Classification and Inheritance of Morphological and Agronomic Characteristics in Kentucky Bluegrass (*Poa pratensis* L.)

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Abstract. The apomictic breeding behavior of Kentucky bluegrass (*Poa pratensis* L.) results in many unique cultivars. A classification system was previously developed to characterize the large number of Kentucky bluegrass cultivars into different types. However, many new cultivars have been released since the last refinement of the classification system. The objectives of this study were to determine differences in morphological and agronomic characteristics among select Kentucky bluegrass cultivars representing the major classification types and to determine broad-sense heritability estimates for important morphological (plant height, panicle length, flag leaf height, and flag leaf length and width) and agronomic (rhizome spread) traits in Kentucky bluegrass. A spaced-plant nursery trial was established in the spring of 2003 at Adelphia, NJ. One hundred seventy-three cultivars and selections were planted in a randomized complete block design with three replications. The morphological and agronomic traits listed were measured on spaced plants. High Density type cultivars (formerly the Aggressive type cultivars) had the most prostrate growth habit with plant heights of 33 and 43 cm in 2004 and 2005, respectively. Mid-Atlantic and Texas × Kentucky bluegrass hybrids had the widest rhizome spread (Mid-Atlantic = 73 and 121 cm; Texas × Kentucky bluegrass hybrids = 72 and 122 cm) in 2004 and 2005, respectively. Broad-sense heritability estimates were high for plant height ($H = 0.84$), panicle length ($H = 0.88$), flag leaf height ($H = 0.85$), and rhizome spread ($H = 0.85$); moderate for flag leaf length ($H = 0.71$); and low for flag leaf width ($H = 0.11$). This study characterizes new cultivars into respective groups and identifies the genetic inheritance of important morphological and agronomic traits in Kentucky bluegrass.

Kentucky bluegrass (*Poa pratensis* L.) is a perennial turfgrass species that is widely adapted to many distinct environments. The extensive rhizome system of Kentucky bluegrass gives it the ability to tolerate and recover from many environmental stresses more quickly than bunch-type species (Bonos and Murphy, 1999; Meyer and Funk, 1989).

Kentucky bluegrass reproduces through an asexual process called apomixis. Apomixis allows for the development of true-to-type seed from the maternal plant (Bashaw and Funk, 1987; Funk, 2000; Turgeon, 1999). It reduces outcrossing, which serves to prevent recombination and fix hybrid vigor (Bicknell and Koltunow, 2004). This results in many unique genotypes of Kentucky bluegrass. This is beneficial because once superior genotypes are identified, they can be preserved through apomixis and produce uniform, stable cultivars (Bashaw and Funk, 1987; Funk, 2000).

A classification system was previously developed to characterize the large number of Kentucky bluegrass cultivars based on common growth and performance characteristics (Bara et al., 1993; Bonos et al., 2000; Murphy et al., 1997). This classification system was developed to characterize the similarities and differences between cultivars and as a guide to help turfgrass managers increase diversity and uniformity when developing blends of Kentucky bluegrass. The description of the classification types has been previously reported (Bonos et al., 2000; Murphy et al., 1997). Many new Kentucky bluegrasses have been developed since the previous classification based on spaced plants was completed and other older cultivars have been discontinued (Bonos, 2007; Bonos et al., 2000). Therefore, we felt it was important to characterize recently developed Kentucky bluegrass cultivars that are or will become commercially available.

Morphological and agronomic characteristics are used by breeders in the development of improved cultivars and by managers for specific cultivar selection. Plant height and rhizome spread are useful characteristics because a low-growing, aggressive spreading cultivar should be able to tolerate lower heights of cut, recover quickly, and fill in

damaged areas (Meyer and Funk, 1989). Leaf texture (measured here as leaf width) is also an important characteristic used in the development of new turfgrass cultivars. Fine leaf texture is typically correlated with higher shoot density in mowed turf situations (Bashaw and Funk, 1987; Turgeon, 1999). Turfgrass breeders have been selecting for higher shoot density for decades (Meyer and Funk, 1989) because it results in improved turf quality and better weed competition.

