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Genetic Variability and Relationships for Adaptive, Morphological, and Biomass Traits in Chinese Bermudagrass Accessions

Y. Q. Wu,* C. M. Taliaferro, D. L. Martin, J. A. Anderson, and M. P. Anderson

ABSTRACT

Bermudagrass, *Cynodon dactylon* (L.) Pers., is geographically widely distributed and represents the most important taxon in the genus in terms of its extensive uses for turf, forage, soil stabilization, and remediation. This warm-season, sod-forming grass is indigenous to China, but limited information is available for adaptive, morphological, and biomass traits in the Chinese germplasm. Accordingly, objectives of this study were to quantify genetic variability for 24 morphological, adaptive, and biomass-related traits and to characterize relationships among traits of 114 Chinese clonal accessions in a field experiment at Stillwater, OK. 'Tifsport', 'Tifway', 'Midland', and 'Tifton 44' bermudagrass cultivars were used as controls in the field experiment. Differences among the accessions were significant ($P < 0.01$ or $P < 0.05$) and of large magnitude for all response traits. When grouped by ploidy level, variation among accessions was far greater in tetraploids (104) than in pentaploids (3) and hexaploids (7). Response traits of plant height, leaf blade length and width, and internode length and diameter were significantly and positively correlated with each other to various degrees. Biomass yield was significantly associated with the traits of spring greenup, plant height, winter kill rate, internode, and sod density. Winter kill was positively correlated with weed prolificacy, but negatively with spring greenup. Multiple regression and path coefficient analyses indicated plant height, winter kill, greenup, sod density, and internode size to be predictive of forage yield. The large amount of genetic variability among the Chinese accessions should be a valuable resource for the development of improved turf and forage cultivars.

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Abbreviations: AIL, average internode length; FLL, first leaf blade length on third node; FLW, first leaf blade width on third node; GC, genetic color; GCR, ground coverage; GUI, greenup rated on 9 Apr. 2002 and 29 Mar. 2003; GUII, greenup rated on 19 Apr. 2002 and 16 Apr. 2003; GUIII, greenup rated on 30 Apr. 2002 and 27 Apr. 2003; HNS, height without seedhead; HWS, height with seedhead; SD, sod density; SID, second internode diameter; SIL, second internode length; SL, stolon length; SLL, second leaf blade length on third node; SLW, second leaf blade width on third node; TID, third internode diameter; TIL, third internode length; WA, weed abundance; WCR, winter color retention; WK, winter kill.

Bermudagrass [*Cynodon dactylon* (L.) Pers.] is a polymorphic warm-season, sod-forming, perennial species widely used for turf, forage, soil stabilization, and remediation in warmer regions of the world (Harlan and de Wet, 1969; Beard, 1973; Taliaferro, 1995, 2003). The grass belongs to the tribe *Cynodonteae* Dumort., subfamily *Chloridoideae* Rouy, and family *Gramineae* Juss. (*Poaceae* Barnh.) (Clayton and Renvoize, 1986). The species is found on every continent and most islands between about 45°N and S latitudes. It penetrates to approximately 53°N in Europe and is found up to 3000 m elevation in South Asia and below sea level in West Asia and North Africa (Harlan and de Wet, 1969; Harlan et al., 1970). Variety *dactylon* is the cosmopolitan and ubiquitous taxon, and provides the most important and diverse genetic resources in the species for its use as forage and turf (Harlan, 1970; Taliaferro, 1995).

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There is enormous genetic variability available in bermudagrass, ranging from very small, fine-textured plants used for turf to large, leafy robust plants used as pasture grasses (Harlan and de Wet, 1969; Kneebone, 1973). The variability within *C. dactylon* var. *dactylon* was thought to have resulted from its interaction with two taxonomic varieties, *C. dactylon* var. *aridus* and var. *afghanicus* (Harlan and de Wet, 1969). In the United States, many superior turf bermudagrass cultivars were derived from bermudagrass germplasm imported primarily from Africa during the last century (Taliaferro, 1995; 2003). Juska and Hanson (1964) reported substantial variation among bermudagrass cultivars for morphological characteristics related to general turf use. Wofford and Baltensperger (1985) and Coffey and Baltensperger (1989) reported that variation in bermudagrass for various morphological and turf performance characters was heritable, and several traits including leaf length and leaf width had moderate to high narrow sense heritability values. Bermudagrass is the principal species used for turf in the southern United States, and other regions in the world with similar climatic conditions.

Burton (1947) reported a correlation coefficient of 0.80 between first year hay yield after establishment and the four-year total yield indicating that the hay yield for the first year should give an excellent index of later yield performance. De Silva (1991) observed significant amounts of genetic variation for shoot dry weight among populations collected in Sri Lanka. Avis et al. (1980) reported significant genotype × environment interactions for bermudagrass forage yield suggesting the necessity to use multiple environment testing through time (years) and space (locations) to characterize relative genotypic differences. Bermudagrass is grown on an estimated 10 to 12 million hectares in the southern United States for forage (Taliaferro et al., 2004).

The full range of genetic variability in *C. dactylon* is likely not represented in current germplasm collections and much potential exists to add valuable new germplasm to the collected pool (Taliaferro, 2003). Harlan (1970) noted that only a tiny fraction of the total germplasm that exists in the taxon had been studied and even less used in breeding improvement programs up to that time. The situation remains essentially the same, especially with respect to Asian germplasm.

Cynodon dactylon is indigenous to and widely distributed in China. The species is common in the southern region, ranging from tropical Hainan Island to a line connecting the northern edge of Sichuan province eastward to Shanghai. *Cynodon dactylon* is also found in northern China, especially in the region south of the Yellow River (Anonymous, 1990). In the far northwest China, *C. dactylon* is sparsely distributed in the southern and northern oasis plains in Xinjiang (Abulaiti et al., 1998). In southwestern China, it is present in natural settings including sites at approximately 3000 m in elevation in Yunnan, and in some valleys of Tibet. The wide geographic distribution suggests the potential for large variation in Chinese native *C. dactylon* germplasm. However, little information exists on genetic variation for agronomic and biological characters in native Chinese bermudagrass. In a previous study (Wu et al., 2006b), we reported significant variability among Chinese *Cynodon* accessions for seed yield and its components. This paper reports the results of research designed to assess genetic variation in traits related to vegetative growth and forage accumulation among 114 *C. dactylon* accessions from China. Specific objectives of the study were to (i) quantify genetic variability for morphological, adaptive, and biomass-related traits; and (ii) characterize relationships among traits.

