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Broad-sense Heritability Estimates of Turfgrass Performance Characteristics in Native Prairie Junegrass Germplasm

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***Abstract*. Prairie junegrass [*Koeleria macrantha* (Ledeb.) Shultes] is a perennial, short-grass prairie species distributed throughout the Northern Hemisphere that is being evaluated for use as a low-input turf. In June 2007, 300 genotypes representing collection locations derived from Colorado, Nebraska, and Minnesota germplasm were grown and evaluated 3 years for turfgrass performance characteristics in a randomized complete block design with five clonal replications at two locations (St. Paul, MN, and Becker, MN). After establishment, plots received no supplemental irrigation or fertility and were mowed weekly to a height of 6.4 cm. Broad-sense heritability estimates were calculated on a clonal mean (Hc) and single-plant (Hsp) basis for turf quality (Hc = 0.62, Hsp = 0.13), crown density (Hc = 0.55, Hsp = 0.09), mowing quality (Hc = 0.59, Hsp = 0.09), and genetic color (Hc = 0.45, Hsp = 0.06). The heritability estimates indicate that selection for these traits should result in significant gains in germplasm improvement. Differences were observed in the means and variances among clones, collection locations, and/or collection regions for many of the traits evaluated including rust severity (*Puccinia* spp.), spring green-up, plant height, lateral spread, vertical regrowth, and flowering traits. The positive correlations among some of these traits and those with moderate heritability estimates should allow for multi-trait selection in cultivar development.**

Native grass species, when used as low-input turf, offer many benefits that could address concerns about water use, sustainability, and increased turf management operating expenses (Diesburg et al., 1997). Low-maintenance turf often has lower visual and performance expectations than highly managed areas, and lower quality may be acceptable to the turf manager (Johnson, 2003). Hanks et al. (2005) suggested that acceptable turf quality is defined by color, leaf texture, density, and aesthetic appeal for the particular area in which it is grown. Low-input turf areas can include home lawns, roadsides, cemeteries, military installations, low-use parks and schools, or golf course roughs (Dernoeden et al., 1994; Hanks et al., 2005). The low-input turf area must provide a uniform appearance, compete with unwanted species, and stabilize the soil (Dernoeden et al., 1994; Diesburg et al., 1997).

Plant breeders have been evaluating and developing native and introduced grasses for use as low-input turf. The traditional turfgrasses are better adapted to high-input areas, whereas native grasses may perform better under lower traffic and at higher mowing heights (Johnson, 2008). Native grasses that have evolved under local conditions in North America are logical candidates for low-maintenance turf (Mintenko and Smith, 1999; Mintenko et al., 2002). Native species should be exploited in breeding programs for their adaptation to a broad range of soil and climate conditions (Willms et al., 2005) and their ability to withstand heat and drought stress with less irrigation (Johnson, 2000). Major obstacles in developing native grasses for turf include a poor tolerance to mowing, low seed production, and extended summer dormancy. Native accessions being developed as turf cultivars must also demonstrate limited growth, fine-textured leaves, and quick recovery from damage caused by traffic and wear (Romani et al., 2002).

The native species buffalograss [*Buchloë dactyloides* (Nutt.) Engelm.] has been extensively studied and developed for use as a low-input turf. Its benefits include tolerance to mowing and a vigorous, stoloniferous growth habit, which allows for a dense, uniform turf (Johnson, 2008). However, it requires more mowing than other species in both optimal and low-input treatments (Brede, 2002). Another potential limitation for this species is that as a warm-season grass, buffalograss may be dormant during cool temperatures, which can limit its use in the northern United States (Johnson, 2003). Meyer and Pedersen (1999) evaluated buffalograss and blue grama [*Bouteloua gracilis* 'Alma' (Willd. Ex Kunth) Lag. ex Griffiths], another warm-season native species, as low-input alternatives and found that neither provided acceptable cover, color, or quality in Minnesota. Other native grasses that have been evaluated for use as low-input turf include prairie junegrass (Watkins and Clark, 2009), sheep fescue (*Festuca ovina* L.) (McKernan et al., 2001), and tufted hairgrass [*Deschampsia caespitosa* (L.) P. Beauv.] (Watkins and Meyer, 2005). Very few native turfgrass cultivars have been developed.