Because these traits are widely used to predict cultivar performance in a number of different environments, it would be helpful to turfgrass breeders to know the heritability of these morphological traits in Kentucky bluegrass. Broad-sense heritability estimates the total genetic effects influencing a trait and includes additive, dominance, and epistatic effects (Nyquist, 1991; Poehlman and Sleper, 1995). In crosspollinated species, narrow-sense heritability is typically more useful to plant breeders because it measures the additive gene effects, which are passed on to the progeny more predictably than dominant or epistatic gene effects (Poehlman and Sleper, 1995). However, when working with apomictic or asexually propagated crops, in which hybrid vigor and both additive and nonadditive gene action are fixed, estimates of broad-sense heritability are more appropriate (Poehlman and Sleper, 1995). This technique has been used by Berry et al. (1969) to calculate heritability of several agronomic traits in Kentucky bluegrass. Heritability partitions the phenotypic variation into genetic and environmental components so that the effect of the environment on a specific trait can be determined. Characters with low heritability are typically highly affected by the environment, and characters with high heritability are less affected by the environment. Therefore, characters with high heritability have little environmental influence and should be consistent in multiple environments.

Materials and Methods

One hundred seventy-three Kentucky bluegrass cultivars and selections were evaluated in this study (Table 1). These cultivars and selections represented all of the entries included in the 2000 National Kentucky bluegrass test sponsored by the National Turfgrass Evaluation Program (Morris, 2000). Single seedlings were transplanted into 48-cell flats (90 cm × 45 cm) and allowed to establish in the greenhouse. The plants were screened for apomixis in the greenhouse and all off-types were discarded. The plants were then established in a spaced-plant nursery at the Rutgers University Plant Biology and Pathology Research and Extension Farm in Adelphia, NJ, in April 2003 on a well-drained Freehold sandy loam (fine-loamy, mixed, mesic, Typic Hapludult). The experiment was established in a randomized complete block design with three replications. Four plants of each entry were planted per replicate for a total of 12 plants per entry. The

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Table 1. Kentucky bluegrass (*Poa pratensis* L.) cultivars and selections evaluated in a spaced-plant nursery established in May 2003.

Classification type	Cultivar or selection
High Density	HV 140 ^z , Limousine, Julius, North Star, Bariris
BVMG	Baron, Envicta, Goldrush, Abbey, Raven, Marquis
Common	Wellington, Kenblue
Compact	Wildwood, Hallmark, PST-B5-125 ^z , Blue-tastic, PST-B4-246 ^z , Alpine, Ascot, Ba 82-288 ^z , Skye, Diva, Goldstar, Princeton P-105, Chicago II, Moon Shadow, Moonlight, Blackstone
Compact-America	Bedazzled, Royale, Glenmont, PST-604 ^z , Brilliant, PST-222 ^z , Mallard, Apollo, Delight, Arrow, Dynamo, Casablanca, PST-H6-150 ^z , Valor, Boutique, Showcase, Kingfisher, Sonoma, Bordeaux, SR 2284, Langara, PST-B3-170 ^z , Baroness, Barnique, BAR Pp 0566 ^z , BAR Pp 0573 ^z , Unique
Compact-Midnight	Midnight, Midnight II, Quantum Leap, Arcadia, Unknown, Impact, Total Eclipse, Odyssey, NuGlade, Perfection, Tsunami, Ginney, Courtyard, Alexa, J-2885 ^z , Blue Velvet, Everest, Awesome, Excursion, Freedom III, EverGlade, Nu Destiny, Barrister, Beyond, Rugby II, Award, Freedom II, Liberator, Bluestone
CELA	Jefferson ^y
Julia	Avalanche, Pick 453 ^z , Rampart, H92-558 ^z , Julia
Mid-Atlantic	Eagleton, PST-161 ^z , Cabernet, Appalachian
Shamrock	Shamrock, Lakeshore, Moonshine, Katie, Brooklawn, Champagne, Durham, Mongoose, A98-1028 ^z , Champlain
Texas × Kentucky bluegrass hybrid	Thermal Blue, Longhorn
Other	Lily, Limerick, Bodacious, Boomerang, Cheetah, Yvette, Pp H 7929 ^z , Ulysses, Pp H 7907 ^z , Monte Carlo, Coventry, PST-108-79 ^z , Voyager II, Bluemax, PST-York Harbor 4, Blacksburg II, Blue Ridge, HV 238 ^z , Mercury, B5-43 ^z , B5-45 ^z , Markham, B5-144 ^z , Misty, Fairfax, Baronette, Ba 83-113 ^z , Ba 84-140 ^z , Chateau, CVB-20631 ^z , Chelsea, A97-1409 ^z , Allure, Blue Sapphire, NA-K992 ^z , SRX 26351 ^z , SRX 27921 ^z , Jewel, Blue Knight, DLF-76-9032 ^z , DLF-76-9034 ^z , DLF-76-9036 ^z , DLF-76-9037 ^z , SI A96-386 ^z , SRX 2114 ^z , SRX QG-245 ^z , 99AN-53 ^z , A98-407 ^z , A98-183 ^z , Royce, A98-365 ^z , Rambo, A96-739 ^z , PST-H5-35 ^z , B4-128A ^z , Washington, A96-742 ^z , A97-857 ^z , Bartitia, Baritone, Barzan, Baronie, Serene, Rita