MATERIALS AND METHODS

The Chinese *C. dactylon* accessions used in this study consisted of 114 clonal accessions described by Wu et al. (2006b). Bermudagrass cultivars 'Tifsport' (Hanna et al., 1997), 'Tifway' (Burton, 1966), 'Midland' (Hein, 1953), and 'Tifton 44' (Burton and Monson, 1978) were included as standards in the field study. The Chinese accessions comprised 104 tetraploids ($2n = 4x = 36$), three pentaploids ($2n = 5x = 45$), and seven hexaploids ($2n = 6x = 54$) (Wu et al., 2006a).

The experimental design and methods of establishing and managing the field plots were reported by Wu et al. (2006b). Briefly, greenhouse-grown clonal plants of each accession were transplanted to field plots on the Agronomy Research Station, Oklahoma State University, Stillwater, OK, in 2001. The experimental design was a randomized complete block with three replications. Plot size was 2.5 by 2.5 m separated by 0.5-m alleys between plots. The soil type was a Renfrow loam (fine, mixed, superactive, thermic Udertic Paleustoll). Fertilization and weed control practices were as reported by Wu et al. (2006b).

Response traits are listed in Table 1, along with information on time and method of evaluations. Ground coverage, winter color retention, greenup, genetic color, sod density, slime mold, leaf spot (caused by *Bipolaris cynodontis* Marignoni), and weed abundance were assessed by visual ratings of field plots. Stolon length (plant establishment rate), plant height with seedhead, and height without seedhead were measured in the field. In August of 2002 and 2003, five full-length stems were collected randomly in each plot and placed in a plastic bag, and then stored in a freezer at −20°C for subsequent measurements of morphological traits. The traits were (i) length of second and third internodes from the terminal end, and average over all internodes of each stem, (ii) diameter of second and third internodes, and (iii) lengths and widths of first and second leaf blades originating from the third node (Table 1). After collection of individual stems, aboveground biomass (subsequently referred to simply as biomass) samples were harvested from each plot by hand clipping a 0.3 by 0.3 m area. The biomass samples were dehydrated at 55°C (130°F) in forced air ovens for 72 h. The

Table 1. Duration and date of data collection, and methods of trait evaluations on 114 Chinese *Cynodon* accessions and four cultivars.

Duration	Date	Trait descriptor (abbreviation)	Method (per plot)
1-yr	13 Aug. 2001	Stolon length (SL)	Measurements (cm) of 10 longest stolons
	21 Sept. 2001	Ground coverage (GCR)	Visual estimate of plant coverage (%)
	10 July 2002	Slime mold (SM)	1– 9, 1 being no slime mold, 9 most seriously infected
	13 July 2002	Leaf spot (LS)	1–9, 1 being no leaf spot, 9 most seriously infected
	1 Aug. 2003	Weed abundance (WA)	1–9, 1 being least weeds, 9 most weeds
2-yr	9 Apr. 2002–29 Mar. 2003	Greenup (GUI)	1–9 scale, with 1 being brown, 9 completely green
	19 Apr. 2002–16 Apr. 2003	Greenup (GUII)	Same scale as for GUI
	30 Apr. 2002–27 Apr. 2003	Greenup (GUIII)	Same scale as for GUI
	30 Apr. 2002–1 May 2003	Winter kill (WK)	Visual estimate (%) of plant ground coverage killed
	10 May 2003–25 May 2003	Genetic color (GC)	1–9, with 1 being light green, 9 dark green
	12 May 2002–25 May 2003	Sod density (SD)	1–9, with 1 being least dense, 9 most dense
	8 Aug. 2002–2 Aug. 2003	Height with seedhead (HWS)	Measurements (cm) of five random plant heights with seedhead
	9 Aug. 2002–2 Aug. 2003	Height without seedhead (HNS)	Measurements (cm) of five random plant heights without seedhead
2-yr	17 Aug. 2002–16 Aug. 2003	Average internode length (AIL)	Measurements (mm) on five random stems
	17 Aug. 2002–16 Aug. 2003	Second internode length (SIL)	Measurements (mm) on five random stems
	17 Aug. 2002–16 Aug. 2003	Third internode length (TIL)	Measurements (mm) on five random stems
	17 Aug. 2002–16 Aug. 2003	Second internode diameter (SID)	Measurements (mm) on five random stems
	17 Aug. 2002–16 Aug. 2003	Third internode diameter (TID)	Measurements (mm) on five random stems
	17 Aug. 2002–16 Aug. 2003	First leaf blade width on third node (FLW)	Measurements (mm) on five random stems
	17 Aug. 2002–16 Aug. 2003	First leaf blade length on third node (FLL)	Measurements (mm) on five random stems
	17 Aug. 2002–16 Aug. 2003	Second leaf blade width on third node (SLW)	Measurements (mm) on five random stems
	17 Aug. 2002–16 Aug. 2003	Second leaf blade length on third node (SLL)	Measurements (mm) on five random stems
3-yr	3 Dec. 2001–15 Nov. 2002–12 Nov. 2003	Winter color retention (WCR)	Same scale as for GUI

biomass yield (Mg ha^{-1}) was calculated from the dried sample weight (g m^{-1}) by multiplying a coefficient of 0.1111.

Plot means were used for statistical analyses for traits with multiple measurements. A randomized complete block design was used with entry, year, and replication as random effects, while entry was the main effect. The SAS/MIXED procedure was used for analysis of variance (ANOVA) and to obtain REML estimates of the variance components (SAS Institute, 2003). A test was conducted for differences within and among the ploidy levels, and unequal variance methods were used if heterogeneity of variances among ploidy levels was detected. The PROC CORR procedure was used to perform phenotypic correlation (subsequently referred to simply as correlation) analyses. Multiple regression with stepwise procedure was used to select significant traits at 0.05 probability level for biomass. Path coefficient analyses were performed using standard methods (Dewey and Lu, 1959; Das et al., 2004).

RESULTS AND DISCUSSION

Variability of 24 Adaptive, Morphological, and Biomass Traits

Significant ($P < 0.01$ or 0.05) differences among accessions were detected for all traits (Table 2). Effects of year, replication, and accession by year interaction were significant ($P < 0.01$ or 0.05) respectively in 16, 15, and 16 of the 19 traits with two- or three-year data (Table 2). Replication effects were also significant ($P < 0.01$ or 0.05) in the five one-year data traits (Table 2). The ANOVA results clearly indicated different magnitudes of variation among accessions within the three ploidy levels (Tables 3–5). For the 104 tetraploids, significant effects ($P < 0.01$ or 0.05) were attributable to accessions for 22 of the 24 traits, third internode length (TIL) and winter color retention (WCR) being exceptions. Additionally, year and the accession × year interaction were significant ($P < 0.01$ or 0.05) for 17 of the 19 traits with two- or three-year data (Table 3). The three pentaploid accessions did not differ ($P > 0.05$) for any trait, though year and the accession × year interaction were significant ($P < 0.01$ or 0.05) for some traits (Table 4). Differences among the seven hexaploid accessions were significant ($P < 0.01$) for four traits, with year and the year × accession interaction also being significant for certain traits (Table 5).