Prairie junegrass, a native, cool-season perennial bunchgrass, is found throughout the Northern Hemisphere and has several attributes that make it a useful low-input turfgrass. The species may, in the northern United States, provide earlier spring green-up and produce adequate turf stands earlier than buffalograss. Prairie junegrass exhibits drought tolerance (Milnes et al., 1998), has a flexible root system, which allows it to adapt to water availability (Mueller-Dombois and Sims, 1966), is adapted to sandy soil (Pammell et al., 1901–1904), and survives at extreme temperatures (Dixon, 2000). This species is also slow-growing (Dixon, 2000; Soovali and Bender, 2006), which could reduce mowing requirements. Prairie junegrass has been shown to have a very low seed set for self-pollination compared with cross-pollination (Smith, 1944).

The Estonian cultivar Ilo (Soovali and Bender, 2006) and two Dutch cultivars, Barleria and Barkoel, released by Barenbrug Holland B.V. (Oosterhout, The Netherlands) (Alderson and Sharp, 1994) are the only cultivars of *Koeleria macrantha* developed for use as turf and all were derived from European germplasm. 'Barkoel' was a top performer for turf quality compared with other native species in low-input turfgrass trials in Manitoba, Canada (Mintenko et al., 2002). In another low-input study, unimproved native prairie junegrass accessions displayed early spring green-up almost immediately after snow melt, sooner than many other species (Mintenko and Smith, 1999); this has also been observed in Minnesota (personal observation). Early spring green-up is highly desired in northern climates for improving the early-season aesthetic value and playability of warm-season turf surfaces. It is proposed that as a result of their local adaptation, North American prairie junegrass ecotypes can provide unique and beneficial traits to the University of Minnesota breeding program.

The diverse natural range of this species provides plant breeders with a broad genetic base from which to select important turfgrass quality traits. Significant variation has been shown among 48 globally diverse National Plant Germplasm System accessions of prairie junegrass on important seed production characteristics (Clark and Watkins, 2010a) and turf quality traits (Clark and Watkins, 2010b).

Quantifying the variation in North American germplasm will assist the breeder in choosing the appropriate characteristics, selection intensities, and mating designs to achieve top-performing cultivars. It is important to

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evaluate the presence of genetic variability in the base population before initiating a selection program, because limited variability will lead to less significant gains over time (Surprenant and Michaud, 1988). Understanding the phenotypic variation of morphological and agronomic traits within a breeding population is crucial to the plant breeder in determining the potential application of the material such as for turf (Wright et al., 1983).

Genetic variation and heritability estimates help predict the response to selection for desired traits (Dudley and Moll, 1969). Estimating heritability, which is the amount of phenotypic variation in a population resulting from genetic differences, is important in choosing appropriate traits for selection (Fehr, 1991). Selecting for characteristics with high broad-sense heritability will lead to faster and increased gains in the offspring than selecting for traits with low heritability (Browning et al., 1994). Highly heritable traits could be correlated with important or complex traits, and these interactions could be exploited by the plant breeder (Kenworthy et al., 2006).

The selection of material to advance in a breeding program can be based on the performance of the genotype per se as well as the performance of its relatives. Broad-sense heritabilities have been calculated for turfgrasses using replicated clones on both an individual plant basis as well as based on the performance of the clonal mean (Bokmeyer et al., 2009; Burton and DeVane, 1953).

In addition to evaluating individual genotypes, the performance of germplasm from specific collection sites should be examined to elicit if any pooled set has greater genetic potential than the other materials in the study; turfgrass breeders could then focus future collection efforts on the site that resulted in superior germplasm. Superior performance could be the result of a significant combining ability, a high mean performance of desired traits, sufficient variation within the population, or high heritability. The objectives of this study were to 1) identify superior performing genotypes of prairie junegrass; 2) estimate the genetic variation in native prairie junegrass collection sites; and 3) calculate broad-sense heritability estimates for important turfgrass quality traits.

Materials and Methods

Plant materials. Prairie junegrass germplasm was collected as seed from five sites in western Nebraska and four sites in northeastern Colorado in July 2005. At each collection location (each ≈1 ha), seed was harvested throughout the site from multiple plants based solely on the presence of mature seed. In Fall 2005, plants were grown from seed and planted into a nursery at the University of Minnesota in St. Paul, MN. In June 2006, after inflorescence emergence and before anthesis, plants from each collection site were transplanted into No. 3 pots and placed into isolated crossing blocks (one block for each of the collection sites). The crossing blocks for the Nebraska collection sites (KN 1–5) were composed of 17, 22, 19, 16, and nine plants, respectively. The crossing blocks for the four Colorado collection sites (KC 1,3–5) were composed of 15, 20, 27, and five plants, respectively. Plants were watered regularly to reduce stress. Plants within a crossing block were allowed to intercross, and seed was harvested from each plant individually. In 2006, seed was also collected from a small native grass area in southeastern Minnesota. The Minnesota plant material was treated as its own crossing block with 17 maternal plants. Seed collected at the Minnesota site was harvested from individual plants as was done with the isolated crossing blocks.

