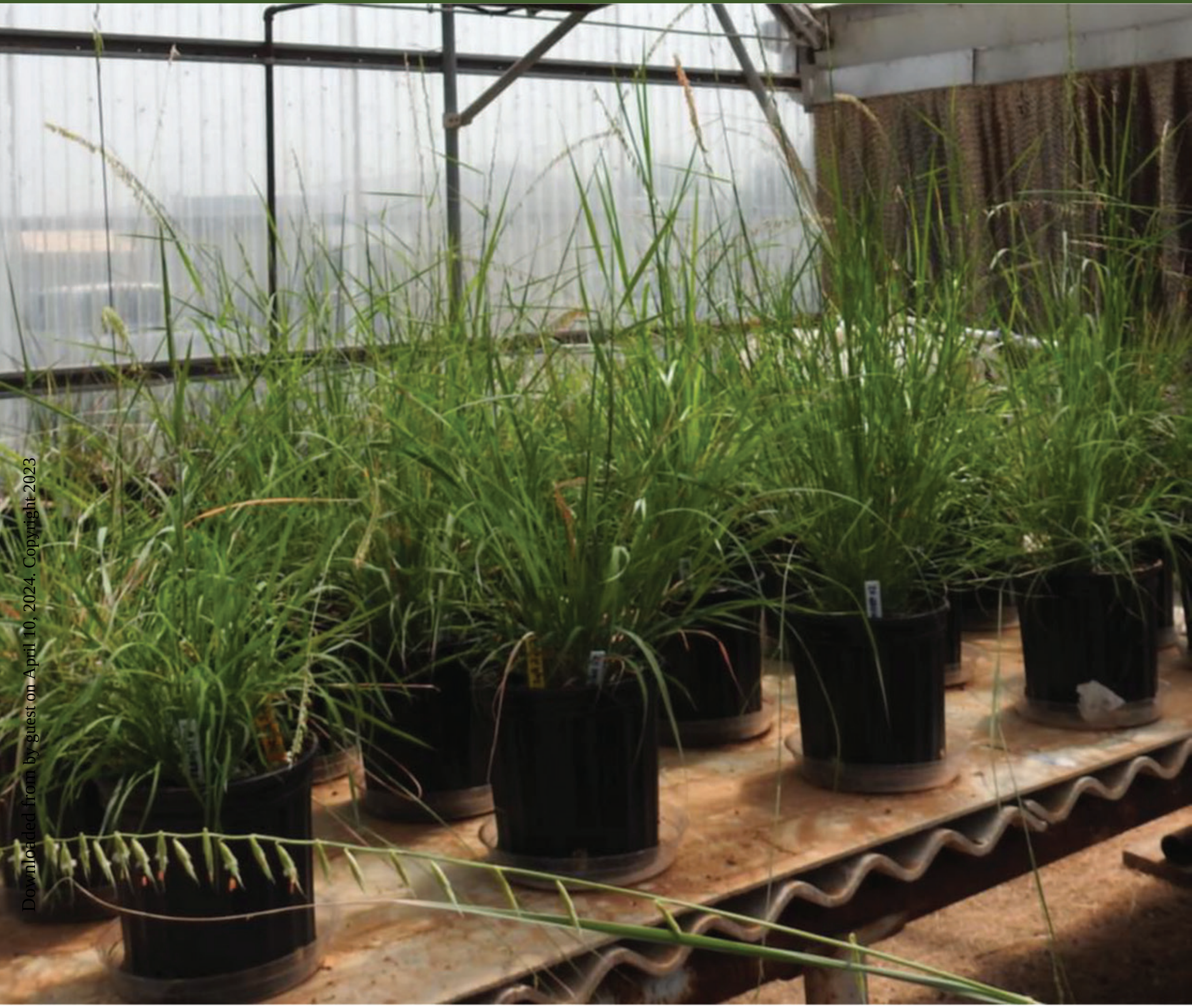

Ornamental bunchgrasses (Poaceae) before a water treatment in Stephenville, Texas.

Native and introduced ornamental bunchgrass seedling response to restricted soil-moisture conditions

Stephanie Gutiérrez, James P Muir, Darrel B Murray, W Brandon Smith, and J Randal Bow

ABSTRACT

Our greenhouse study compared seedlings of native Texas sideoats grama (SOG; *Bouteloua curtipendula* (Michx.) Torr.) and little bluestem (LBS; *Schizachyrium scoparium* (Michx.) Nash) to introduced fountaingrass (*Pennisetum alopecuroides* (L.) Spreng.), feather reed grass (*Calamagrostis x acutiflora* (Schrad.) Rchb.), and pheasant tail grass (*Stipa arundinacea* (Hook.f.) Benth.), bunchgrasses of the Poaceae family that are currently used as ornamental bunchgrasses. The objectives were to 1) determine seedling phenotypic ornamental variability in relation to soil water deficiency of selected SOG and LBS accessions under greenhouse conditions at Stephenville, Texas, and 2) compare simulated soil moisture stress on SOG and LBS performance compared to widely utilized non-native ornamental bunchgrasses. Species and accessions within species differed primarily in herbage dry matter yield (DMY) and canopy diameter. At 25% soil-saturation ($P \leq 0.05$), LBS seedlings yielded 23.8% and SOG 26.7% of the herbage DMY as they did at 100% soil-saturation. When compared to the 15.9% and 12.6% DMY ($P \leq 0.05$) for fountaingrass and feather reed grass, respectively, at the same irrigation levels, the native seedlings suffered less decline under persistently low soil-moisture conditions. When averaged across irrigation levels, there was a 34.0% difference ($P \leq 0.05$) in LBS entries DMY between the greatest and least DMY while there was a 26.8% difference between the greatest and least yielding LBS, indicating high variability in DMY within these germplasms. Native accessions likewise showed variation in plant heights and inflorescence color within each species. Field trials comparing native and exotic ornamental seedlings as well as epigenetic variability within species are warranted.

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KEY WORDS

municipal water restrictions, native bunchgrass, ornamental bunchgrass, irrigation, sideoats grama, little bluestem, *Bouteloua curtipendula*, *Schizachyrium scoparium*, Poaceae

NOMENCLATURE

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Photos by James Muir

In the past decade, the amount of water used in south-central North America to irrigate ornamentals has become a concern, especially in urban landscapes where, in warm-climate areas such as Dallas, Texas, USA, up to 40% of household water consumption occurs outdoors (Hermitte and Mace 2012). Many cities have implemented water restrictions, especially during drought, to limit irrigation used by residential or commercial ornamental plantings (Texas Commission on Environmental Quality, unpublished data). Limiting irrigation alone does not solve the underlying issue. We hypothesize that non-native ornamental plants not adapted to these climates are likely to require more watering. When this occurs, they cease contributing to soil, wildlife, and overall environmental health, in addition to failing to be aesthetically pleasing to urban gardeners. We hypothesize that non-native ornamental bunchgrasses currently sold and planted in landscapes may not be as well adapted to restricted soil moisture in the hot, dry climates of south-central North America as native bunchgrasses.