Means and ranges for all traits of the 114 Chinese accessions and the four standard cultivars are presented by year in Table 6, because significant entry × year interactions were present for most traits in Table 2. For two establishment rate descriptors, stolon length (SL) and ground coverage (GCR), the ranges were larger in the Chinese collection than in the four cultivars. Among Chinese accessions, pentaploid and hexaploid plants tended to have a faster establishment rate than tetraploid accessions, though the SL and GCR ranges for tetraploids were greater (Table 6). This indicates that some tetraploid accessions were superior in establishment rate to either pentaploid or

Table 2. Analyses of variance on 24 adaptive, morphological and biomass traits for 114 Chinese *Cynodon* accessions.

Source	Mean squares					
	Accession (G)	Replication (R)	G × R	Year (Y)	G × Y	Residual
			2-yr data			
df	113	2	226	1	113	228
GC†	0.9**	0.5	0.2	275.3**	0.4**	0.2
SD	2.7**	14.3**	0.4	24.5**	1.4**	0.4
HWS	156.0**	113.4**	18.1	104.5	30.0**	18.1
HNS	113.3**	87.8**	15.5	264.8**	39.6**	14.6
WK	0.20**	0.22**	0.02	9.84**	0.07**	0.02
GUI	2.9*	8.2**	0.4	66.7**	1.9**	0.4
GUII	6.3**	16.5**	0.6	13.3**	2.2**	0.6
GUIII	7.6**	15.1**	0.7	5.9	2.6**	0.6
AIL	174.6**	342.2**	16.2	5733.0**	27.4**	18.3
SIL	88.8**	99.7**	10.2	3822.3**	16.3	12.9
TIL	162.2**	106.5**	14.3	52.0	19.7	17.2
SID	0.07**	0.02	0.01	10.57**	0.02*	0.01
TID	0.08**	0.02	0.01	10.88**	0.02**	0.01
FLW	1.07**	0.03	0.21*	12.35**	0.20	0.17
FLL	1555**	785**	182	42126**	314**	163
SLW	0.89**	0.39*	0.13*	10.72**	0.17**	0.10
SLL	1681**	881*	203	52933**	420**	206
Biomass	34**	205**	9	219**	13**	8
			3-yr data			
df	113	2	226	2	226	456
WCR	1.14*	1.42**	0.22	475.01*	0.80**	0.22
			1-yr data			
df	113	2	226	N/A		
SL	1596**	1842**	253			
GCR	0.14**	0.27**	0.02			
SM	8.4**	11.9**	1.6			
LS	4.8**	5.3**	1.2			
WA	5.3**	45.9**	2.0			

*Significance at the probability level of 0.05.

**Significance at the probability level of 0.01.

†GC, genetic color; SD, sod density; HWS, height with seedhead; HNS, height without seedhead; WK, winter kill; GUI, greenup rated on 9 Apr. 2002 and 29 Mar. 2003; GUII, greenup rated on 19 Apr. 2002 and 16 Apr. 2003; GUIII, greenup rated on 30 Apr. 2002 and 27 Apr. 2003; AIL, average internode length; SIL, second internode length; TIL, third internode length; SID, second internode diameter; TID, third internode diameter; FLW, first leaf blade width on third node; FLL, first leaf blade length on third internode; SLW, second leaf blade width on third node; SLL, second leaf blade length on third internode; WCR, winter color retention; SL, stolon length; GCR, ground coverage; SM, slime mold; and LS, leaf spot; WA, weed abundance.

Table 3. Analyses of variance on 24 adaptive, morphological, and biomass traits for 104 tetraploid Chinese *Cynodon* accessions.

Source	Mean squares					
	Accession (G)	Year (Y)	Replication (R)	G × Y	G × R	Residual
			2-yr data			
df	103	1	2	103	206	208
GC†	0.4**	245.5**	0.6	0.4**	0.2	0.2
SD	1.0**	19.8**	13.2**	1.0**	0.5	0.4
HWS	26.2*	158.8*	143.3**	26.6**	16.9	18.3
HNS	30.8**	470.4**	98.4**	30.7**	14.7	14.0
WK	0.07**	10.94**	0.23**	0.07**	0.02	0.02
GUI	1.8**	40.5**	7.9**	1.8**	0.4	0.4
GUII	2.1**	24.9**	17.5**	2.0**	0.6	0.6
GUIII	2.5**	14.4*	15.5**	2.4**	0.7	0.6
AIL	21.4*	4410.9**	307.7**	22.6*	14.0	16.0
SIL	16.1**	3285.9**	73.4**	15.9**	9.2	10.4
TIL	17.0	32.0	46.6*	17.2	11.9	15.1
SID	0.02*	9.03**	0.04*	0.02*	0.01	0.01
TID	0.02*	9.48**	0.04*	0.02*	0.01	0.01
FLW	0.14*	11.00**	0.22	0.13*	0.12*	0.09
FLL	241**	41997**	794**	242**	181	158
SLW	0.15**	7.87**	0.45*	0.15**	0.14*	0.11
SLL	300**	51707**	930**	305**	192	200
Biomass	35**	167**	229**	13**	9	8
			3-yr data			
df	103	2	2	206	206	416
WCR	1.06	396.48**	1.19**	1.05	0.22	1.10
			1-yr data			
df	103	N/A	2	N/A	206	
SL	1149**		1553**		254	
GCR	0.13**		0.30**		0.02	
SM	8.1**		13.3**		1.6	
LS	4.4**		6.4**		1.3	
WA	4.2**		42.0**		2.1	

*Significance at the probability level of 0.05.