Seed was germinated from each plant within a crossing block and from the Minnesota collection site. Thirty seedlings were randomly selected from each of the 10 crossing block populations for a total of 300 genotypes. The selected genotypes were vegetatively propagated to produce 10 clonal propagules each. Genotypes were labeled to indicate the origin of the material; for example, an individual was labeled as "KC1-2a" where "KC" refers to the region (KC = Colorado, KN = Nebraska, and WD = Minnesota); "1" refers to the collection location within the region, "2" refers to the plant in the crossing block, and "a" refers to the seedling (all seedlings from a single maternal plant would be considered half-sibs). The Minnesota seedlings are labeled as "WD10-1," where "10" refers to the maternal plant and "1" to the seedling.

On 20 June 2007, 300 genotypes were planted in a randomized complete block design consisting of five replications at two locations [University of Minnesota–St. Paul Campus, St. Paul, MN (lat. 44°59′23″ N, long. 93°10′28″ W), and the Sand Plains Agricultural Experiment Station, Becker, MN (lat. 45°23′47″ N, long. 93°53′21″ W)]. Plants were transplanted into dead sod as spaced plants on 30.5-cm centers. The soil at St. Paul is a Waukegan silt loam (fine-silty over sandy, mixed, mesic Typic Hapludoll) with pH 6.5, and the soil at Becker is a Hubbard loamy sand (sandy, mixed, frigid Entic Hapludoll) with pH 6.9. Fertilizer was applied at a rate of 24 kg N ha^{-1}, 48 kg P_2O_5 ha^{-1}, and 24 kg K_2O ha^{-1} at the time of planting. At Becker, 0.64 cm of water was applied each week in two irrigation events. At St. Paul, an equivalent volume of water was applied each week with daily irrigation events. Irrigation was only provided at each location from the time of planting until 21 Aug. 2007. Pendimethalin (LESCO, Cleveland, OH), a pre-emergent herbicide, was applied each spring to control weeds at a rate of 1.68 $kg{\cdot}ha^{-1}$ a.i. Plots were weeded manually as needed throughout each growing season. After establishment, plots were mowed to 6.4 cm weekly. In early spring 2009, plots were mowed twice weekly to remove emerging seedheads and to encourage vegetative growth.

Evaluation of traits. All traits were evaluated at both locations; however, several traits were evaluated in only 1 year or analyzed separately for different years. Rust severity (unknown *Puccinia* spp.) was rated in 2007 at Becker (9 Sept. 2007) and St. Paul (30 Aug. 2007) using a 1–9 scale (9 = least disease symptoms). Inflorescence emergence was rated at Becker (6 June 2008) and St. Paul (7 June 2008) using a 1–9 scale to describe the number of inflorescences observed in relation to a plant's size (9 = no inflorescences, 1 = all tillers flowering). Two weeks after the inflorescence rating, straw persistence was rated on a 1–9 scale as the amount of straw debris present in the verdure after 2 weeks of mowing (9 = least amount of straw and/or debris). Spring green-up was visually rated at Becker (24 Apr. 2009) and at St. Paul (25 Apr. 2009) using a 1–9 scale (9 = most green). Lateral spread [diameter (mm) at 4 cm above the soil] was measured at the widest expanse of the crown in one direction as well as measurements taken on vertical regrowth 1 week after mowing (longest leaf blade in mm) on 11 June 2009 at Becker and 15 June 2009 at St. Paul.

Turfgrass performance characteristics including turf quality (overall uniformity, density, texture, color, etc.), density, texture, and color were evaluated on a 1–9 scale (9 = best rating for the specific trait) following the guidelines provided by the National Turfgrass Evaluation Program (NTEP) (Morris and Shearman, 2008). A rating of 5.0 or higher indicated acceptable performance for that trait (modified from NTEP guidelines to reflect that the germplasm was not advanced breeding material or cultivars). A similar scale was used to score mowing quality, i.e., the amount of leaf shredding (9 = no shredded leaf tips). Turf quality ratings were taken Aug. to Nov. 2007, May to Oct. 2008, and May to Aug. 2009, and averaged for each year. Density was rated once in 2007 and then twice in 2008 and 2009. Mowing quality and color were rated once each year.

