (table 6). Sideoats/hairy/Texas grama, Indian grass, and green sprangletop showed increased germination success compared to spring sowing. Foxtail millet, the only species in the TXDOT summer mix had relatively low germination success (table 6).

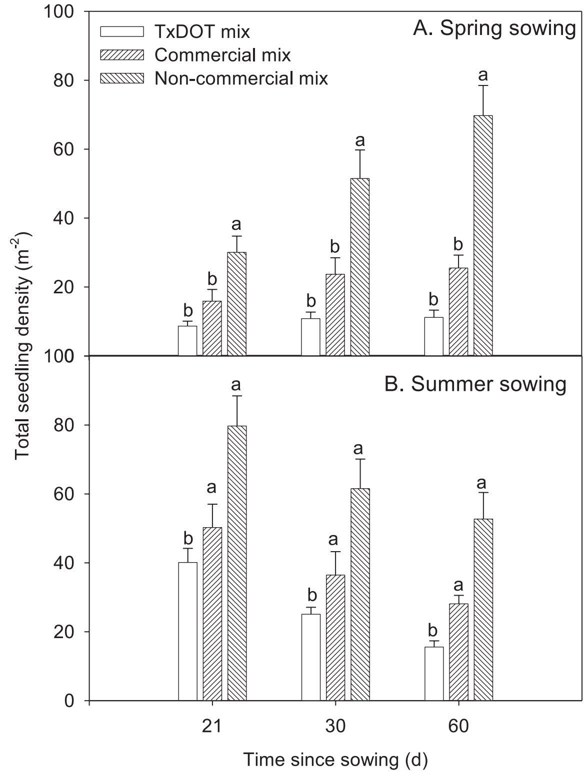

Figure 1: The effect of seed mix on identified and unidentified mean seedling density after 21, 30, and 60 days following sowing in spring and summer. Error bars represent 1 S.E. Bars with different letter are significantly different at P<0.05 level.

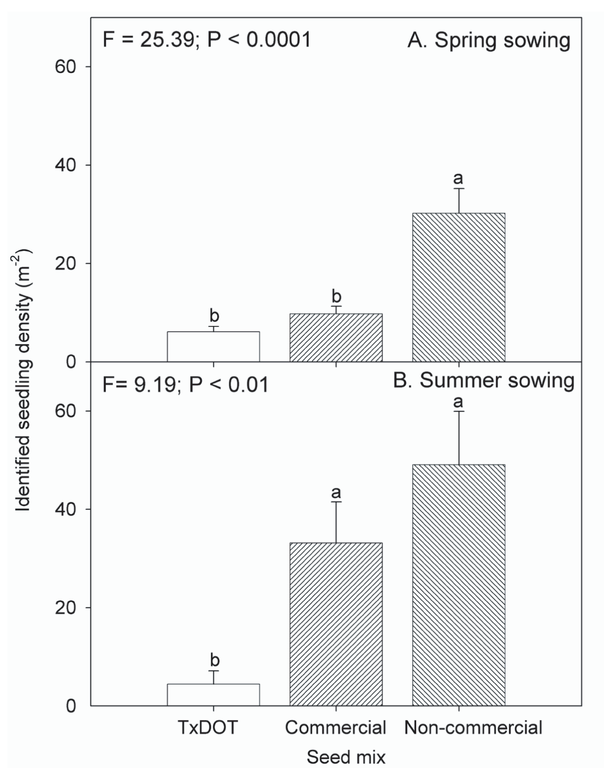

Figure 2: The effect of seed mix on identified mean seedling density at 60 days after sowing in spring and summer. Error bars represent 1 S.E. Bars with different letter are significantly different at P<0.05 level.