^zDenotes experimental selection.

^yNot included in principal component analysis or Table 3 as a result of the limited number of cultivars.

field received 98 kg-ha⁻¹/year N using a 3.5–4.4–8.3 fertilizer (elemental nitrogen, phosphorus, and potassium, respectively) applied half in the spring and half in the fall. The field was mowed at a height of 20 cm twice per year, once after seed maturity and once before the onset of winter. Labeled pre-(DCPA and dithiopyr) and postemergence (dicamba and halosulfuron) herbicides were used to control broadleaf weeds, sedges, and *P. annua*. The field was not irrigated and no severe disease outbreaks were observed.

The agronomic and morphological characteristics were measured on spaced plants in 2004 and 2005 following the experimental methods required for Plant Variety Protection (PVP) applications (USDA, 2005). Plant morphological measurements (plant height, panicle length, flag leaf height, width, and length) were taken ≈2 weeks after anthesis, when all plant panicles were fully expanded (late-May to mid-July in both years). Plant height was measured from the soil surface to the average height of the majority of the panicles. Rhizome spread was measured, after mowing, in two directions perpendicular to each other and represented the longest extending rhizomes in those two directions. Rhizome spread measurements were used to characterize cultivars and selections that have been described as having extensive, spreading rhizome systems. Rhizome spread and plant height were taken on an individual plant basis with each plant receiving one

observation per plant. Data were collected on each of the four plants per replicate and averaged to obtain one value per replication. Panicle length, flag leaf height, and width and length measurements were calculated as the average of three separate flowering culms from each of the four plants per replicate. Panicle length was measured from the bottom node to the tip of the longest panicle. Flag leaf height was measured as the distance between the soil surface and the collar of the flag leaf. Flag leaf blade width was measured at the widest point on the flag leaf. Flag leaf blade length was measured from the collar to the tip of the blade. Flag leaf length and width measurements were used to characterize those types with distinct leaf texture differences such as narrow leaf blades. As a result of the large number of entries and the hot temperatures of late spring/early summer, plants were measured in order of maturity; which helped to minimize differences in the plant's response to desiccation caused by seed maturity.

Statistical analysis

Means separation of types. To determine differences in morphological and agronomic characteristics between the Kentucky bluegrass classification types, data from cultivars and selections within types were combined and subjected to analysis of variance. Means were separated using Fisher's protected least significant difference at the 0.05 *P* level

(Table 2). As a result of space restrictions, the data on individual cultivar responses were not included in this article. It was previously reported by Shortell et al. (2006).

Broad-sense heritability. All characteristics were subjected to analysis of variance to determine broad-sense heritability estimates on an entry-mean basis. Broad-sense heritability estimates were determined from restricted maximum likelihood variance and covariance components using the random model of Proc MIXED (Bonos et al., 2004) (SAS Institute, Cary, NC). Ninety-five percent confidence intervals for heritability estimates were determined according to Steel et al. (1997). This technique (or a variation thereof) has previously been used to calculate broad-sense heritability from clonally replicated turfgrass plants (Berry et al., 1969; Bonos et al., 2003; Burton and DeVane, 1953).