**Significance at the probability level of 0.01.

†GC, genetic color; SD, sod density; HWS, height with seedhead; HNS, height without seedhead; WK, winter kill; GUI, greenup rated on 9 Apr. 2002 and 29 Mar. 2003; GUII, greenup rated on 19 Apr. 2002 and 16 Apr. 2003; GUIII, greenup rated on 30 Apr. 2002 and 27 Apr. 2003; AIL, average internode length; SIL, second internode length; TIL, third internode length; SID, second internode diameter; TID, third internode diameter; FLW, first leaf blade width on third node; FLL, first leaf blade length on third internode; SLW, second leaf blade width on third node; SLL, second leaf blade length on third internode; WCR, winter color retention; SL, stolon length; GCR, ground coverage; SM, slime mold; LS, leaf spot; WA, weed abundance.

hexaploid accessions. The four standard cultivars generally had better winter color retention than the Chinese accessions, though there was variation among the latter. The ranges for the three spring greenup ratings (greenup rated on 9 Apr. 2002 and 29 Mar. 2003 [GUI], greenup rated on 19 Apr. 2002 and 16 Apr. 2003 [GUII], and greenup rated on 30 Apr. 2002 and 27 Apr. 2003 [GUIII]) were larger than those for the standard cultivars, indicating some Chinese accessions initiated growth earlier than the standard cultivars. Among the three ploidy levels, the hexaploids had highest GU averages, the pentaploids lowest, while the tetraploids had the largest ranges both years. The winter kill (WK) ranges were larger in the 114 Chinese accessions compared to the four cultivars over the two years. The hexaploids on average had the lowest WK rates, while the tetraploids had the largest ranges, and the pentaploids had the highest WK averages. Variability for genetic color (GC) was greater among Chinese accessions compared to control cultivars. Interestingly, the

Table 4. Analyses of variance on 24 adaptive, morphological, and biomass traits for three pentaploid Chinese *Cynodon* accessions.

Source	Mean squares					
	Accession (G)	Year (Y)	Replication (R)	G × Y	G × R	Residual
2-yr data						
df	2	1	2	2	4	6
GC†	0.4	17.0*	0.0	0.4	0.2	0.1
SD	0.1	53.4**	2.1**	0.1	0.1	0.2
HWS	20.6	322.7	1.5	20.5	5.9	7.6
HNS	18.5	888.2*	8.6	18.5	29.0	17.1
WK	0.00	0.17**	0.01	0.00	0.01	0.01
GUI	0.0	3.1**	0.0	0.0	0.1	0.1
GUII	0.1	11.7**	0.1	0.1	0.3	0.2
GUIII	0.01	16.1**	0.3	0.01	0.2	0.2
AIL	4.5	987.6**	95.6*	4.5	10.2	52.5
SIL	2.2	150.8**	19.7	2.2	13.9	48.6
TIL	37	158.4	208.6	36.5	34.8	35.4
SID	0.01	0.39**	0.02	0.01	0.01	0.02
TID	0.01	0.22*	0.03	0.01	0.01	0.07
FLW	0.16	0.26	0.04	0.16	0.10	0.66
FLL	40	1957*	383	40	179	1047
SLW	0.12	0.28	0.03	0.17	0.05	0.30
SLL	23	3394**	247	23	173	773
Biomass	4	60	2	20*	8	3
3-yr data						
df	2	2	2	4	4	12
WCR	0.00	18.00**	3.30**	0.00	0.00	0.40
1-yr data						
df	2	N/A	2	N/A	4	
SL	107		585		701	
GCR	0.00		0.00		0.02	
SM	1.0		3.0		2.0	
LS	0.0		0.3		0.3	
WA	0.1		7.4		3.1	

*Significance at the probability level of 0.05.

**Significance at the probability level of 0.01.

†GC, genetic color; SD, sod density; HWS, height with seedhead; HNS, height without seedhead; WK, winter kill; GUI, greenup rated on 9 Apr. 2002 and 29 Mar. 2003; GUII, greenup rated on 19 Apr. 2002 and 16 Apr. 2003; GUIII, greenup rated on 30 Apr. 2002 and 27 Apr. 2003; AIL, average internode length; SIL, second internode length; TIL, third internode length; SID, second internode diameter; TID, third internode diameter; FLW, first leaf blade width on third node; FLL, first leaf blade length on third internode; SLW, second leaf blade width on third node; SLL, second leaf blade length on third internode; WCR, winter color retention; SL, stolon length; GCR, ground coverage; SM, slime mold; LS, leaf spot; WA, weed abundance.

Table 5. Analyses of variance on 24 adaptive, morphological, and biomass traits for seven hexaploid Chinese *Cynodon* accessions.

Source	Mean squares					
	Accession (G)	Year (Y)	Replication (R)	G × Y	G × R	Residual
2-yr data						
df	6	1	2	6	12	14
GC†	0.2	14.9**	0.2	0.2	0.3	0.4
SD	1.1	3.7	0.1	1.2**	0.2	0.4
HWS	38.0	42.0	26.6	31.7	39.5	18.9
HNS	33.5	24.4	17.2	33.8	24.1	22.7
WK	0.01	0.04**	0.00	0.00	0.01*	0.01
GUI	1.1*	52.6**	0.5	1.3*	0.6	0.4
GUII	0.7	5.0*	0.3	0.6	0.5	0.5
GUIII	1.4	4.7	0.3	1.3	1.1	0.6
AIL	43.5	846.9**	23.9	43.6	46.5	35.3
SIL	23.7	421.8**	31.8	27.8	24.2	33.7
TIL	39.1	0.8	37.5	39.9	21.4	40.2
SID	0.02	1.27**	0.02	0.02	0.01	0.01
TID	0.04	1.28**	0.02	0.03	0.01	0.02
FLW	0.49	1.12	1.84	1.41	1.54	1.26
FLL	665*	4513*	110	662*	178	3191
SLW	0.17	4.26**	0.03	0.29**	0.06*	0.92
SLL	743	8073*	102	924	401	4721
Biomass	8	21	1	6	114	84
3-yr data						
df	6	2	2	12	12	28
WCR	0.61	94.5**	0.59	0.61	0.38	1.14
1-yr data						
df	6	N/A	2	N/A	12	
SL	158		34		97	
GCR	0.001		0.001		0.001	
SM	7.7**		2.3		1.3	
LS	0.7**		0.2		0.1	
WA	0.78		0.33		0.28	

*Significance at the probability level of 0.05.