Native bunchgrasses with aesthetic ornamental value may be of interest for use in ornamental applications for their ability to thrive in low-water environments compared to introduced non-native bunchgrasses. Globally, water limitation is a top concern in plant production (Hatfield and others 2001; Ghannoum 2009). Urban landscape irrigation is among the top irrigation uses (Sun and others 2012; Cabrera and others 2013). Little bluestem (LBS; *Schizachyrium scoparium* (Michx.) Nash [Poaceae]) has been used as an ornamental, but we have limited knowledge on how it compares to non-native grasses under soil moisture stress. In the US, LBS has been used as an urban landscape grass (Harris-Shultz 2015). By comparison, little information is available on sideoats grama (SOG; *Bouteloua curtipendula* (Michx.) Torr. [Poaceae]), the Texas state grass (Loflin and Loflin 2006), for ornamental use in general and irrigation efficiency specifically. Both native grasses benefit the livestock industry, particularly cattle, and are important forage in native rangelands. In grassland, LBS provides grazers with high quality forage early in the growing season (Loflin and Loflin 2006; Shaw 2012); however, it is susceptible to overgrazing due to its palatability. Both species thrive in various soils, as well as landscapes, provided soils are well drained (Loflin and Loflin 2006). However, SOG performs better in fine-textured soils that are rich in calcium (Ca-rich) (Loflin and Loflin 2006). Abundant limestone subsoil and Ca-rich water in much of Texas (Weil and Brady 2017) may, therefore, favor SOG. Warm-season grasses native to south-central North America are generally adapted to drought stress, but data comparing them to introduced ornamental bunchgrasses are nonexistent.

Texas urban centers in past drought years have imposed water restrictions that make water limitation response, as measured by aesthetics, a top priority in ornamental plantings. Determining which native plant species and their accessions are better adapted to utilize less water to survive while still providing visually pleasing appearances may interest urban landscapers. Water-wise landscaping provides conditions for aesthetically pleasing plants that reduce water consumption (Rafi and others 2020).

Bunchgrass response to soil moisture stress varies depending on species architecture (Caldwell and others 1983; Calado and others 2013). Tightly clumped grasses may exhibit hindered growth due to shaded older foliage. This appearance may affect aesthetic appeal to urban landscapers. Likewise, stomatal control declines as leaves are retained and foliage ages. Despite this, bunchgrasses can still have high drought tolerance. Other drought-dependent factors include root-to-shoot ratios, stomatal conductance, and root density (Hamerlynck and others 2016). C4 plants have more efficient water use under water-stressed conditions than do C3 plants (Ghannoum 2008). Therefore, we compared warm-season C4 grasses in this experiment. Perennials tend to use water more efficiently than annuals, and perennial bunchgrasses follow this trend at the ecosystem level (Lenz and others 2003; Schnoor and others 2011; Davies and Johnson 2017). Soil water evaporation increases in grasses when exposed to drought conditions (Hamerlynck and others 2014; Bayat and others 2016).

Introducing and establishing more native, warm-season perennial grasses can improve the wildlife resources in urban and suburban settings. Both LBS and SOG have been used in habitat restoration. These warm-season bunchgrasses provide cover and allow maneuverability of ground-dwelling game birds and small mammals, as well as offer elements needed for invertebrate prey (Fettinger and others 2002). Excellent as forage, SOG also provides an ample seed source for wildlife. LBS is also used for this purpose, but, given its small seed size, wildlife benefits are debated (Loflin and Loflin 2006; Shaw 2012). The importance of landscape plants for urban wildlife, however, is less debatable (Kay and others 2022). For example, they can provide seed, denning, and nesting material for grassland birds and act as larvae butterfly host plants while not invading nearby established plants.

Introduced, ornamental fountaingrass (*Pennisetum alopecuroides* (Forssk.) Chiov [Poaceae]) is invasive in Arizona (Poulin and others 2005), while purple fountaingrass (*Pennisetum setaceum* (Forssk.) Chiov. [Poaceae]) is a common invasive plant in Texas (Loflin and Loflin 2006). Since the fountaingrass used in this study is closely related, it could conceivably become invasive in north-central Texas as well.

Municipal water restrictions limit the soil moisture available for ornamental plant growth. Reduced water availability encourages absorption farther down in the soil profile and root system. Drought-tolerant plants use this adaptation to better consume water on occasion rather than regularly (Sun and others 2012). The amount of transpiration also adjusts with the fraction of remaining transpirable soil water (FTSW). Growing evidence supports that the degree of change of transpiration depends on genotype (Cathey and others 2013), allowing quicker acclimatization to dry conditions and thus better visual appeal. However, most ornamental grass irrigation research focuses on turf grass (Cathey and others 2011, 2013), with very different areal and root architectures. It is therefore important to determine which bunchgrasses can acclimate better and quicker to low soil-moisture conditions during establishment.

We hypothesized that native SOG and LBS bunchgrasses subjected to soil-moisture restrictions would maintain superior plant health, ecosystem function (inflorescences and leaves for pollinators, soil protection, and so forth), and appearance (ornamental aesthetics) compared to non-native ornamental bunchgrass under municipal watering restrictions, likely translating to reduced municipal water consumption in landscaping. Our specific objectives were to 1) determine phenotypic ornamental variability in relation to soil water deficiency of selected SOG and LBS accessions under greenhouse conditions at Stephenville, Texas, and 2) compare soil moisture restrictions on SOG and LBS performance compared to non-native ornamental bunchgrasses currently utilized in north-central Texas.

MATERIALS AND METHODS

Experimental Design

We arranged our pots in a greenhouse as a strip-split plot in a complete randomized block with 2 factors. The first factor was bunchgrass species and accession. We used 3 non-native Poaceae grasses: fountaingrass, feather reed grass (*Calamagrostis* x*acutiflora* (Schrad.) Rchb.), and pheasant tail grass (*Stipa arundinacea* (Hook.f.) Benth. homonym *Anemanthele lessoniana* (Steud.) Veldkamp), as well as 11 SOG and 11 LBS accessions (Table 1). The second factor was soil-saturation level. The 4 irrigation treatments were determined based on soil water-holding capacity: 1) 100% field capacity, 800 ml (31.5 in)/pot; 2) 50% field capacity, 400 ml (15.7 in); 3) 25% field capacity, 200 ml (7.9 in); 4) 12.5% field capacity, 100 ml (3.9 in). Plants

TABLE 1

Little bluestem (LBS) and sideoats grama (SOG) accession origin data.