Principal component analysis. The relationships between cultivars and selections based on all morphological characteristics were tested using multivariate principal component analysis PROC PRINCOM (SAS Institute, Cary, NC) as used by Bonos et al. (2000) (Figs. 1 and 2). One hundred seventy-three cultivars and selections and seven morphological variables were included in the data set analyzed. However, the addition of the "Other" group of cultivars (66 cultivars or selections that possess characteristics intermediate between the two groups) in the principal component analysis graph made it difficult to see relationships between cultivars and selections within the major groups. Therefore, cultivars and selections in the "Other" group were omitted from the principal component analysis graph (Figs. 1 and 2; Table 1).

Results and Discussion

Significant differences between types were observed for all morphological measurements except flag leaf length and width in both years of the study (Table 2). Measurements in both 2004 and 2005, under spaced-plant conditions, indicated that the High Density (formerly Aggressive type), BVMG, and Compact (including Compact-Midnight and Compact-America) type cultivars evaluated in this study had the shortest plant heights. Common type cultivars and selections were the tallest entries in both years of the study. This is consistent with previous research (Bonos et al., 2000; Burt and Christians, 1990; Ebdon et al., 1998). Mid-Atlantic type and Texas × Kentucky bluegrass hybrids were intermediate in height. Compact and Compact-Midnight type entries had similar morphological traits in both years. Compact-America type cultivars and selections exhibited similar morphological traits as the BVMG types.

High broad-sense heritability estimates were observed for traits affecting plant stature [plant height: *H* = 0.84; panicle length: *H* = 0.88; and flag leaf height: *H* = 0.85 (Table 3)]. High heritability estimates have also been observed for plant height measurements in

Table 2. Morphological and agronomic characteristics of Kentucky bluegrass classification types established in a field trial in May 2003.

Type	Plant ht		Panicle length		Flag leaf ht		Rhizome spread		Flag leaf length		Flag leaf width	
	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005
Common	69	71	8	9	36	45	65	116	0.27	0.31	4.1	3.4
Julia	46	67	8	9	27	39	61	102	0.40	0.32	3.7	2.6
Mid-Atlantic	50	61	9	10	26	34	73	121	0.34	0.31	4.2	3.5
Shamrock	50	58	8	8	26	32	69	120	0.35	0.30	3.8	2.8
Other	45	55	8	8	24	32	58	101	0.33	0.29	3.7	3.1
TB × KB Hybrids ^z	51	53	8	8	34	39	72	122	0.35	0.33	5.1	3.6
Compact	47	53	8	8	25	29	62	108	0.31	0.28	3.7	3.0
BVMG	40	51	7	8	21	30	64	103	0.37	0.31	3.5	3.3
Compact-Midnight	43	50	8	8	23	29	60	101	0.31	0.28	4.1	3.3
Compact-America	38	47	7	7	23	30	47	79	0.31	0.29	4.2	3.3
High Density	33	43	5	6	15	23	47	74	0.31	0.26	3.1	2.5
Least significant difference _{0.05}	5	6	1	2	3	5	8	6	NS	NS	NS	NS
CV % ^y	22	24	17	19	20	21	23	24	NS	NS	NS	NS

^zTexas × Kentucky bluegrass hybrids.^yThe CV presented is the total CV for the analysis of variance.

NS = nonsignificant.

Fig. 1. Principal component analysis (PCA) of Kentucky bluegrass cultivars and selections based on morphological characteristics in 2004. PC1 accounted for 68.7% of the variation and was strongly influenced by rhizome spread. PC2 accounted for 22.5% of the variation and was strongly influenced by plant height.

Kentucky bluegrass (Pepin and Funk, 1974) and maize (*Zea mays* L.) (Soleri and Smith, 2002).