Analysis of data. Analysis of variance was calculated for each variable to compare the mean performance by genotype, collection site, and/or collection region (Minnesota, Colorado, or Nebraska) using PROC GLM (SAS Institute, Cary, NC). Data were analyzed across environments (locations and years) and variances were estimated (Gordon et al., 1972). Mean separation analyses (least significant difference 0.05) were performed on genotypic means for trial location separately as a result of a significant difference between Becker and St. Paul for most variables. Mean separation analysis was also performed on collection location means and on collection region means. Correlation coefficients were calculated among the turfgrass performance traits using PROC CORR (SAS Institute, 2002).

Broad-sense heritability estimates were calculated on an entry-mean basis from restricted maximum likelihood (REML) variance and covariance components using the random model of PROC MIXED (Bokmeyer et al., 2009; Bonos et al., 2004; Burton and DeVane, 1953; SAS Institute, 2002). The F- and *P* values were calculated using the appropriate error term based on the split-plot design of this study. Broad-sense heritability was calculated on a clonal basis as well as on a single-plant basis (Bokmeyer et al., 2009). The following models were used:

$$Hc = \sigma^2_c/(\sigma^2_c + \sigma^2_{cy}/y + \sigma^2_{cl}/l + \sigma^2_{cr(1)}/rl + \sigma^2_{cyl}/ly + \sigma^2_e/rly)$$

$$Hsp = \sigma^2_c/(\sigma^2_c + \sigma^2_{cy} + \sigma^2_{cl} + \sigma^2_{cr(1)} + \sigma^2_{cyl} + \sigma^2_e)$$

where σ^2_c = the total genetic variance of clones, σ^2_{cy} = clone × year variance, σ^2_{cl} = clone × location variance, $\sigma^2_{cr(l)}$ = clone × replication within location variance, σ^2_{cyl} = clone × year × location variance, and σ^2_e = experimental error (clone × year × replication within location). The denominators used for Hc indicate the number of replications (five), replications within locations (10), locations (two), and years (2 or 3 depending on the trait evaluated) (Bokmeyer et al., 2009; Poehlman and Sleper, 1995).

Results and Discussion

Analysis of genotypes. Data were analyzed as a randomized complete block design. Variance component estimates and descriptive statistics are shown for rust severity, inflorescence emergence, straw persistence, spring green-up, vertical regrowth (mm), and lateral spread (mm) (Table 1). Table 1 demonstrates that the sources of variation can be quite different for each trait. For example rust severity, vertical regrowth, and lateral spread exhibited greater variation as a result of the environment. Rust was significantly more prevalent at the Becker location. The low variation of replication within a location for rust severity, inflorescence emergence, and straw persistence suggests that the experimental design was adequate for each location. Analysis of variance revealed significant variation for important turfgrass performance traits (turf quality, density, mowing quality, and color) among the native prairie junegrass clones (Table 2). Broad-sense heritability estimated from REML variance components on a clonal means basis were moderate for overall turf quality (H = 0.62) and three turf quality components: density (H = 0.55), mowing quality (H = 0.59), and color (H = 0.45) (Table 2). Using clones replicated over multiple years and locations accounts for a significant amount of the genotype × environment variance, thus removing it from the genetic variance (Bokmeyer et al., 2009; Burton and DeVane, 1953). The broad-sense heritability estimates based on a single plant were considerably lower: for average turf quality, H = 0.13; for density and mowing quality, H = 0.09; and for color, H = 0.06. Correlation coefficients were calculated for several of the traits and reported in Table 3.

Analysis of collection site. Mean separation analysis was conducted on the means of germplasm from the 10 collection sites (Table 4). There was a significant location effect for each of the traits ($P < 0.05$) (analysis of variance data not shown). Plants from the Minnesota collection site (WD) had the lowest severity for rust (2007) at Becker and St. Paul. At Becker, the WD plants had a significantly higher rating for inflorescence emergence. The plants from this collection site were also the tallest at both locations and had the lowest mowing quality rating. Plants from KC1 demonstrated the largest lateral spread at St. Paul (107.83 mm). This collection location also had the highest average turf quality rating at St. Paul and although ranking first at Becker, it did not differ significantly from several other collection locations at Becker.

Analysis by collection region. Means separation analysis was conducted by collection region (Table 5). There was a significant location effect for many of the traits ($P < 0.05$). The germplasm derived from Minnesota had the lowest incidence of rust in 2007 and 2009. At St. Paul there were no differences in inflorescence emergence. The persistence of straw was rated the highest for the germplasm from Colorado. Spring green-up was different between the locations with the Minnesota population having a higher rating at St. Paul and Colorado and Nebraska populations having the higher rating at Becker. The Minnesota germplasm had taller plants at both locations. At both locations, the Colorado germplasm had the largest lateral spread, whereas Minnesota germplasm had the smallest lateral spread.