Accession	Latitude	Longitude	Mean annual temp (°C)	Annual rain (mm)	Soil
LBS					
OK select	35.0473	–97.8722	16.1	826	Zaneis loam
Cimarron	36.7936	–102.6216	12.4	418	Dalhart fine sandy loam
9110960	31.4387	–98.30789	18.1	742	Clay loam
9110987	30.7831	–99.7311	17.7	599	Clay loam
9110978	30.2084	–99.2250	17.8	711	Very cobbly clay
9085822	33.1419	–97.179-	17.9	902	Somervell gravelly loam
9089229	29.2684	–98.0465	20.6	736	Vernia very gravelly loamy sand
9089176	29.4201	–98.5721	20.6	688	Aluf sand
9064461	28.8801	–99.7233	21.1	559	Antoso-Bobillo sand
9092979	32.8233	–101.4339	17.3	498	Olton Clay loam
9093042	34.0792	–101.2524	14.7	528	Manske clay loam
SOG					
El Reno	35.5323	–97.9550	15.3	811	Norge silt loam
Vaughn	34.6017	–105.2083	11.2	327	Clovis loam
Haskell	33.1576	–99.7337	17.9	633	Abilene clay loam
9112300	30.6483	–97.9176	18.9	822	Oakalla silty clay loam
9112062	30.8437	–99.2029	17.8	667	Sunev clay loam
9107926	32.0879	–98.0169	17.9	796	Frio clay loam
9088961	28.8661	–98.5721	21.0	687	Weigang sandy clay loam
9088948	28.8314	–99.1013	21.2	613	Duval loamy fine sand
9093236	29.8688	–101.1617	19.8	452	Zorra clay loam
9110007	30.2349	–101.8000	19.2	391	Dev gravelly loam
9110049	30.0000	–103.3587	16.9	387	Sanmoss-Medley gravelly loam

Notes: (°C × 1.8) + 32 = °F

were watered every 3 d and fertilized every week for the first month and then every 2 wk thereafter. Each treatment combination was replicated 3 times, with each replication arranged in blocks consisting of greenhouse tables.

Plants

We grew all grasses from seed in plug trays to 4 leaflets, which were then transplanted to plastic 3.8 l (1 gal) pots (experimental units) filled with a homogenized sandy loam field soil. Coffee filters were placed over the drain holes. Each water treatment group consisted of 25 randomized pots representing each entry (3 non-native species, 11 SOG accessions, and 11 LBS accessions). Columns were spaced 18 cm (7 in) apart, rows approximately 4 cm (1.6 in) apart, and tables spaced approximately 0.8 m (32 in) apart on either side of the greenhouse with a 1.1 m (43 in) aisle dividing the tables in sets of 3. Each pot was labeled with an accession entry number followed by replication (1-3) and irrigation treatment (1-4).

Site and Timeline

The study site was a greenhouse at the Texas A&M AgriLife Research and Extension Center at Stephenville (32.253056 N, 98.1925 W). The study began 1 June 2020 and ran through the final harvest on 25 August 2020. Greenhouse temperature and humidity readings were taken every 3 d.

Seed Sources

Native bunchgrass seeds were acquired from commercial seed companies and the Texas Native Seeds collection, representing different Texas regions. SOG commercial cultivars included Haskell, El Reno, and Vaughn. LBS cultivars included OK Select and Cimarron. Non-native seed came from commercially available sources as ornamentals.

Soil and Amendments

We used homogenized Windthorst fine sandy loam (Web Soil Survey 2020) topsoil collected from 0 to 20 cm (7.9 in) depths at Stephenville, Texas. Pots were fertilized with Miracle-Gro (Marysville, Ohio) Water-Soluble All-Purpose Plant Food (24-8-16) every 7 d per label guidelines. The 100 ml (3.4 oz) solution was subtracted from total water of each treatment. We applied mild insecticidal soap as needed to suppress insects.

Data Collection

Inflorescence dates and colors were noted if/as they appeared and during monthly measurements. Dependent variable measurements during the trial included inflorescence, plant, dry matter biomass harvests, and nutrient analyses. We recorded inflorescence height, the number of shoots that formed, if any were aborted, and seed approximation (counting the spikelets on one shoot, multiplying by each inflorescence, and then by the number of inflorescences). Plant canopy diameter, height, number of shoots, and base diameter were recorded.

Inflorescence color variation of 3 sideoats grama trial plants.

All aboveground plant biomass was harvested 1 mo after the trial start, on 1 July 2020. Harvest height was half the tallest leaf height (not including inflorescence height) for that individual pot. This height was chosen to allow sufficient remaining biomass for rapid regrowth. We harvested plants a second time on 10 August to the same height as the first harvest. The final harvest was on 25 August 2020, and we collected the entire plant and separated the aboveground and root material. Harvested materials were dried at 55 °C (131 °F) in a forced-air oven until weight loss ceased. The material was separated into green and senesced leaves. At the end of the trial (final harvest), we batched all aboveground green material and recorded herbage and root dry matter yields (DMY). Each sample was then ground to pass through a 1 mm (0.04 in) screen for analysis in a Thomas Scientific Wiley mini cutting mill (Troemner, Thorofare, New Jersey). Nitrogen and carbon analyses were carried out on batched, aboveground herbage and roots using a LECO C and N analyzer (LECO, St Joseph, Michigan).

Statistical Analysis

We analyzed data with SAS version 9.4 (SAS Institute Inc, Cary, North Carolina) using a linear mixed model ANOVA test on the dependent variables to determine differences among entries and irrigation levels (Zaixing and others 2013). The model fixed effects included water treatment and species.

Random effects included herbage and root DMY, plant height, canopy diameter, C percent and yield, and N percent and yield. The alpha level was set to 0.05 unless otherwise noted. Least-significant difference multiple-mean separation was carried out as needed. Secondarily, a regression test (Salas-Eljatib and others 2018) on irrigation was run to predict water treatment effects on entries.

RESULTS AND DISCUSSION

We observed a visible difference in how the bunchgrass species reacted to varying water treatments by saturation level. Full soil-saturation produced larger plants, many with an unkempt appearance. Algae growth around the top of the soil and overflow into the catch trays was more common. The lowest water treatment (12.5% saturation) produced dry foliage or dead plants. Pheasant tail grass seedlings were weak prior to transplant and grew sparsely throughout. It will appear in data but will not be discussed. The primary dependent variables affected by irrigation were herbage DMY, plant height, and canopy diameter. There were few differences in root DMY (Table 2) and nutrients (herbage C and N percent and yield).

SOG had more fully developed inflorescences compared to the other species (Table 3). Among the feather reed grass plants, only a single plant produced an inflorescence culm. It was undeveloped, so inflorescence data for this species were limited. In a Beijing study, another feather reed species (*Calamagrostis brachytricha* Steud. [Poaceae]) was used to observe effects of evapotranspiration-based water limitation (Yuan and others 2015). Treatments were 25, 50, 75, and 100% evapotranspiration. No inflorescences were produced in the first year, and in the second year the 100% treatment produced more culms than the lower treatments. Based on the study in China and ours, feather reed grass inflorescence may be delayed until the second year. More inflorescences could have resulted in the Beijing study because the trial was longer, extending into October and November, and was closer to the region the genus originated from (Susan Mahr, University of Wisconsin).

Inflorescence shoot number of SOG and LBS decreased with decreasing water treatment, except for some plants irrigated at 50% soil-saturation that produced more than those watered at 100% (Table 3). Fountaingrass and feather reed grass had few inflorescence shoots, but those that did were watered at 50 to 100% soil-saturation.

Herbage DMY

All species responded to decreasing water treatments with stunted growth (Table 4; Figure 1). Average LBS and SOG at the 100% soil-saturation level had the greatest herbage DMY followed by the 50% soil-saturation level plants with less yield. The 25 and 12.5% soil-saturation levels had less DMY than those with greater irrigation ($P < 0.10$). Less irrigated non-native plants predictably accumulate less DMY compared to those receiving more irrigation (Yuan and others 2015), which we also observed. In the second year of a Beijing study, however, DMY in reed grasses receiving irrigation equivalent to 75% evapotranspiration was lower than those receiving 100%. Yields varied much less in our trial among 100 and 50% soil-saturation treatments of feather reed grass. Growing conditions may have differed between the 2 sites, explaining the differences.