**Significance at the probability level of 0.01.

†GC, genetic color; SD, sod density; HWS, height with seedhead; HNS, height without seedhead; WK, winter kill; GUI, greenup rated on 9 Apr. 2002 and 29 Mar. 2003; GUII, greenup rated on 19 Apr. 2002 and 16 Apr. 2003; GUIII, greenup rated on 30 Apr. 2002 and 27 Apr. 2003; AIL, average internode length; SIL, second internode length; TIL, third internode length; SID, second internode diameter; TID, third internode diameter; FLW, first leaf blade width on third node; FLL, first leaf blade length on third internode; SLW, second leaf blade width on third node; SLL, second leaf blade length on third internode; WCR, winter color retention; SL, stolon length; GCR, ground coverage; SM, slime mold; LS, leaf spot; WA, weed abundance.

hexaploids had higher GC means in each of the two years, while the tetraploids had larger ranges. For sod density (SD), the Chinese accessions had a larger range than the four cultivars in 2002, while Tifsport and Tifway showed better SD values than any of the Chinese accessions in 2003. The pentaploid Chinese accessions had higher average sod density than the other two ploidy levels in 2002, but its average value was the lowest in 2003, probably due to greater winter injury. For the 11 morphological descriptors (height with seedhead [HWS], height without seedhead [HNS], average internode length [AIL], second internode length [SIL], third internode length [TIL], second internode diameter [SID], third internode diameter [TID], first leaf blade width on third node [FLW], first leaf blade length on third node [FLL], second leaf blade width on third node [SLW], and second leaf blade length on third node [SLL]), the forage-type cultivars Tifton 44 and Midland had larger mean values than the Chi-

Table 6. Means, standard deviations, and ranges for 24 trait descriptors of adaptation, morphology, and biomass in 2001 through 2003 on 114 Chinese *Cynodon* accessions and four standard cultivars.

Trait[†]	Chinese accessions								Standard cultivars			
	Overall		Tetraploid (4*x*)		Pentaploid (5*x*)		Hexaploid (6*x*)		Tifsport	Tifway	Midland	Tifton 44
	Mean ± SD	Min. – Max.	Mean ± SD	Min. – Max.	Mean ± SD	Min. – Max.	Mean ± SD	Min. – Max.	Mean ± SD			
					2001							
SL, cm	88.8 ± 26.6	32.2–202.1	85.1 ± 23.7a[‡]	32.2–202.1	159.6 ± 22.9b	136.0–197.6	111.8 ± 10.4c	94.0–128.3	28.1 ± 12.0	42.4 ± 10.1	77.8 ± 8.3	95.5 ± 7.1
GCR, %	71.5 ± 24.2	10.0–100.0	68.8 ± 23.7a	10.0–100.0	100.0b	100.0–100.0	99.3 ± 2.4b	90.0–100.0	6.7 ± 2.9	21.7 ± 10.4	53.3 ± 25.2	80.0 ± 0.0
WCR	1.7 ± 0.7	1.0–4.0	1.8 ± 0.7a	1.0–4.0	1.0 ± 0.0b	1.0–1.0	1.1 ± 0.4b	1.0–2.0	4.3 ± 0.6	3.7 ± 0.6	2.3 ± 0.6	2.7 ± 0.6
					2002							
GUI	2.8 ± 1.4	1.0–6.5	2.7 ± 1.3a	1.0–6.5	1.8 ± 0.4b	1.5–2.5	4.7 ± 1.2c	2.5–6.5	1.2 ± 0.3	2.0 ± 0.5	3.8 ± 0.3	2.3 ± 0.3
GUII	3.5 ± 1.6	1.0–8.0	3.4 ± 1.5a	1.0–8.0	2.6 ± 0.6b	1.5–3.5	5.9 ± 1.2c	4.0–7.5	1.2 ± 0.3	2.5 ± 1.0	4.7 ± 0.3	3.8 ± 0.3
GUIII	4.0 ± 1.6	1.5–8.5	3.8 ± 1.5a	1.5–8.0	2.9 ± 0.6b	2.0–4.0	6.5 ± 1.2c	5.0–8.5	1.5 ± 0.0	3.3 ± 1.6	5.3 ± 0.3	5.0 ± 0.0
WK, %	58.4 ± 26.9	10.0–99.0	60.3 ± 26.1a	10.0–99.0	76.7 ± 8.7b	60.0–90.0	22.4 ± 12.3c	10.6–55.0	97.0 ± 1.0	75.0 ± 13.0	31.7 ± 10.4	30.0 ± 0.0