Low growth habit is a trait often selected for turfgrass breeding (Meyer and Funk, 1989). Plants with lower growth habits can typically tolerate closer mowing as a result of the lower placement of the crown relative to the soil surface and the slower rate of leaf elongation (Meyer and Funk, 1989; Turgeon, 1999). The high broad-sense heritability estimates observed for these traits indicate that they are under strong genetic control and not strongly affected by the environment. This indicates that selected plants should maintain a low growth habit across differing environments.

Rhizome spread is an indication of rhizome elongation and vigorous lateral growth. This is a beneficial characteristic in Kentucky bluegrass because plants with more lateral spread should be able to recover more quickly from stresses, including mowing or traffic. Mid-Atlantic type cultivars, Texas × Kentucky bluegrass hybrids, and Common type cultivars exhibited the most extensive rhizome spread (Table 2). This is a defining attribute of these types (Bonos et al., 2000; Murphy et al., 1997; Shortell et al., 2005), so it is not surprising that they exhibited the farthest spreading capability. Cultivars within the High Density and Compact-America types exhibited the shortest rhizome spread (Table 2) when evaluated as spaced plants.

The results for the High Density (formerly Aggressive) type cultivars are somewhat contradictory because this type exhibited aggressive rhizome growth in a previous study (Bonos et al., 2000). However, the only cultivar replicated in both trials was 'Limousine' and when grown as a spaced-plant in New Jersey, Limousine is very decumbent and slow-growing (personal observation). Previous studies have suggested that this type may dominate blends or mixtures at lawn-type cutting heights (Bonos et al., 2000; Murphy et al., 1997; Park et al., 2005). However, at fairway cutting heights, this group did not exhibit improved wear tolerance (Park et al., 2005; Shortell et al., 2005), which would be

Principal Component Analysis Year 2, 2005

Fig. 2. Principal component analysis (PCA) of Kentucky bluegrass cultivars and selections based on morphological characteristics in 2005. PC1 accounted for 73.3% of the variation and was strongly influenced by rhizome spread. PC2 accounted for 21.6% of the variation and was strongly influenced by plant height.

expected from a cultivar with aggressive spreading capabilities. Because of these contradictory results, this group has been renamed the High Density type (Shortell et al., 2006) because they may not exhibit aggressive spreading characteristics in all environments.

High broad-sense heritability estimates were observed for rhizome spread measurements (Table 3), which supports previous data collected on rhizome spread in Kentucky bluegrass (Berry et al., 1969; Pepin and Funk, 1974) and sand bluestem (*Andropogon hallii* Hack.) (Kneebone, 1958). However, selection for this trait when grown as a spaced plant is not necessarily correlated to aggressive lateral rhizome spread when maintained under frequently mowed (Brosnan et al., 2005) or worn turf conditions (Park et al., 2005).

There were no significant differences between Kentucky bluegrass classification types for flag leaf length or width, indicating that these measurements were not useful in differentiating the classification types. Additionally, flag leaf length was moderately heritable ($H = 0.71$) and flag leaf width was not heritable ($H = 0.11$) (data not shown). These results indicate that selection for fine or wide leaf texture may be difficult and that the phenotype may not be the same across environments. This agrees with the data reported by Simon (1999) on wheat (*Triticum aestivum* L.). However, earlier research on Kentucky bluegrass (Berry et al., 1969), perennial ryegrass (*Lolium perenne* L.) (Rogers, 1989), and bermudagrass (*Cynodon dactylon* [L.] Pers.) (Wofford and Baltensperger, 1985) has shown this trait to be more heritable.

Not surprisingly, leaf texture (or leaf width) has been shown to be correlated with plant and/or tiller density (Turgeon, 1999). Thereby, plants that have a high tiller density also have finer leaves and plants with low tiller density have wider leaves (Nilsen and Orcutt, 1996). This can be partially attributed to the space available for the plants to grow within the turfgrass community. If plants are not competing for space, leaves have the opportunity to elongate and widen to maximize photosynthesis (Nilsen and Orcutt, 1996). Additionally, as plants mature, flowering culms begin to desiccate and flag leaves start to senesce. As a result of the considerable number of plants to measure and a short timeframe for collecting these data in the field flag leaf width measurements may have been partly influenced by plant desiccation. Flag leaf width is a standard measurement required for PVP applications. Claims are often made regarding variety performance compared with other cultivars. The low heritability of this trait indicates that the flag leaf width measurement may not be as reproducible as once perceived.