In the 100% soil-saturation treatment, SOG had greater herbage DMY than did fountaingrass, pheasant tail grass, or feather reed grass (Table 4). At 50% irrigation, SOG had greater DMY than pheasant tail grass and feather reed grass, while no differences among species were observed at 12.5 and 25%. We

TABLE 2

Root dry matter yield (g/potted plant) of sideoats grama (mean of 11 accessions), little bluestem (mean of 11 accessions), feather-grass, feather reed grass, and pheasant-tail grass (species × water; P ≤ 0.05).

Species	Soil saturation % 100	50	25	12.5	Standard error
Sideoats grama	5.4 ab A*	7.1 a A	2.6 a A	2.7 a A	1.34
Little bluestem	7.9 a A	7.3 a A	3.2 a A	3.2 a A	1.30
Feather grass	7.4 a A	4.9 ab A	2.9 a A	3.4 a A	1.34
Feather reed grass	10.5 a A	4.3 ab B	3.1 a B	3.7 a B	1.34
Pheasant tail	0.2 b A	0.3 b A	0.1 a A	0.9 a A	1.30
Standard error	1.30	1.34	1.34	1.34	

*Values within each column (lower case) and each row (upper case) followed by the same letter do not differ ($P \leq 0.05$) according to Tukey-Kramer multiple means separation test.

TABLE 3

Mean bunchgrass inflorescences during trial.

Entry	Irrigation treatment (%)	Spikelets	Inflorescence shoots
Feather reed grass	50	0	0.3
Fountaingrass	100	—	2.1
	50	—	0.3
Little bluestem	100	0	1.7
	50	0	1.0
	25	0	0.3
Sideoats grama	100	24.7	8.5
	50	23.2	4.6
	25	20.8	1.7
	12.5	14.5	1.1

*Inflorescence shoot values are the average of all harvests including "0."
— represents inflorescence where spikelets were difficult to count.

TABLE 4

Aboveground herbage dry matter yield (g/potted plant) for 5 bunchgrass species irrigated with 12.5 to 100% soil-saturation every 3 d (species × water $P \leq 0.05$; averages of all accessions for sideoats grama and little bluestem).

Species	Soil saturation % 100	50	25	12.5	Standard error
Sideoats grama	43.7 a A*	26.7 a B	10.4 a C	4.3 a C	2.36
Little bluestem	34.1 ab A	16.5 ab B	9.1 a BC	2.7 a C	2.36
Fountaingrass	27.7 b A	16.3 ab AB	4.4 a BC	2.5 a C	2.49
Feather reed grass	25.9 b A	12.9 bc B	3.2 a B	2.2 a B	2.49
Pheasant tail	0.7 c A	0.9 c A	1.0 a A	1.1 a A	2.36
Standard error	2.36	2.49	2.36	2.49	

*Values within each column (lower case) and each row (upper case) followed by the same letter do not differ ($P \leq 0.05$) according to Tukey-Kramer multiple means separation test.

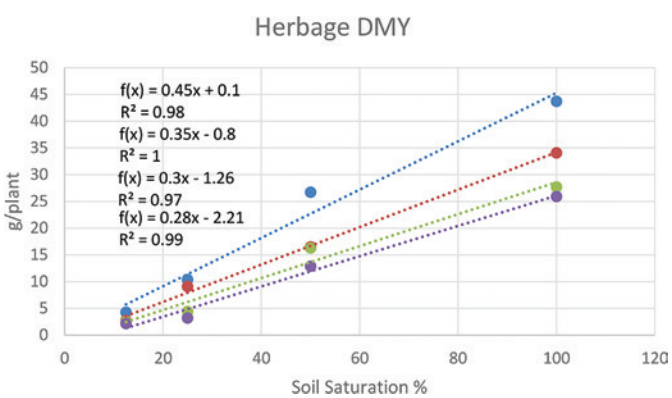


Figure 1. Mean herbage dry matter yield (DMY) for sideoats grama (SOG; blue), little bluestem (LBS; red), fountaingrass (FG; green), and feather reed grass (FRG; purple) at 4 soil-saturation irrigation levels.

observed no herbage DMY differences between LBS and SOG accession averages.

However, when averaged over all irrigation treatments, the largest and smallest DMY among SOG accessions were 9112062 (21.3 g [0.75 oz]/potted plant) and 91123600 (14.8 g [0.52 oz]/potted plant), respectively, a 30.5% difference (Table 5). When averaged across all irrigation treatments, 9112062 (21.3 g [0.75 oz] DM/plant) produced 26.8% more DMY than the average for the 3 commercial releases (16.8 g [0.59 oz] DM/plant). The accession with the highest DMY was collected from central Texas, the lightest from south Texas, where the climate is hotter. While accession origin climatic variables did not appear to play a prominent role in how these accessions performed, they may have in other SOG accessions. Among the greatest yielding accessions were south Texas accessions 9088961 and 9088948. The region has higher temperatures that could have better acclimated those accessions to drought; however, the

TABLE 5

Herbage dry matter yield (DMY) (g/plant) among accessions of little bluestem and sideoats grama averaged over 4 levels of irrigation (accession × irrigation; $P > 0.05$).

Little bluestem	Herbage DMY (g/plant)	Sideoats grama	Herbage DMY (g/plant)
9089229	17.3 a* A	9112062	21.3 a A
OK Select	16.2 a AB	9088948	19.4 ab AB
9064461	15.6 ab AB	9088961	18.9 ab AB
Cimarron	15.5 abc AB	9110007	18.5 ab ABC
9089176	14.9 abc ABC	9107926	18.2 ab ABC
9110987	13.9 abc BCD	9110049	17.7 ab BC
9110978	13.6 abc BCD	Haskell	17.5 ab BC
9110960	13.5 abc BCD	El Reno	16.7 ab BC
9085822	12.0 bc CD	Vaughn	16.1 b BC
9092979	11.7 bc CD	9093236	15.4 b BC
9093042	11.4 c D	9112300	14.8 b C
Standard error	1.57		1.58

*Values within each column followed by the same lower-case letter ($P \leq 0.05$) upper case letter ($P \leq 0.10$) do not differ according to least significant difference multiple means separation test.

smallest yielding accession also originated there. South Texas soils may have been more of a factor. The 2 greater yielding accessions came from locations with coarser soils containing some sandy properties that the least yielding accession did not. Plants were probably better adapted to a lower water-holding soil texture and were therefore better able to grow in the Stephenville sandy loam.

Averaged over all irrigation treatments, the largest and smallest LBS accessions were 9089229 (17.3 g [0.61 oz]/potted plant) and 9093042 (11.4 g [0.40 oz]/potted plant), respectively, with a 34.0% difference (Table 5). Longitude of accession collection made a difference in seedling DMY. The LBS accession 9089229, with the greatest seedling DMY, was collected from south Texas while the least productive accession 9093042 came from west Texas. Accessions 9089229, 9064461, and 9089176 originally collected from warmer south Texas were among the greatest yielding. However, commercial cultivars Cimarron and OK Select also produced among the greatest DMY but originated from cooler regions at greater latitudes. These commercial releases may have been originally selected to survive in poorer growing conditions to expand their growing region. OK Select also grew larger despite originating from a region with higher precipitation, while low-precipitation west Texas accessions 9092979 and 9093042 produced the smallest yields. For LBS, soil texture may also have been a regional factor. Accession 9089229 grew larger, originating from a region with coarser soil, while accessions 9092979 and 9093042 grew smaller, originating from a region with finer textured soil.