GC	6.9 ± 0.4	5.0–8.0	6.9 ± 0.4a	5.0–8.0	7.1 ± 0.2ab	7.0–7.5	7.4 ± 0.3b	6.5–7.5	5.7 ± 0.6	5.7 ± 0.6	6.5 ± 0.0	5.8 ± 0.8
SD	5.2 ± 1.0	3.0–8.0	5.1 ± 1.0a	3.0–8.0	6.7 ± 0.5b	6.0–7.0	5.4 ± 0.8a	4.0–7.0	6.0 ± 0.0	5.7 ± 0.6	4.7 ± 0.6	4.7 ± 0.6
HWS, cm	32.6 ± 7.0	18.0–47.0	31.6 ± 6.4a	19.0–45.0	44.8 ± 2.8b	42.0–47.0	42.3 ± 4.9b	34.0–44.0	25.0 ± 5.0	29.7 ± 3.5	57.0 ± 3.6	66.3 ± 2.9
HNS, cm	24.6 ± 6.4	9.0–40.0	23.6 ± 5.6a	9.0–37.0	38.2 ± 4.6b	35.0–40.0	32.9 ± 4.4c	26.0–37.0	19.7 ± 7.5	24.7 ± 4.7	52.3 ± 2.5	52.0 ± 3.5
AIL, mm	32.4 ± 7.8	16.6–60.5	31.3 ± 6.7a	16.6–53.7	47.4 ± 7.8b	39.3–60.5	42.1 ± 9.9b	23.8–58.0	28.6 ± 2.3	30.4 ± 3.7	65.4 ± 2.7	76.7 ± 3.7
SIL, mm	22.4 ± 5.8	11.2–51.2	21.8 ± 5.2a	11.2–38.4	32.3 ± 4.7b	26.8–40.0	26.8 ± 8.0c	14.6–51.2	19.9 ± 2.9	16.5 ± 2.4	52.3 ± 11.6	73.7 ± 16.3
TIL, mm	23.0 ± 6.9	12.0–60.8	22.0 ± 5.5a	12.0–43.2	42.8 ± 10.5b	30.2–60.8	28.5 ± 8.2c	15.4–42.2	21.6 ± 4.7	20.3 ± 4.4	58.6 ± 8.8	69.2 ± 13.5
SID, mm	1.0 ± 0.2	0.6–1.7	1.0 ± 0.2a	0.7–1.7	1.1 ± 0.2ab	0.9–1.4	1.2 ± 0.1b	0.9–1.4	0.7 ± 0.2	0.5 ± 0.1	1.1 ± 0.2	1.2 ± 0.1
TID, mm	1.0 ± 0.2	0.6–1.7	1.0 ± 0.2a	0.6–1.7	1.0 ± 0.2ab	0.8–1.3	1.2 ± 0.2b	0.8–1.5	0.7 ± 0.2	0.5 ± 0.0	1.0 ± 0.1	1.2 ± 0.1
FLW, mm	3.0 ± 0.5	2.0–4.8	2.9 ± 0.4a	2.0–4.1	3.8 ± 0.5b	3.0–4.6	3.9 ± 0.6b	2.6–4.8	2.3 ± 0.1	2.0 ± 0.0	3.4 ± 0.1	4.7 ± 0.4
FLL, mm	54.0 ± 21.4	15.8–125.2	50.7 ± 18.6a	15.8–123.8	105.7 ± 9.6b	94.2–125.2	80.0 ± 17.4c	58.0–112.0	42.1 ± 18.1	53.0 ± 10.7	139.6 ± 10.1	126.2 ± 14.3
SLW, mm	3.0 ± 0.5	2.0–4.9	2.9 ± 0.3a	2.0–4.2	3.9 ± 0.4b	3.3–4.4	4.0 ± 0.5b	2.7–4.9	2.2 ± 0.2	2.0 ± 0.1	3.4 ± 0.2	4.7 ± 0.2
SLL, mm	54.7 ± 22.2	15.8–138.2	51.4 ± 19.4a	15.8–138.2	106.6 ± 10.3b	91.2–122.6	80.2 ± 21.8c	50.0–117.5	42.0 ± 17.2	52.9 ± 8.0	140.0 ± 27.3	125.1 ± 17.0
SM	4.1 ± 2.0	1.0–9.0	4.0 ± 2.0a	1.0–9.0	4.0 ± 1.4a	2.0–6.0	5.9 ± 1.8b	2.0–8.0	1.3 ± 1.5	2.3 ± 0.6	4.0 ± 1.7	3.0 ± 1.0
LS	3.8 ± 1.6	1.0–9.0	4.0 ± 1.5a	1.0–9.0	2.3 ± 0.5b	2.0–3.0	2.2 ± 0.5b	1.0–3.0	3.3 ± 2.3	6.7 ± 2.3	4.0 ± 1.0	2.7 ± 0.6
WCR	1.2 ± 0.3	1.0–2.0	1.2 ± 0.4a	1.0–2.0	1.0 ± 0.0a	1.0–1.0	1.1 ± 0.3a	1.0–2.0	2.0 ± 0.0	2.0 ± 0.6	3.0 ± 0.0	3.0 ± 0.0
Biomass (Mg ha^{-1})	13.0 ± 4.3	2.6–23.1	12.8 ± 4.4a	2.6–23.1	13.9 ± 2.2ab	10.5–18.1	15.0 ± 2.3b	10.6–20.1	3.8 ± 3.0	7.9 ± 3.3	15.4 ± 2.7	12.8 ± 2.0
					2003							
GUI	2.1 ± 0.6	1.0–4.0	2.2 ± 0.5a	1.0–4.0	1.0 ± 0.0b	1.0–1.0	2.5 ± 0.7c	1.0–4.0	1.7 ± 0.6	1.7 ± 0.6	2.0 ± 0.0	2.0 ± 0.0
GUII	3.8 ± 1.1	1.0–7.0	3.8 ± 0.9a	1.0–7.0	1.0 ± 0.0b	1.0–1.0	5.2 ± 1.3c	3.0–7.0	4.3 ± 0.6	4.3 ± 0.6	4.0 ± 0.0	4.7 ± 0.6
GUIII	4.2 ± 1.3	1.0–8.0	4.1 ± 1.1a	1.0–8.0	1.0 ± 0.0b	1.0–1.0	5.9 ± 1.6c	3.0–8.0	4.7 ± 0.6	4.7 ± 0.6	4.3 ± 0.6	4.7 ± 0.6
WK, %	34.3 ± 20.4	3.0–98.0	33.7 ± 17.7a	3.0–95.0	96.3 ± 1.6b	95.0–98.0	16.6 ± 11.8c	3.0–50.0	23.3 ± 5.7	28.3 ± 2.9	36.7 ± 5.8	31.7 ± 2.9
GC	5.6 ± 0.7	4.0–8.0	5.6 ± 0.7a	4.0–8.0	5.1 ± 0.6b	4.0–6.0	6.2 ± 0.6c	5.0–7.0	6.0 ± 0.0	6.3 ± 0.6	5.7 ± 0.6	5.0 ± 0.0
SD	4.8 ± 1.0	2.0-7.0	4.7 ± 1.0a	2.0–7.0	3.2 ± 0.7b	2.0–4.0	6.0 ± 0.5c	5.0–7.0	7.7 ± 0.6	8.0 ± 0.0	5.7 ± 1.2	5.7 ± 0.6
HWS, cm	33.4 ± 6.2	28.0–48.0	32.6 ± 5.3a	28.0–45.0	35.1 ± 2.7a	33.0–34.0	44.3 ± 7.8b	32.0–48.0	27.7 ± 2.5	25.7 ± 0.6	47.0 ± 12.3	44.7 ± 5.5