Table 5: Proportional (%) species composition of the 60-day plant density for spring and summer sowing. Species are combined where they were indistinguishable at the seedling stage. <1 = 0-1 % total. 0 = sown but not present

	Spring sowing			Summer sowing		
SPECIES	**Commer-cial**	**Non-commer-cial**	**TxDOT**	**Commer-cial**	**Non-commer-cial**	**TxDOT**
Aristida purpurea	12	3		40	13	
Bouteloua curtipendula	19	20	14	23	17	
Bouteloua hirsute/Bouteloua rigidiseta		4			6	
Bothriochloa laguroides	6	<1		1	0	
Buchloe dactyloides/Hilaria belangeri	35	31	47	14	9	
Cynodon dactylon			34			
Elymus canadensis	1			0	0	
Engelmannia pinnatifida/Gaillardia pulchella		7		0	<1	
Erioneuron pilosum		12			19	
Ipomopsis rubra		4			1	
Digitaria cognatum		<1			4	
Leptochloa dubia	15	3	5	20	10	
Monarda citriodora		3			0	
Nassella leucotricha		9			1	
Panicum hallii		0			18	
Ratibida columnifera	6	1		0	0	
Rudbeckia hirta		1			<1	
Schizachyrium scoparium	6	2	0	0	0	0
Setaria italica						100
Sorghastrum nutans	0	0	0	2	1	

Table 6: Relative (to initial sowing density) establishment success (%) of species by 60-day plant density spring and summer sowing. Species are combined where indistinguishable at the seedling stage. 0 = 100% mortality, blank cell = species not sown

	Spring sowing			Summer sowing		
SPECIES	**Commer-cial**	**Non-commer-cial**	**TxDOT**	**Commer-cial**	**Non-commer-cial**	**TxDOT**
Aristida purpurea	2.0	4.0		24.8	30.5	
Bouteloua curtipendula/Bouteloua hirsute/ Bouteloua rigidiseta	2.4	2.4	1.2	10.2	3.7	
Bothriochloa laguroides	0.2	0.3		0.1	0.0	
Buchloe dactyloides/Hilaria belangeri	6.4	10.9	9.0	8.6	4.4	
Cynodon dactylon			0.4			
Elymus canadensis	0.1	0.0		0.0	0.0	
Engelmannia pinnatifida/Gaillardia pulchella	0.0	4.8		0.0	0.3	
Erioneuron pilosum		8.5			22.0	
Ipomopsis rubra		5.0			1.7	
Digitaria cognatum		0.2			3.2	
Leptochloa dubia	1.4	1.4	0.4	6.1	9.4	
Monarda citriodora		3.5			0.0	
Nassella leucotricha		8.3			2.0	
Panicum hallii		0.0			27.4	
Ratibida columnifera	1.3	1.3		0.0	0.0	
Rudbeckia hirta		1.0			0.7	
Schizachyrium scoparium	0.7	1.7	0.0	0.0	0.0	
Setaria italica						0.3
Sorghastrum nutans	0.0	0.0	0.0	0.8	1.1	

Discussion

This study demonstrates that following spring and summer sowing, several native species are particularly well-suited to bare-ground revegetation and can perform as well if not better than the non-native species examined in this study. The poor performance of Bermudagrass, normally associated with good revegetation characteristics, raises questions about the justification of the widespread application of this species in landscape projects in this region.

Although normal for the region, the study conditions are not representative of other areas where this species is used, and relative performance may differ across regions. Also, the unusually heavy rains two days after planting could have resulted in seed 'wash-out,' or alternatively supplemental watering, which was the same for all treatments, may not have occurred at a critical time for Bermudagrass. Many varieties of Bermudagrass are sterile hybrids and therefore not sown from seed. More commonly, this species is propagated vegetatively from rhizomes, stolons or mature stems (Stichler and Bade, 2003). In the southern United States, most seed suppliers recommend that for successful establishment Bermudagrass seedbeds should be kept moist for approximately 2 – 3 weeks. Studies both in US (Landphair et al., 2004) and elsewhere (Andrés and Jorba, 2000; Holmes, 2001) have demonstrated poor establishment of Bermudagrass from seed, and these studies suggest that although mature plants demonstrate a high degree of drought tolerance, and regenerate readily from vegetative tissue, the germination performance of this widely used grass may be overestimated in less mesic environments. The poor germination performance of Bermudagrass may also have been due to the method of planting. In this study, seeds were simply hand-sown, raked, and compacted, due to the small areas to be planted. Actual revegetation projects are much larger and seeds are combined in a hydromulch and sprayed onto the sites. This technique not only supplies immediate moisture but also helps to anchor seeds as well as provide nutrients. However, if this poor performance of a non-native is based on planting technique, this still supports the hypothesis that natives are more effective and are less expensive in the long term. If extra care must be taken in order to ensure a non-native seed's ability to anchor and germinate, then planting technique may lead to extra expense.