The Colorado population had the overall best turf quality over years and locations with the exception of at Becker in 2009 where all collection regions performed similarly (data not shown). There was no difference in turf quality performance between Colorado and Nebraska populations at Becker, but the Colorado population did perform better than either Nebraska or Minnesota at St. Paul. At Becker, there was no difference in density or color among the populations. At St. Paul, the Colorado population had the best ratings for density and mowing quality.

The range of variation in the germplasm indicates that there is potential for developing prairie junegrass cultivars for use as a low-input turf. Under low-input conditions, a number of genotypes showed an average turf quality performance of 5.0 or higher (data not shown). Moderate broad-sense heritability estimates were calculated for turf quality, density, mowing quality, and color. Improving overall turf quality in a breeding program is typically done through recurrent selection on multiple traits because most cultivars of cross-pollinated perennial grasses are typically bred to develop synthetic varieties or improved populations (De Araujo and Coulman, 2002). The strong correlations (Table 3) between turf quality and density, lateral spread, spring green-up, and color is promising for the breeder for increased gains in multi-trait selection for these important traits (Vogel et al., 1989). Multi-trait selection for turf quality and spring green-up could improve both of these traits simultaneously.

The germplasm in this study exhibited variation in crown density. Higher turf density reduces weed pressure and results in a uniform appearance. Plant density was influenced by environmental factors such as crown damage from mowing and freezing and by genetic factors including tiller die-out after flowering, growth habit, and plant architecture. The long-term perenniality of this species is not known, although when grown as unmown plants, center die-off was apparent at 6–7 years (Looman, 1978).

The moderate clonal broad-sense heritability estimate for mowing quality in our study suggests that direct phenotypic selection for this trait should result in significant gains. Early studies of prairie junegrass in low-input trials indicated that improving poor mowing quality would be necessary. The shredding of leaf tips, which is attributed to tough vascular bundles, has been observed in some perennial ryegrass cultivars and gives the mowed surface an unacceptable appearance

Table 1. Variance component estimates and descriptive statistics for turfgrass performance traits of native prairie junegrass genotypes grown at two locations, Becker and St. Paul, MN.

	Variance estimates					
Source	Rust severity[z]	Inflorescence emergence	Straw persistence	Spring green-up	Vertical regrowth (mm)[y]	Lateral spread (mm)[x]
Location	6.18 ± 4.12	0.24 ± 0.16	0.03 ± 0.02	2.12 ± 1.41	242.82 ± 161.88	426.43 ± 284.35
Genotypes	0.30 ± 0.02	0.30 ± 0.01	0.11 ± 0.00	0.13 ± 0.00	32.16 ± 26.24	50.71 ± 288.28
Genotype*location	1.57 ± 0.03	0.72 ± 0.01	0.16 ± 0.00	0.42 ± 0.00	5.42 ± 19.34	127.02 ± 399.13
Replication (location)	0.05 ± 0.00	0.03 ± 0.00	0.01 ± 0.00	0.15 ± 0.00	66.08 ± 893.18	133.72 ± 3675.91
Error	2.48 ± 0.01	2.85 ± 0.01	0.89 ± 0.00	1.67 ± 0.00	225.44 ± 49.51	555.57 ± 301.28
Mean	3.01	7.14	5.30	5.16	86.23	83.83
Minimum	1	1	1	1	1	2
Maximum	9	9	9	9	190	219

[z] Rust severity, inflorescence emergence, straw persistence, and spring green-up were rated using a 1–9 scale, where 9 equals the best performance for that trait.

[y] Vertical regrowth (mm) was measured as the length of the longest leaf blade of each plant one week after mowing at 6.4 cm.

[x] Lateral spread measured as the diameter of the crown at its widest point at a height of 4 cm.

Table 2. Analysis of variance and broad-sense heritability estimates of turf quality, density, mowing quality, and color of 300 prairie junegrass clones grown at Becker and St. Paul, MN, over 3 years (2007 to 2009).