Canopy Diameter

Feather reed grass plants had larger canopy diameters, on average, than the natives in the higher irrigation treatments (Table 6), despite SOG having greater herbage DMY (Table 7). We observed a positive correlation between irrigation and canopy diameter for all species (Figure 2). A previous study suggested that a more compact structure would lead to reduced growth (Caldwell and others 1983). No differences occurred between fountaingrass and native bunchgrasses (Table 6) or between the 2 natives.

TABLE 6

Canopy diameter (cm/potted plant) among 5 bunchgrass species at 4 irrigation levels (species × irrigation P ≤ 0.05; averages of all accessions for sideoats grama and little bluestem).

	Soil saturation %				Standard
Species	100	50	25	12.5	error
Sideoats grama	50.3 b A*	42.6 b A	29.2 a A	29.1 a A	4.92
Little bluestem	40.0 b A	34.7 b A	27.5 a A	25.9 a A	4.92
Fountaingrass	52.7 ab AB	58.0 ab A	36.3 a AB	30.0 a B	4.92
Feather reed grass	77.3 a A	71.0 a A	51.3 a AB	43.3 a B	4.92
Pheasant tail	45.7 b A	31.7 b A	43.7 a A	40.0 a A	4.92
Standard error	4.92	4.92	4.92	4.92	

*Values within each column (lower case) and each line (upper case) followed by the same letter do not differ ($P \leq 0.05$) according to Tukey-Kramer multiple means separation test.

TABLE 7

Canopy diameter (cm) among little bluestem and sideoats grama accessions averaged over 4 levels of soil-saturation (accession × irrigation P > 0.05).

Little bluestem	Canopy diameter (cm)	Sideoats grama	Canopy diameter (cm)
9089229	32.83 abc*	9112062	37.42 a
OK Select	35.33 ab	9088948	36.83 a
9064461	40.17 a	9088961	37.17 a
Cimarron	32.17 abc	9110007	32.33 a
9089176	33.71 ab	9107926	41.83 a
9110987	33.83 ab	9110049	34.75 a
9110978	32.67 abc	Haskell	37.17 a
9110960	33.58 ab	El Reno	39.92 a
9085822	29.83 bc	Vaughn	36.92 a
9092979	24.21 c	9093236	43.50 a
9093042	24.13 c	9112300	38.03 a
Standard error	1.96		2.56

*Values within each column followed by the same letter do not differ ($P \leq 0.05$) according to Tukey-Kramer multiple means separation test. 1 cm = 0.4 in

Height

Averaged heights (Figure 3) throughout the trial varied little across irrigation treatments and species (Table 8) or within accessions (Table 9). Plant heights among native bunchgrass species also did not differ overall. However, the top SOG accession was 9112062 at 44.4 cm (17.5 in) in height while the shortest accession was El Reno at 30.5 cm (12 in) in height with 31.4% lower plant height between them. Latitude also affected SOG height with the tallest accession collected from central Texas, the shortest, El Reno, from Oklahoma to the north. The tallest and shortest LBS accessions were 9064461 (39.0 cm [15.4 in]) and 9110978 (28.5 cm [11.2 in]), respectively, with a 26.8% difference. Average rainfall at collection sites could have played a role in the difference. Accession 9064461 was collected in a south Texas region that receives substantially less average annual precipitation (559 mm [22 in]) than occurs in a central part of the state (711 mm [28 in]) where the 9110978 accession was collected (WorldClim). Adaptation to less soil moisture may have led the tallest accession to adapt more easily to simulated soil-moisture restrictions.

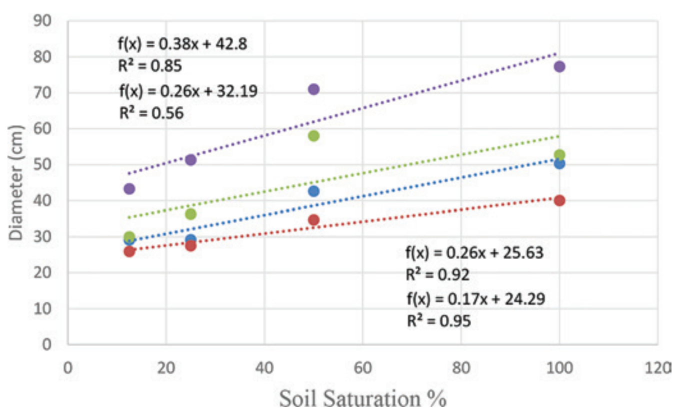


Figure 2. Mean canopy diameter for sideoats grama (SOG; blue), little bluestem (LBS; red), fountaingrass (FG; green), and feather reed grass (FRG; purple) at 4 soil-saturation irrigation levels.

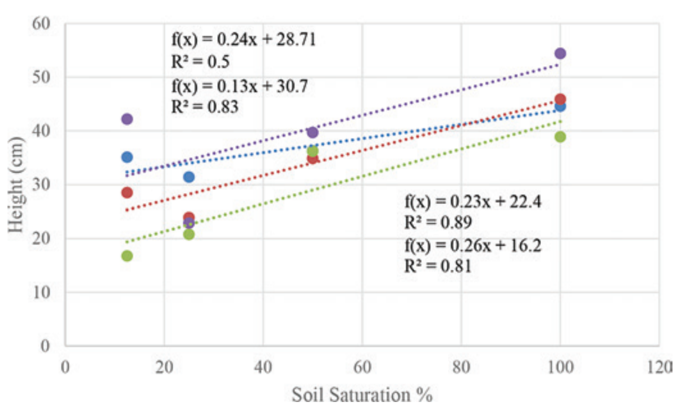


Figure 3. Mean plant heights for sideoats grama (SOG; blue), little bluestem (LBS; red), feather grass (FG; green), and feather reed grass (FRG; purple) at 4 soil-saturation irrigation levels.

TABLE 8

Height (cm/potted plant) among 5 bunchgrass species (species × water; P ≤ 0.05; averages of all accessions for sideoats grama and little bluestem).

	Soil saturation %				Standard
Species	100	50	25	12.5	error
Sideoats grama	44.6 a A*	36.3 a A	31.4 a A	35.1 ab A	3.49
Little bluestem	45.9 a A	34.9 a AB	23.9 a B	28.5 ab AB	3.49
Feather grass	38.9 ab A	36.2 a A	20.8 a AB	16.8 b B	3.49
Feather reed grass	54.4 a A	39.7 a AB	22.9 a B	42.2 a A	3.49
Pheasant tail	24.2 b A	33.7 a A	25.1 a A	36.5 a A	3.49
Standard error	3.49	3.49	3.49	3.49	

*Values within each column (lower case) and each row (upper case) followed by the same letter do not differ ($P \leq 0.05$) according to Tukey-Kramer multiple means separation test.

TABLE 9

Height (cm) of little bluestem and sideoats grama accessions averaged over 4 irrigation levels (accession × saturation; P > 0.05) in a greenhouse trial.