Table 6. Continued.

Trait†	Overall		Chinese accessions: Tetraploid (4x)		Chinese accessions: Pentaploid (5x)		Chinese accessions: Hexaploid (6x)		Standard cultivars: Tifsport	Tifway	Midland	Tifton 44
	Mean ± SD	Min. – Max.	Mean ± SD	Min. – Max.	Mean ± SD	Min. – Max.	Mean ± SD	Min. – Max.	Mean ± SD			
					2003							
HNS, cm	25.9 ± 5.7	18.0–40.0	25.4 ± 5.0a	19.0–37.0	22.3 ± 4.6a	18.0–25.0	34.4 ± 7.6b	24.0–40.0	19.3 ± 1.2	19.3 ± 1.2	39.3 ± 13.6	37.7 ± 2.5
AIL, mm	26.4 ± 5.6	14.5–45.2	25.8 ± 5.1a	14.5–45.2	32.6 ± 3.7b	25.6–37.5	33.2 ± 6.5b	21.9–43.3	27.2 ± 1.8	27.6 ± 0.8	62.4 ± 6.4	58.5 ± 2.3
SIL, mm	17.6 ± 4.2	8.8–39.2	17.2 ± 3.8a	8.8–32.0	26.5 ± 6.0b	18.4–39.2	20.5 ± 4.2c	13.0–27.6	13.6 ± 4.2	10.1 ± 1.2	38.8 ± 5.3	41.1 ± 2.8
TIL, mm	22.4 ± 5.9	11.2–47.0	21.5 ± 4.9a	11.2–47.0	36.8 ± 6.8b	26.2–46.6	28.8 ± 7.2c	17.4 ± 41.6	20.9 ± 5.3	13.3 ± 4.0	49.2 ± 9.9	55.3 ± 6.6
SID, mm	0.8 ± 0.1	0.4–1.1	0.8 ± 0.1a	0.4–1.1	0.8 ± 0.10a	0.7–0.9	0.8 ± 0.1a	0.6–1.1	0.5 ± 0.1	0.5 ± 0.0	0.9 ± 0.2	1.1 ± 0.0
TID, mm	0.8 ± 0.1	0.4–1.1	0.8 ± 0.1a	0.4–1.2	0.8 ± 0.1a	0.7–0.9	0.8 ± 0.1a	0.6–1.1	0.4 ± 0.0	0.4 ± 0.0	1.0 ± 0.2	1.2 ± 0.0
FLW, mm	2.8 ± 0.7	1.9–4.0	2.7 ± 0.5a	1.9–4.0	3.5 ± 0.1b	3.2–3.7	3.3 ± 0.3c	2.8–3.9	1.9 ± 0.1	2.0 ± 0.1	3.3 ± 0.4	4.7 ± 0.1
FLL, mm	69.9 ± 20.0	28.4–135.0	67.4 ± 18.3a	28.4–124.6	84.8 ± 16.5b	56.2–119.3	100.8 ± 19.0c	74.4–135.0	56.1 ± 3.6	45.8 ± 6.1	140.5 ± 32.0	137.4 ± 7.7
SLW, mm	2.8 ± 0.6	1.8–4.0	2.7 ± 0.5a	1.8–4.0	3.6 ± 0.2b	3.3–3.8	3.3 ± 0.3c	2.8–3.9	2.0 ± 0.1	1.9 ± 0.1	3.4 ± 0.4	4.6 ± 0.2
SLL, mm	72.4 ± 22.1	22.0–159.0	70.0 ± 19.9a	22.0–142.0	79.2 ± 13.8a	56.0–104.0	108.0 ± 25.2b	74.0–159.0	55.7 ± 7.3	50.0 ± 0.0	176.0 ± 72.0	120.0 ± 23.8
WA	3.5 ± 1.8	1.0–9.0	3.5 ± 1.7a	1.0–8.0	6.8 ± 1.9b	4.0–9.0	1.7 ± 0.7c	1.0–3.0	2.3 ± 1.5	1.7 ± 0.6	1.7 ± 0.6	1.3 ± 0.6
WCR	3.4 ± 0.9	1.0–6.0	3.4 ± 0.9a	1.0–6.0	3.0 ± 0.0a	3.0–3.0	4.1 ± 0.9b	3.0–6.0	6.0 ± 0.0	6.0 ± 0.0	4.6 ± 0.6	5.3 ± 0.6
Biomass (Mg ha^{-1})	11.9 ± 3.1	3.5–17.3	11.8 ± 3.1a	3.5–17.3	9.3 ± 2.7b	5.8–12.3	13.6 ± 3.0c	9.7–17.2	10.4 ± 1.8	10.2 ± 1.2	9.3 ± 2.4	13.3 ± 1.5

†SL, stolon length; GCR, ground coverage; WCR, winter color retention; GUI, greenup rated on 9 Apr. 2002 and 29 Mar. 2003; GUII, greenup rated on 19 Apr. 2002 and 16 Apr. 2003; GUIII, greenup rated on 30 Apr. 2002 and 27 Apr. 2003; WK, winter kill; GC, genetic color; SD, sod density; HWS, height with seedhead; HNS, height without seedhead; AIL, average internode length; SIL, second internode length; TIL, third internode length; FLW, first leaf blade width on third node; FLL, first leaf blade length on third internode;SLW, second leaf blade width on third node; SLL, second leaf blade length on third internode; WA, weed abundance; SM, slime mold; LS, leaf spot.

‡Significance is at the 0.05 level of probability. Within a trait of the same year, different letters (i.e., a, b, c) after mean values of the three ploidy levels indicated significant differences.

nese accessions for most traits, while some Chinese accessions were similar to or smaller than the turf type cultivars Tifsport and Tifway in certain traits. Hexaploid and pentaploid accessions had mean morphological trait values generally similar in size, and generally larger than those for Chinese tetraploid accessions. However, some large tetraploids were similar to pentaploids and hexaploids in size. For the two diseases leaf spot and slime mold, the Chinese accessions had mean ratings ranging from 1 to 9. In 2003, weeds occurred in significant numbers in some plots. Again, the Chinese accessions had a large range in weed abundance (WA) ratings, while WA ratings for the standard cultivars were relatively low. For the Chinese accessions, the mean and range of biomass was higher in 2002 than in 2003. Compared to the four standards, the Chinese accessions had larger ranges for biomass yield in both years. Among the three ploidy levels of the Chinese accessions, the tetraploids had largest range, while hexaploids had highest yearly averages.

Estimates of variance components and associated standard errors for the 24 traits examined in 114 Chinese accessions are presented in Table 7. Genotypic variance estimates (σ^2_G) were significant ($P < 0.01$) for all traits, and accession × year interaction variance estimates ($\sigma^2_{G\times Y}$) were significant ($P < 0.01$ or 0.05) for all traits but FLW and SLW (Table 7). For the 104 tetraploids, σ^2_G was significant for all traits except GUI, and $\sigma^2_{G\times Y}$ was significant for 16 of 19 traits (data not provided). For the pentaploids, σ^2_G was significant for TID and SLW ($P < 0.01$). For the hexaploid accessions, σ^2_G was significant ($P < 0.01$ or 0.05) for GUII and WA, and $\sigma^2_{G\times Y}$ significant ($P < 0.05$) for FLL only.

The results clearly indicated the presence of substantial genetic variation among the 114 Chinese accessions for the 24 descriptor traits. Such variation was expected based on previous reports of variation among *C. dactylon* accessions from geographic areas other than China (Burton, 1947, 1965; Juska and Hanson, 1964; Harlan and de Wet, 1969; Kneebone, 1973; Harlan, 1970). Genetic variation in bermudagrass for many forage and turf performance traits has been demonstrated to be heritable and useful in breeding improvement (Burton, 1947, 1951, 1956, 1959, 1965; Wofford and Baltensperger, 1985; Coffey and Baltensperger, 1989).

Trait Relationships and Biomass Component Analysis

Significant ($P < 0.05$ or 0.01) correlation coefficients among the adaptive, morphological, and biomass trait descriptors are presented in Table 8.

Table 7. Estimates of variance components and their associated standard errors for 24 adaptive, morphological, and biomass traits in 114 Chinese bermudagrass accessions.