Foxtail millet, used for the TxDOT summer seed mix, also demonstrated relatively poor performance. Species in the tropical genus *Setaria* are warm-season annuals and perennials that demonstrate good tolerance to higher temperatures. However, moist, well-drained soil conditions during the first two weeks of growth, when the species is least competitive, are critical for the successful establish of foxtail millet, (Baltensperger, 1996). Although this species has low water requirements relative to many cereal crops, it is still prone to poor recovery following drought due to a shallow root system (Creamer, 1999). These characteristics suggest that foxtail millet may have higher water requirements in the early stages of growth than many of the native species used in this study.

One further error may be dependent on the viability tests that were intended to ensure that live, viable seed numbers were comparable across treatments. Because of low viability readings, the non-commercial mix contained approximately 3 times the seed density. This difference in bulk of the non-commercial mix may have prevented seed 'wash-out' that the TxDOT mix may have experienced.

The results from the 60-day studies raise further questions concerning roadside vegetation species selection. Some species did as well as expected (e.g. sideoats grama, buffalo grass, and green sprangletop) which justifies their presence in the existing recommended TxDOT mix. Other native species that had acceptable establishment rates warrant further investigation, particularly Texas wintergrass, purple three-awn, Indian blanket, and hairy and Texas grama. While some of these species are not currently in commercial production, many of their congeners are, suggesting that they could be effectively produced in the industry.

Although germination was lower than expected on the research plots, there were significant amounts of regrowth, particularly of Bermudagrass, due to vegetative (stolons/rhizomes) from within the plots and from the plot perimeter. As much as possible, regrowth was not considered in the final count. For regrowth of species that were included in the seed mix, notes were made during the 14 and 21-day surveys. If growth of a planted species was seen and it was evident it did not come from the planted seed, then that sprout was not considered. This established an approximate percentage of that species that should be deducted from the later surveys. Bermudagrass was the only regrowth that could have possibly skewed the later results. However, since there was low germination rate of planted Bermuda grass seed, deduction was made only for regrowth coming in from outside the perimeters of the TxDOT research plots.

These data represent results from two seasons only and focus on germination. Data from fall, and winter studies may reveal other germination responses of the same species under different regeneration conditions. In addition, data gathered over several growing seasons may reveal differences in maintenance of diversity, endurance, and resistance to invasion among seed mixes.

Conclusions

Given the desire to reduce the use of non-natives, this study indicates that some native species may be more than adequately suited for roadside revegetation projects. This finding needs to be tested during other seasons, and in regions. Further study is required to obtain information regarding species-specific germination and commercial production potential for those species that are currently unavailable. Given the invasive characteristics of Bermudagrass, these results call into question the widespread recommended use of this species for revegetation projects. Native species can provide adequate establishment performance without potentially undesirable consequences, with the added benefits associated with wholly native plant communities. These data indicate that examination of suites of early- and late-succesional native species can provide a highly effective mix for revegetation as well as restoration. Too frequently where non-natives are being utilized out of convenience (availability and cost) there are negative ecological consequences. The argument that there are no native alternatives may be an erroneous assumption. However identification of suitable alternative native species will require regional examination.

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