Principal component analysis is used to take a large number of variables and convert them into a smaller number of informative factors that account for more variation than any one variable alone. These factors, or principal components, can then be visualized to determine whether any correlations exist. Principal components are created through matrix algebra using SAS. The residuals from a least squares estimation of the morphological parameters are used to construct a matrix. Principal components 1 to 6 are generated through a singular value decomposition of this matrix (Saxton, 2004). The resulting components are then ordered and the variation can be graphed.

Principal Component 1 (PC1) and Principal Component 2 (PC2) in 2004 accounted for 68.7% and 22.5% of the variation, respectively, or 91.2% of the total variation (Table 4). Principal Component 3 (PC3) raised the total variation to 95.6% but did not change the overall pattern of the graph and therefore is not presented. PC1 and PC2 in 2005 accounted for 73.3% and 21.6% of the variation, respectively, or 94.9% of the total variation (Table 4). PC3 raised the total variation to 99.8% but did not change the overall pattern and therefore is not presented. Rhizome spread had the strongest influence on PC1 and plant height had the strongest influence on PC2 in both 2004 and 2005. Certain cultivars and selections formed distinct clusters, including the Common, Shamrock, Compact-America, Compact-Midnight, and BVMG types in both 2004 and 2005 (Figs. 1 and 2). However, Compact-America types were more widely dispersed than the other groups in 2005.

Compact-America and Compact-Midnight cultivars did segregate, but the general Compact type was dispersed across both Compact-Midnight and Compact-America types. Mid-Atlantic, Texas $\times$ Kentucky bluegrass hybrids, and to some degree the Shamrock types were morphologically similar based on

Table 3. Analysis of variance and broad-sense heritability estimates (H) of plant height, panicle length, flag leaf height, and rhizome spread of 173 Kentucky bluegrass cultivars and selections (includes all entries of the 2000 National Kentucky bluegrass test sponsored by the National Turfgrass Evaluation Program) evaluated in 2004 and 2005 in a spaced-plant nursery established in Adelphia, NJ, in 2003.

	Plant ht				Panicle length			
	MS	F value	P value	Var. comp. ^z	MS	F value	P value	Var. comp.
Year	71,674.9	1,242.7	0.0008		58.5	67.8	0.0144	
Rep ^y	6,211.1	107.7	<0.0001		1.9	2.2	0.1162	
Year × rep	906.6	15.7	<0.0001		14.3	16.5	<0.0001	
Cult ^x	1,274.1	22.1	<0.0001	177.4	27.7	32.2	<0.0001	4.1
Cult × year	209.8	3.6	<0.0001	19.1	3.3	3.8	<0.0001	0.2
Cult × rep × year	95.1			15.9	2.0			0.3
H = 0.835 ^w 95% confidence interval for three-replicate mean heritability = 0.88–0.79					H = 0.881 95% confidence interval for three-replicate mean heritability = 0.93–0.84			
	Flag leaf ht				Rhizome spread			
	MS	F value	P value	Var. comp.	MS	F value	P value	Var. comp.
Year	43,923.7	2,585.2	0.0004		1,507,579.2	14,682.0	0.0001	
Rep	389.1	22.9	<0.0001		4,787.8	46.6	<0.0001	
Year × rep	545.2	32.1	<0.0001		1,899.5	18.5	<0.0001	
Cult	517.5	30.5	<0.0001	72.9	4,588.4	44.7	<0.0001	687.2
Cult × year	79.9	4.7	<0.0001	6.7	465.1	4.5	<0.0001	34.9
Cult × rep × year	39.6			6.6	255.4			42.6
H = 0.846 95% confidence interval for three-replicate mean heritability = 0.89–0.80					H = 0.846 95% confidence interval for three-replicate mean heritability = 0.88–0.79			

^zVariance components were determined using restricted maximum likelihood estimation using the random model of Proc Mixed Procedure in SAS (Cary, NC).