	Turf quality[z]					Density[y]				
	df	MS	F value	*P* value	Var. comp.[x]	df	MS	F value	*P* value	Var. comp.
Year	2	118.22	53.02	<0.0001		2	1958.12	496.69	<0.0001	
Location	1	833.19	231.52	<0.0001		1	355.65	49.06	<0.001	
Replication (location)	8	3.60	1.61	NS		8	7.25	1.84	NS	
Year × location	2	153.81	68.98	<0.0001		2	237.69	60.29	<0.0001	
Year × replication(location)	16	2.23	5.63	<0.0001		16	3.94	6.35	<0.0001	
Clone	299	4.29	6.12	<0.0001	0.0957	299	5.20	5.02	<0.0001	0.1014
Year × clone	598	1.05	2.65	<0.0001	0.0295	598	1.90	3.05	<0.0001	0.0476
Location × clone	299	1.43	2.04	<0.0001	0.0222	299	2.04	1.97	<0.0001	0.012
Year × location × clone	595	0.82	2.07	<0.0001	0.0812	590	1.47	2.37	<0.0001	0.1681
Clone × replication (location)	2339	0.70	1.77	<0.0001	0.0949	2324	1.03	1.67	<0.0001	0.1286
Error	4364	0.40			0.4156	4321	0.62			0.6448
	Hc[w]	0.62				Hc	0.55			
	Hsp[w]	0.13				Hsp	0.09			

	Mowing quality[v]					Color[u]				
	df	MS	F value	*P* value	Var. comp.	df	MS	F value	*P* value	Var. comp.
Year	2	373.49	50.26	<0.0001		1	1603.64	596.05	<0.0001	
Location	1	488.94	34.47	<0.001		1	148.86	21.16	<0.01	
Replication (location)	8	14.18	1.91	NS		8	7.04	2.61	NS	
Year × location	2	376.33	50.64	<0.0001		1	332.17	123.46	<0.0001	
Year × replication (location)	16	7.43	5.45	<0.0001		8	2.69	6.16	<0.0001	
Clone	299	6.85	4.20	<0.0001	0.1604	299	2.16	4.53	<0.0001	0.039
Year × clone	598	2.65	1.94	<0.0001	0.0847	299	1.31	2.99	<0.0001	0.0637
Location × clone	299	2.22	1.36	<0.0001	0.0276	299	0.79	1.65	<0.0001	0.0006
Year × location × clone	573	1.96	1.43	<0.0001	0.1203	298	0.72	1.64	<0.0001	0.064
Clone × replication (location)	2317	1.63	1.20	<0.0001	0	2319	0.48	1.09	<0.05	0.0142
Error	3766	1.36			1.4626	2267	0.04			0.4432
	Hc	0.59				Hc	0.45			
	Hsp	0.09				Hsp	0.06			

[z] Turf quality ratings were taken at least twice monthly and averaged for each year on a 1–9 scale (9 = best quality).

[y] Density was rated once in 2007, and twice each year after, using a 1–9 scale (9 = highest crown density).

[x] Variance components were determined using restricted maximum likelihood estimation (REML) using PROC MIXED in SAS.

[w] Broad-sense heritability was determined from variance components using the following equations:

$$Hc = \sigma^2_c \Big/ \left(\sigma^2_c + \sigma^2_{cy} \Big/ y + \sigma^2_{cl}/l + \sigma^2_{cr(1)} \Big/ rl + \sigma^2_{cyl} \Big/ ly + \sigma^2_e/rly\right)$$

$$Hsp = \sigma^2_c \Big/ \left(\sigma^2_c + \sigma^2_{cy} + \sigma^2_{cl} + \sigma^2_{cr(1)} + \sigma^2_{cyl} + \sigma^2_e\right)$$

where c = cultivar, y = year, l = location, r = replication, and e = error.

[v] Mowing quality was rated once in 2007 and two times in 2008 and 2009 on a 1–9 scale (9 = best quality, least shredding).

[u] Color was rated once in 2008 and once in 2009 using a relative 1–9 scale (9 = darkest green plant in the study).

HC = clonal mean; Hsp = single plant.

NS = nonsignificant.

Table 3. Correlation coefficients among several turfgrass performance characteristics of prairie junegrass accessions at St. Paul, MN, above and Becker, MN, below.

	Spring green-up	Vertical regrowth (mm)[z]	Lateral spread (mm)[y]	Avg turf quality	Density	Mowing quality	Color
Spring green-up		0.31***	0.49***	0.46***	0.38***	–0.08**	0.05*
Vertical regrowth	0.37***		0.21***	0.13***	0.10***	–0.23***	0.04 NS
Lateral spread	0.61***	0.36***		0.53***	0.42***	–0.10***	0.04 NS
Average turf quality	0.61***	0.30***	0.69***		0.78***	0.11***	0.20***
Density	0.31***	0.25***	0.49***	0.73***		0.08***	0.22***
Mowing quality	–0.18***	–0.22***	–0.13***	–0.01 NS	0.01 NS		0.01 NS
Color	0.05 NS	0.10***	0.09**	0.27***	0.28***	0.02 NS	

*, **, ***Significant at the 0.05, 0.01, and 0.001 levels, respectively.