Little bluestem	Height (cm)	Sideoats grama	Height (cm)
9089229	33.5 ab*	9112062	44.4 a
OK Select	34.3 ab	9088948	36.1 bcd
9064461	39.0 a	9088961	38.9 abc
Cimarron	30.4 b	9110007	34.9 cd
9089176	35.4 ab	9107926	34.0 cd
9110987	35.4 ab	9110049	37.0 abcd
9110978	28.5 b	Haskell	31.7 cd
9110960	35.9 ab	El Reno	30.5 d
9085822	30.9 ab	Vaughn	36.1 bcd
9092979	32.6 ab	9093236	38.9 abc
9093042	30.3 b	9112300	43.7 ab
Standard error	1.80		2.00

*Values within each column followed by the same letter do not differ ($P \leq 0.05$) according to Tukey-Kramer multiple means separation test. 1 cm = 0.4 in

When comparing the best native accessions to the non-native species, SOG had greater herbage DMY than did the non-natives at the 100% soil-saturation level. Native bunchgrass accession averages did not differ from the introduced species. At the 100% soil-saturation level, native canopy diameters were as wide as the non-natives. At the 50% soil-saturation level, SOG had a smaller canopy than feather reed grass while the widest LBS accession had a similar diameter. (See Appendix material at the end of this article.)

Larger plants (higher yields and heights), while showing greater response to irrigation, were not necessarily as aesthetically pleasing. Some of the smaller plants appeared neater in structure and may be more sought after as ornamentals. It may be ornamentally relevant that at the 100% saturation irrigation level, feather reed grass was wider than SOG despite less herbage DMY. This gave feather reed grass a more open appearance compared to a tighter SOG canopy architecture.

In future studies, we recommend extending the time interval between harvests and the collected data for a longer period. Some plants, especially LBS, had undeveloped inflorescences at harvest. Longer observation into late summer or fall may provide more inflorescence data, which is important for ornamental selection. Water stress could play a role in lack of or delayed flowering (Kazan and Lyons 2016). Alternatively, it could have contributed to more SOG inflorescence production as a species that responds more favorably, in terms of aesthetics, than other species (Takeno 2016).

CONCLUSIONS

Our results generally indicate that native Texas bunchgrass seedling growth parameters declined less under soil water deficiency when compared to non-natives. This outcome occurred despite no differences in root DMY or plant nutrients within the same irrigation treatment. First-year native grasses, especially SOG, under water stress produced more inflorescences than non-natives. Non-natives grew very few culms. Preferred ornamental plant appearance is subjective, but the standard for ornamental grass aesthetics generally includes developed inflorescences. We focused our research on first-year seedling performance, so second-year results, to be tested in a subsequent field study, may differ.

Accessions of LBS and SOG varied in their response to soil water deficiency, likely based on original collection site edaphoclimatic differences. When we compared native species accessions, LBS height varied 27% and herbage DMY 34% whereas SOG varied 31% and 27%, respectively. These ranges indicate that future releases could be selected based on epigenetics as much as genetics under soil moisture stresses. In our trial, Texas natives originating in warmer latitudes (south) grew larger under similar soil moisture limitations compared to those originating in cooler latitudes. Higher temperatures and lower annual average rainfalls may have better predisposed bunchgrass accessions to superior growth and varying appearances. However, soil texture appeared to be an even more impactful environmental factor. Accessions originating from locations with coarser soils, more similar to that used in the trial, performed better than those with fine-textured soils. Commercial cultivars of LBS performed well despite their cooler, wetter origins.

Entries, especially native accessions, growing with 50% to 100% soil-saturation irrigation had tighter, less aesthetically pleasing appearances compared to those subjected to greater moisture stress. When municipal water restrictions are not in effect, overwatering may therefore become an aesthetic concern. The 100% soil-saturation irrigation created undesirable conditions and potential for leaching whereas the 12.5% to 25% saturation levels were insufficient to maintain healthy, aesthetically pleasing plants, regardless of species. The main differences among the bunchgrasses were in herbage DMY and canopy diameter, both of which could influence aesthetic appeal, which is entirely subjective. For example, at 100% soil-saturation irrigation, SOG grew larger but more compact than feather reed grass. This contradicts previous bunchgrass research that indicated that a larger canopy should have reduced the overall yield of SOG plants (Caldwell and others 1983).

Overall, our results indicate that natives are at least as hardy as non-native ornamental bunchgrasses and can provide added color to landscapes. SOG inflorescence color and LBS leaf hues, as well as canopy structure for both species, varied sufficiently to merit selection among accessions for marketable ornamental differences. Additional survey-type research is merited to identify ornamental traits desired by municipal gardeners. Outdoor field studies at various latitudes and soil moisture levels should also be undertaken on transplants and multi-year stands to further discern differences among ornamental bunchgrass between natives and non-natives, among species, and among accessions of the same species.

APPENDICES

APPENDIX A

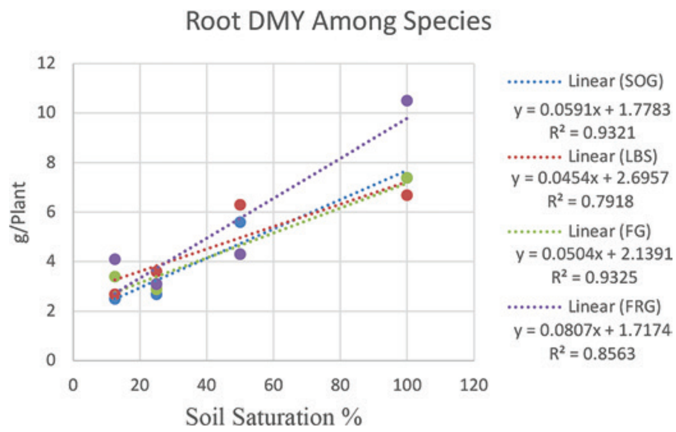
Root DMY (g/plant) among accessions of LBS and SOG averaged over 4 levels of soil-saturation (accession × saturation; P > 0.05).

Little bluestem (LBS)	Root DMY (g/plant)	Sideoats grama (SOG)	Root DMY (g/plant)
9089229	4.82 a*	9112062	4.18 a
OK Select	4.73 a	9088948	4.18 a
9064461	4.32 a	9088961	3.80 a
Cimarron	4.90 a	9110007	3.84 a
9089176	5.19 a	9107926	3.74 a
9110987	5.28 a	9110049	4.27 a
9110978	5.13 a	Haskell	4.06 a
9110960	5.39 a	El Reno	4.51 a
9085822	4.41 a	Vaughn	4.55 a
9092979	4.04 a	9093236	4.42 a
9093042	4.73 a	9112300	8.21 a
Standard error	0.48		1.27

*Values within each column followed by the same letter do not differ ($P \leq 0.05$) according to Tukey-Kramer multiple means separation test.

APPENDIX B

Root DMY among species.