^yRep = replication.

^xCult = cultivar.

^wHeritability was determined from variance components using the following equation = σ^2_C / σ^2_P , where $\sigma^2_P = \sigma^2_C + \sigma^2_{CY} + \sigma^2_{CRY}$, where P = phenotype, C = cultivar, R = replication, and Y = year.

Table 4. Eigenvectors of the principal component axes (PC) from principal component analysis of Kentucky bluegrass types.^z

	PC1		PC2		PC3		PC4		PC5		PC6	
	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005
Character	Eigenvectors											
Plant height	0.41	0.27	0.70	0.92	-0.58	-0.30	0.04	-0.01	-0.05	0.00	0.00	0.00
Panicle length	0.04	0.03	0.08	0.02	0.06	0.06	0.21	0.80	0.97	-0.60	-0.01	-0.01
Flag leaf height	0.21	0.12	0.54	0.27	0.81	0.95	-0.10	-0.06	-0.08	0.04	0.00	0.00
Flag leaf length	0.00	0.00	0.01	0.00	0.09	0.00	0.97	0.60	-0.21	0.80	-0.03	-0.01
Flag leaf width	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.02	0.01	0.00	1.00	1.00
Rhizome spread	0.89	0.95	-0.46	-0.30	0.08	-0.03	0.00	-0.02	-0.01	0.01	0.00	0.00
Eigenvalue	249.98	553.14	81.72	162.95	16.08	36.73	14.97	1.40	0.90	0.44	0.00	0.00
Percentage of total variation	68.7	73.3	91.2	94.9	95.6	99.8	99.8	99.9	100.0	100.0	100.0	100.0

^zEigenvalues and their contribution to total variation are listed at the bottom of columns.

the traits studied in this experiment. This could be the result of the high correlation of PC1 to rhizome spread measurements. Julia types tended to weakly cluster within the Compact type grouping in 2004 (Fig. 1).

Similar clustering results were reported by Curley and Jung (2004) who evaluated a set of random amplified polymorphic DNA markers among Kentucky bluegrass cultivars and selections. They also found that Compact-Midnight type cultivars formed a distinct cluster separate from the other types evaluated in their study (Curley and Jung, 2004). In our study, Compact-Midnight types also formed a tight cluster, but it was within the general Compact type. Curley and Jung's genetic analysis with molecular markers also agrees with our morphological classification of the Common and BVMG types. This concordance between morphological and molecular-based analysis helps support the Kentucky bluegrass classification system, and further work using a combined approach could help add cultivars and selections from

the Other type into more defined groups. This combination of approaches could also help clarify existing classification groups and help discover new groups with unique traits and uses.

Conclusions

We found significant differences in morphological and agronomic traits between the classification types of Kentucky bluegrass, which is consistent with previous research. However, unlike previous studies, which are now outdated, this project reports on new, recently developed Kentucky bluegrass cultivars. High Density, BVMG, and Compact (including Compact-Midnight and Compact-America) type cultivars have the shortest plant heights. Mid-Atlantic, Texas × Kentucky bluegrass hybrids, and Common type cultivars exhibited the most extensive rhizome spread. Principal component analysis grouped Compact-Midnight and Compact-America types as clusters within the general

Compact type. Common types were consistently grouped separately from the other groups, whereas Mid-Atlantic, Texas × Kentucky bluegrass, and to some extent Shamrock types were grouped in close proximity to each other indicating that these groups have similar morphological characteristics. Principal component analysis results based on morphological measurements were similar to results based on molecular markers indicating that the similarity between groups is consistent with both marker types and should both be useful to help classify Kentucky bluegrass further.

Based on the data reported here, it should be possible to select Kentucky bluegrass genotypes with certain morphological and agronomic traits, including plant height, rhizome spread, panicle height, flag leaf height, and length that behave consistently across environments. This information will help breeders be more successful in developing cultivars with important morphological and agronomic characteristics. It will also be

useful to turfgrass managers in selecting blends of Kentucky bluegrass cultivars with complementary characteristics.

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