[z] Vertical regrowth (mm) was measured as the length of the longest leaf blade of each plant one week after mowing at 6.4 cm.

[y] Lateral spread (mm) was measured as the diameter of the crown at its widest point at a height of 4 cm.

NS = nonsignificant.

(Turgeon, 2005). Mowing quality was based on the 6.4-cm mowing height, and thus plants that were shorter than this height would have received a higher mowing quality rating. A benefit to these very low- and/or slow-growing plants is that they could be used in developing cultivars that would have very reduced mowing requirements.

The broad-sense heritability estimate for color, which was only calculated from 2 years of data, is biased upward as a result of underlying genotype × environment variance that was not accounted for (Poehlman and Sleper, 1995). Genetic color of this species ranges from blue–gray to blue–green to greenish yellow to dark green. The NTEP guidelines for rating genetic color are not well suited for this species because there is no accepted standard from which to judge. In the future, a more appropriate rating would be to categorize the genotypes using a Munsell-type color chart. Alternatively, the use of digital image analysis has been shown to be an accurate way of quantifying color ratings and can improve heritability estimates (Karcher and Richardson, 2003).

Table 4. Mean separation analysis of selected turfgrass performance characteristics of prairie junegrass collection sites grown in low-input conditions and mowed weekly from 2007 to 2009 at Becker and St. Paul, MN.

	Rust severity 2007^z		Inflorescence emergence		Straw persistence		Spring green-up		Vertical regrowth^y (mm)	
	Becker	St. Paul	Becker	St. Paul	Becker	St. Paul	Becker	St. Paul	Becker	St. Paul
KC1	1.09	5.68	3.83	3.40	5.99	5.46	3.58	6.07	66.52	92.82
KC3	1.15	4.39	2.93	2.21	5.51	5.25	4.10	6.57	72.39	96.84
KC4	1.37	5.80	3.27	2.20	5.15	5.14	3.29	5.76	72.82	92.93
KC5	1.48	5.20	3.36	2.69	5.84	5.26	3.47	6.31	68.85	97.84
KN1	1.09	4.05	2.87	2.40	5.66	5.11	4.20	6.24	73.84	100.41
KN2	1.21	5.97	2.83	2.36	5.30	5.14	3.36	5.87	70.03	95.96
KN3	1.07	5.01	2.68	2.10	4.84	4.99	3.86	6.07	69.12	96.75
KN4	1.21	4.11	2.48	2.44	5.28	4.89	4.72	6.44	70.56	92.44
KN5	1.47	5.35	3.23	2.99	5.65	5.42	3.99	6.66	75.40	100.25
WD	1.00	2.13	4.51	2.55	5.18	5.09	4.53	5.66	86.91	106.79
LSD$_{0.05}$	0.25	0.58	0.54	0.34	0.27	0.21	0.40	0.32	3.46	4.02

	Lateral spread^x (mm)		Turf quality		Density		Mowing quality		Color	
	Becker	St. Paul	Becker	St. Paul	Becker	St. Paul	Becker	St. Paul	Becker	St. Paul
KC1	65.50	107.83	4.01	5.12	4.90	5.60	5.43	5.15	4.71	5.60
KC3	72.32	102.60	4.01	4.82	4.99	5.27	5.17	4.78	5.13	5.27
KC4	56.61	92.78	3.85	4.50	4.87	5.11	5.44	4.62	5.07	5.11
KC5	60.46	102.32	3.81	4.81	4.74	5.34	5.42	4.85	4.95	5.34
KN1	80.73	102.50	3.94	4.57	4.95	5.16	4.84	4.13	5.08	5.16
KN2	57.08	94.50	3.45	4.34	4.58	4.96	5.13	4.30	4.94	4.96
KN3	61.70	93.49	3.85	4.47	4.95	5.14	5.23	4.41	5.05	5.14
KN4	69.78	95.25	3.91	4.36	4.75	4.88	5.17	4.73	4.78	4.88
KN5	66.59	101.53	3.84	4.63	4.81	5.22	4.99	4.17	4.94	5.22
WD	72.15	85.11	3.66	4.15	4.77	4.63	4.24	3.53	4.98	4.46
LSD$_{0.05}$	7.58	5.50	0.18	0.12	0.21	0.13	0.22	0.15	0.14	0.12

^{z}Rust severity, inflorescence emergence, spring green-up, turf quality, density, mowing quality, and color were rated using a 1–9 scale, where 9 equals the best performance for that trait.