APPENDIX C

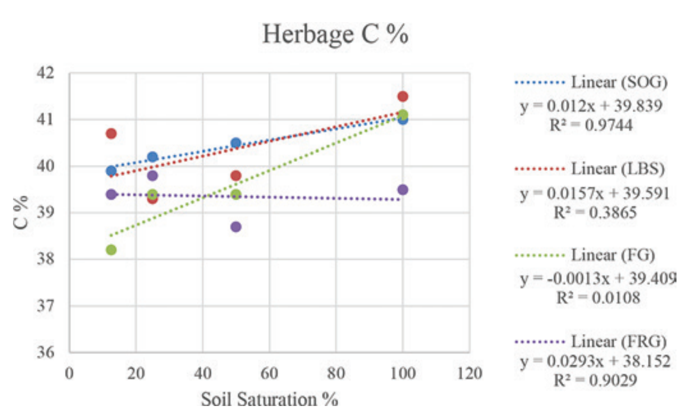
Herbage C (%/potted plant) among 5 bunchgrass species (species × water; P ≤ 0.05) in a greenhouse trial.

	Soil saturation %				Standard
Species	100	50	25	12.5	error
Sideoats grama	41.0 ab A*	40.5 a A	40.2 a A	39.9 ab A	.45
Little bluestem	41.5 a A	39.8 a A	39.3 a A	40.7 a A	.45
FG	41.1 ab A	39.4 a AB	39.4 a AB	38.2 b B	.47
FRG	39.5 ab A	38.7 a A	39.8 a A	39.4 ab A	.47
PTG	38.7 b B	40.1 a AB	41.2 a A	41.2 a A	.45
Standard error	.47	.45	.47	.45	

*Values within each column (lower case) and each line (upper case) followed by the same letter do not differ ($P \leq 0.05$) according to Tukey-Kramer multiple means separation test.

APPENDIX D

Herbage C % among species.



APPENDIX E

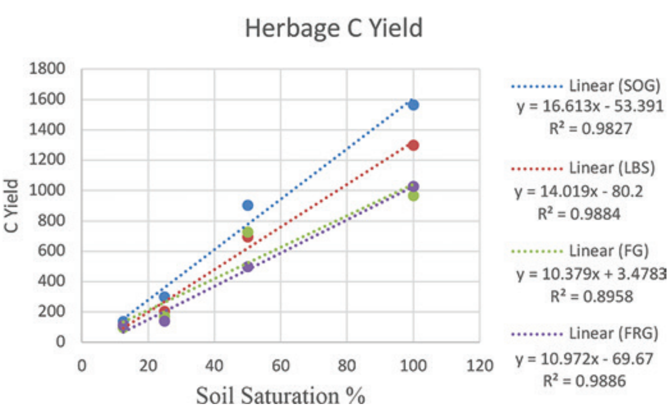
Herbage C (%) among accessions of LBS and SOG averaged over 4 levels of soil-saturation (accession × saturation; P > 0.05).

Little bluestem	Herbage C (%)	Sideoats grama	Herbage C (%)
9089229	40.15 ab*	9112062	40.28 a
OK Select	40.67 ab	9088948	40.41 a
9064461	41.17 a	9088961	40.64 a
Cimarron	40.73 ab	9110007	40.47 a
9089176	40.21 ab	9107926	40.49 a
9110987	39.87 ab	9110049	40.70 a
9110978	39.60 b	Haskell	40.28 a
9110960	40.83 ab	El Reno	39.90 a
9085822	40.23 ab	Vaughn	40.55 a
9092979	40.37 ab	9093236	40.58 a
9093042	39.82 ab	9112300	40.93 a
Standard error	0.33		0.39

*Values within each column followed by the same letter do not differ ($P \leq 0.05$) according to Tukey-Kramer multiple means separation test.

APPENDIX F

Herbage C yield among species.



APPENDIX G

Herbage C yield (g/potted plant) among 5 bunchgrass species (species × water; P ≤ 0.05) in a greenhouse trial.

Species	Soil saturation % 100	50	25	12.5	Standard error
Sideoats grama	1563.5 a A*	902.0 a B	298.7 a C	137.2 a C	65.51
Little bluestem	1299.9 ab A	693.6 ab B	204.5 a C	109.8 a C	65.51
FG	967.5 b A	725.2 ab A	171.9 a B	95.4 a B	69.16
FRG	1028.0 b A	498.8 b B	141.4 a BC	110.3 a C	69.16
PTG	25.6 c A	37.7 c A	42.5 a A	44.2 a A	65.51
Standard error	68.43	65.51	68.43	65.51	

*Values within each column (lower case) and each line (upper case) followed by the same letter do not differ ($P \leq 0.05$) according to Tukey-Kramer multiple means separation test.

APPENDIX H

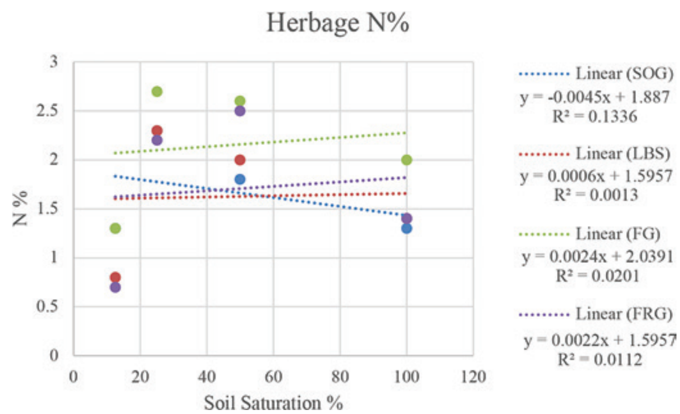
Herbage N (%/potted plant) among 5 bunchgrass species (species × water; P ≤ 0.05) in a greenhouse trial.

Species	Soil saturation % 100	50	25	12.5	Standard error
Sideoats grama	1.3 a B*	1.8 bc AB	2.3 a A	1.3 a B	0.14
Little bluestem	1.4 a BC	2.0 abc AB	2.3 a A	0.8 a C	0.14
FG	2.0 a AB	2.6 a A	2.7 a A	1.3 a B	0.14
FRG	1.4 a B	2.5 ab A	2.2 a AB	0.7 a C	0.14
PTG	1.6 a A	1.7 c A	1.4 b A	1.2 a A	0.14
Standard error	0.14	0.14	0.14	0.14	

*Values within each column (lower case) and each line (upper case) followed by the same letter do not differ ($P \leq 0.05$) according to Tukey-Kramer multiple means separation test.

APPENDIX I

Herbage N % among species.



APPENDIX J

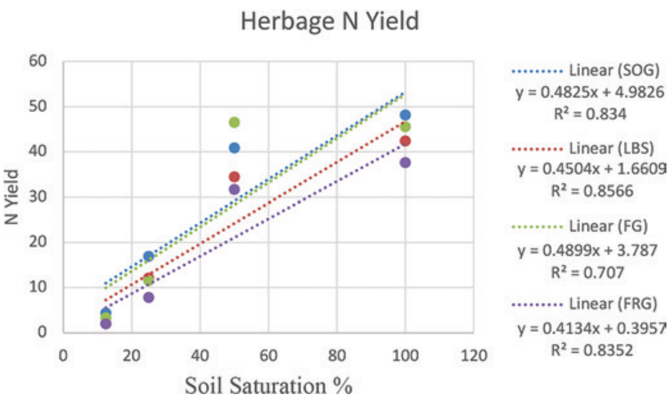
Herbage N (%/plant) among accessions of LBS and SOG averaged over 4 levels of soil-saturation (accession × saturation; P > 0.05).