^{y}Vertical regrowth (mm) was measured as the length of the longest leaf blade of each plant one week after mowing to 6.4 cm.

^{x}Lateral spread (mm) was measured as the diameter of the crown at its widest point at a height of 4 cm.

KC = Colorado; KN = Nebraska; WD = Minnesota; LSD = least significant difference.

Table 5. Mean separation analysis of selected turf quality characteristics of prairie junegrass collection locations pooled by collection region (Colorado, Nebraska, Minnesota) at Becker and St. Paul, MN, grown in low-input conditions and mowed weekly from 2007 to 2009.

	Rust severity 2007^z		Inflorescence emergence		Straw persistence		Spring green-up		Vertical regrowth^y (mm)	
	Becker	St. Paul	Becker	St. Paul	Becker	St. Paul	Becker	St. Paul	Becker	St. Paul
Colorado	1.28	5.28	3.35	2.64	5.63	5.28	3.64	6.18	70.1	95.15
Nebraska	1.21	4.9	2.82	2.45	5.34	5.11	4.03	6.25	71.67	97.11
Minnesota	1	2.13	4.51	2.55	5.18	5.09	4.53	5.66	86.91	106.79
LSD$_{0.05}$	0.17	0.41	0.37	0.24	0.19	0.15	0.27	0.23	2.34	2.79

	Lateral spread^x (mm)		Turf quality		Color		Mowing quality		Density	
	Becker	St. Paul	Becker	St. Paul	Becker	St. Paul	Becker	St. Paul	Becker	St. Paul
Colorado	72.15	101.56	3.92	4.82	4.98	4.78	5.37	4.85	4.87	5.33
Nebraska	67.48	97.39	3.8	4.47	4.96	4.76	5.07	4.35	4.81	5.07
Minnesota	64.23	85.11	3.66	4.15	4.96	4.46	4.24	3.53	4.77	4.63
LSD$_{0.05}$	5.18	3.84	0.13	0.08	0.10	0.08	0.16	0.11	0.14	0.10

^{z}Rust severity, inflorescence emergence, spring green-up, turf quality, density, mowing quality, and color were rated using a 1–9 scale, where 9 equals the best for that trait.

^{y}Vertical regrowth (mm) was measured as the length of the longest leaf blade of each plant one week after mowing to 6.4 cm.

^{x}Lateral spread (mm) was measured as the diameter of the crown at its widest point at a height of 4 cm.

LSD = least significant difference.

Lateral spread and vertical regrowth were measured as indicators of plant vigor and were correlated at both locations on an individual genotype basis. However, on a collection region basis, the largest vertical regrowth was for the Minnesota population, which had the smallest lateral spread. Multiple trait selection on lateral spread, density, and turf quality is important because they are essential components of an adequately covered and uniform turf stand. Data on plant vertical regrowth were useful in identifying lower growing genotypes but did not give a better understanding of plant vigor. The poor mowing quality made it difficult to consistently identify individual leaf blades, which had been mown the prior week, to accurately measure regrowth. Other plants in the study were slow-growing and may not have been mown at all.

An unknown *Puccinia* species caused rust disease symptoms on a number of genotypes. Prairie junegrass is known to be susceptible to *P. graminis* (Looman, 1978) and *P. koeleriae* (Mains, 1933). Infection was first observed in August each year and persisted each fall. Multiple locations should be used to screen the germplasm for identifying resistant material because different rust species and races may be present in different years and locations.

Broad-sense heritability on clonal means only provides an estimate for the specific germplasm in the study (i.e., the clones) in these environments (Dudley and Moll, 1969). Because broad-sense heritability accounts for all genetic effects (additive, dominant, and epistatic), this should be the maximum heritability expected when selection is based on clonal replications (Bokmeyer et al., 2009). Improvement on phenotyping accuracy could improve heritability estimates by reducing error variation.

The low broad-sense heritability estimates based on single plants indicates that selection based on non-replicated plants in only one environment would not be efficient in improving any of the traits. The moderate broad-sense heritability estimates on clonal means suggest that environment does play a significant role in these traits and that multiple replications in several environments (locations and/or years) should be used in screening and selecting superior genotypes. Breeding progress can be expected in the material evaluated in this study because significant genetic variability for desired traits was observed. The moderate broad-sense heritability estimates on turf quality, color, density, and mowing quality suggest that gains are possible for these traits.

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