Little bluestem	Herbage N (%/plant)	Sideoats grama	Herbage N (%/plant)
9089229	1.78 ab*	9112062	1.58 a
OK Select	1.42 b	9088948	1.56 a
9064461	1.60 ab	9088961	1.68 a
Cimarron	1.52 b	9110007	1.59 a
9089176	1.55 ab	9107926	1.72 a
9110987	1.66 ab	9110049	1.49 a
9110978	1.93 a	Haskell	1.65 a
9110960	1.56 ab	El Reno	1.98 a
9085822	1.55 ab	Vaughn	1.65 a
9092979	1.50 b	9093236	1.66 a
9093042	1.69 ab	9112300	5.15 a
Standard error	0.10		1.12

*Values within each column followed by the same letter do not differ ($P \leq 0.05$) according to Tukey-Kramer multiple means separation test.

APPENDIX K

Herbage N yield among species.



APPENDIX L

Herbage N yield (g/potted plant) among 5 bunchgrass species (species × water; $P \leq 0.05$) in a greenhouse trial.

Species	Soil saturation %				Standard error
	100	50	25	12.5	
Sideoats grama	48.2 a A*	40.9 ab A	16.9 a B	4.4 a B	2.56
Little bluestem	42.4 a A	34.5 ab A	12.1 ab B	2.1 a B	2.56
FG	45.6 a A	46.5 a A	11.6 ab B	3.3 a B	2.70
FRG	37.6 a A	31.7 b A	7.8 ab B	2.0 a B	2.70
PTG	1.1 b A	1.6 c A	1.5 b A	1.2 a A	2.56
Standard error	2.70	2.56	2.70	2.56	

*Values within each column (lower case) and each line (upper case) followed by the same letter do not differ ($P \leq 0.05$) according to Tukey-Kramer multiple means separation test.

APPENDIX M

Greatest native accessions plant height (cm) among 5 bunchgrass species (species × water; $P \leq 0.05$) in a greenhouse trial.

Species	Soil saturation %				Standard error
	100	50	25	12.5	
Sideoats grama	55.0 a A	44.9 a A	38.7 a A	39.2 a A	4.37
Little bluestem	47.3 ab A	45.3 a A	33.8 a A	29.5 a A	4.37
FG	38.9 ab A	32.8 a A	20.8 a A	16.8 a A	4.63
FRG	54.4 a A	39.7 a AB	22.9 a B	41.2 a AB	4.63
PTG	24.2 b A	33.7 a A	25.1 a A	36.5 a A	4.37
Standard error	4.37	4.63	4.37	4.63	

*Values within each column (lower case) and each row (upper case) followed by the same letter do not differ ($P \leq 0.05$) according to Tukey-Kramer multiple means separation test.

APPENDIX N

Greatest native accessions canopy diameter (cm) among 5 bunchgrass species (species × water; $P \leq 0.05$) in a greenhouse trial.

Species	Soil saturation %				Standard error
	100	50	25	12.5	
Sideoats grama	56.3 ab A	40.0 b AB	24.0 a B	29.3 a AB	5.66
Little bluestem	54.3 ab A	47.7 ab AB	34.7 a AB	24.0 a B	5.66
FG	52.7 ab A	58.3 ab A	36.3 a A	30.0 a A	5.97
FRG	77.3 a A	71.0 a AB	51.3 a AB	40.8 a B	5.97
PTG	45.7 b A	31.7 b A	43.7 a A	40.0 a A	5.66
Standard error	5.66	5.97	5.66	5.97	

*Values within each column (lower case) and each row (upper case) followed by the same letter do not differ ($P \leq 0.05$) according to Tukey-Kramer multiple means separation test.

APPENDIX O

Inflorescence colors.

Entry # accession	Corresponding species	Rep	Water treatment	Color
4	SOG (El Reno)	1	1	Red, pink-orange
4	SOG (El Reno)	1	2	Pink-orange, pink
4	SOG (El Reno)	1	3	Pink
4	SOG (El Reno)	1	4	Red
4	SOG (El Reno)	2	3	Pink
4	SOG (El Reno)	3	1	Tan, red
4	SOG (El Reno)	3	3	Red
5	SOG (Vaughn)	1	1	Red-orange, red-purple
5	SOG (Vaughn)	1	2	Purple
5	SOG (Vaughn)	1	3	Pink-orange
5	SOG (Vaughn)	1	4	Pink-orange
5	SOG (Vaughn)	2	1	Pink-orange
5	SOG (Vaughn)	2	3	Red-orange
5	SOG (Vaughn)	2	4	Red
5	SOG (Vaughn)	3	1	Red-orange, red and pink
5	SOG (Vaughn)	3	2	Pink-red-orange, red
5	SOG (Vaughn)	3	4	Red-orange
6	SOG (Haskell)	1	1	Tan, orange
6	SOG (Haskell)	1	3	Red-orange
6	SOG (Haskell)	2	3	Purple
6	SOG (Haskell)	3	1	Tan, pink
6	SOG (Haskell)	3	2	Pink-red-orange, red-purple

(continued)

Entry # accession	Corresponding species	Rep	Water treatment	Color
7	SOG 9112300	1	3	Pink
7	SOG 9112300	2	1	Red-orange
7	SOG 9112300	2	3	Pink-orange
7	SOG 9112300	2	4	Pink
7	SOG 9112300	3	1	Red-orange
8	SOG 9112062	1	2	Yellow
8	SOG 9112062	1	4	Purple
8	SOG 9112062	2	2	Red-orange
8	SOG 9112062	2	3	Pink
8	SOG 9112062	3	1	Tan, pink
8	SOG 9112062	3	2	Red-orange
9	SOG 9107926	1	2	Tan, pink
9	SOG 9107926	1	3	Yellow
9	SOG 9107926	2	1	Tan
9	SOG 9107926	2	2	Yellow
9	SOG 9107926	2	3	Yellow
9	SOG 9107926	3	1	Tan mostly and pink
10	SOG 9088961	2	3	Pink-orange
10	SOG 9088961	3	3	Pink-orange
11	SOG 9088948	1	1	Red-orange
11	SOG 9088948	1	4	Pink-orange
11	SOG 9088948	2	1	Red-orange
11	SOG 9088948	2	2	Pink
11	SOG 9088948	2	4	Pink-orange
11	SOG 9088948	3	1	Red-orange, tan
11	SOG 9088948	3	2	Pink-orange
11	SOG 9088948	3	3	Red-orange
12	SOG 9093236	3	1	Light yellow, tan
13	SOG 9110007	1	1	Pink-orange
13	SOG 9110007	1	3	Red-orange
13	SOG 9110007	2	1	Yellow-orange
13	SOG 9110007	2	4	Pink-orange
13	SOG 9110007	3	1	Tan, red, pink
13	SOG 9110007	3	2	Pink-orange
13	SOG 9110007	3	3	Pink-orange
13	SOG 9110007	3	4	Red-orange
14	SOG 9110049	1	4	Pink-orange
14	SOG 9110049	3	3	Yellow
1	Fountaingrass (FG Pride)	3	1	Brown
16	Little Bluestem (Cimarron)	1	4	Purple
18	Little Bluestem 9110987	3	1	Yellow-red, rusty brown
25	Little Bluestem 9093042	1	3	Yellow

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