Descriptor	Variance components					
	σ^2_G	$\sigma^2_{G\times Y}$	σ^2_Y	$\sigma^2_{G\times B}$	σ^2_B	σ^2_{Res}
Biomass (Mg ha^{-1})	3.48 ± 0.83**	1.54 ± 0.59**	0.60 ± 0.90	0.80 ± 0.56	0.85 ± 0.89	7.67 ± 0.71**
Winter color retention	0.05 ± 0.02**	0.20 ± 0.03**	1.43 ± 1.43	0.00 ± 0.00	0.00 ± 0.00	0.22 ± 0.01**
Genetic color	0.08 ± 0.02**	0.08 ± 0.02**	0.79 ± 1.12	0.00 ± 0.02	0.00 ± 0.00	0.23 ± 0.02**
Sod density	0.22 ± 0.07**	0.35 ± 0.07**	0.07 ± 0.10	0.00 ± 0.00	0.06 ± 0.06	0.44 ± 0.03**
Height with seedhead (cm)	21.12 ± 3.55**	4.41 ± 1.48**	0.14 ± 0.33	0.04 ± 1.16	0.45 ± 0.53	17.70 ± 1.64**
Height without seedhead (cm)	11.41 ± 2.64**	9.30 ± 1.93**	0.58 ± 0.99	0.52 ± 0.97	0.34 ± 0.40	14.24 ± 1.32**
Winter kill	0.024 ± 0.006**	0.028 ± 0.005**	0.037 ± 0.053	0.002 ± 0.002	0.001 ± 0.001	0.020 ± 0.002**
Greenup I	0.17 ± 0.08**	0.50 ± 0.08**	0.18 ± 0.26	0.00 ± 0.00	0.03 ± 0.03	0.40 ± 0.03**
Greenup II	0.66 ± 0.14**	0.54 ± 0.10**	0.04 ± 0.07	0.01 ± 0.04	0.07 ± 0.07	0.56 ± 0.05**
Greenup III	0.80 ± 0.17**	0.66 ± 0.12**	0.02 ± 0.03	0.03 ± 0.04	0.06 ± 0.07	0.63 ± 0.06**
Average internode length (mm)	23.65 ± 3.74**	3.32 ± 1.24**	17.86 ± 25.37	0.00 ± 0.00	1.50 ± 1.57	16.88 ± 1.11**
Second internode length (mm)	12.62 ± 2.07**	1.97 ± 0.80**	12.20 ± 17.32	0.00 ± 0.00	0.43 ± 0.48	11.51 ± 0.76**
Third internode length (mm)	23.64 ± 3.60**	1.88 ± 0.99*	0.23 ± 0.42	0.00 ± 0.00	0.47 ± 0.54	15.67 ± 1.03**
Second internode diameter (mm)	0.011 ± 0.002**	0.002 ± 0.001*	0.031 ± 0.045	0.000 ± 0.000	0.000 ± 0.000	0.012 ± 0.001**
Third internode diameter (mm)	0.012 ± 0.002**	0.002 ± 0.001**	0.032 ± 0.046	0.000 ± 0.000	0.000 ± 0.000	0.012 ± 0.001**
First leaf blade width on third node (mm)	0.164 ± 0.026**	0.000 ± 0.000	0.039 ± 0.056	0.009 ± 0.011	0.000 ± 0.000	0.175 ± 0.013**
First leaf blade length on third node (mm)	195.9 ± 34.2**	54.3 ± 15.0**	116.8 ± 166.5	9.7 ± 11.2	3.2 ± 4.0	159.7 ± 14.8**
Second leaf blade width on third node (mm)	0.142 ± 0.023**	0.012 ± 0.008	0.034 ± 0.048	0.003 ± 0.008	0.001 ± 0.002	0.112 ± 0.011**
Second leaf blade length on third node (mm)	201.7 ± 37.4**	75.6 ± 19.9**	148.9 ± 212.3	0.0 ± 13.5	3.5 ± 4.4	203.0 ± 18.9**
Stolon growth (cm)†	442.45 ± 69.37**				15.12 ± 17.24	247.8 ± 23.05**
Ground coverage†	0.080 ± 0.012**				0.003 ± 0.004	0.029 ± 0.003**
Slime mold†	2.53 ± 0.41**				0.08 ± 0.10	1.69 ± 0.16**
Leaf spot†	1.40 ± 0.24**				0.04 ± 0.05	1.25 ± 0.16**
Weed abundance†	1.09 ± 0.24**				0.36 ± 0.37	2.02 ± 0.19**

*Mean square associated with variance component estimate was significant at the 0.05 probability level.

**Mean square associated with variance component estimate was significant at the 0.01 probability level.

†Traits had 1 yr data.

Table 8. Significant ($P < 0.05$) correlations between the adaptive, morphological, and biomass traits with 2-yr data in 114 Chinese *Cynodon* accessions.

	BM†	SD	HWS	HNS	WK	GUIII	GUII	GUI	AIL	SIL	TIL	SID	TID	FLW	FLL	SLW
2	0.20															
3	0.23	–														
4	0.30	–	0.87													
5	–0.29	–0.17	–0.23	–0.22												
6	0.37	0.30	0.29	0.26	–0.82											
7	0.38	0.27	0.28	0.26	–0.83	0.92										
8	0.40	0.18	0.21	0.18	–0.52	0.71	0.72									
9	0.26	–	0.45	0.46	0.11	0.12	0.10	0.29								
10	0.14	–	0.30	0.34	0.33	–0.12	–0.14	0.09	0.76							
11	0.10	–	0.43	0.49	0.15	–	–	–	0.73	0.80						
12	0.18	–	–	–	0.29	–	–	0.22	0.40	0.31	–					
13	0.16	–0.09	–	–	0.30	–	–0.08	0.21	0.37	0.32	–	0.96				
14	–	–0.08	0.31	0.25	0.14	–	–	0.12	0.40	0.33	0.27	0.46	0.46			
15	–	–	0.45	0.53	–0.20	0.14	0.14	–	0.40	0.26	0.58	0.26	0.31	0.14		
16	–	–0.10	0.31	0.25	0.17	–	–	0.11	0.43	0.36	0.29	0.49	0.50	0.77	0.15	
17	–	–	0.45	0.53	–0.22	0.15	0.14	–	0.40	0.24	0.56	0.27	0.32	0.13	0.97	0.13
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

†1 = biomass (BM); 2 = sod density (SD); 3 = height with seedhead (HWS); 4 = height without seedhead (HNS); 5 = winter kill (WK); 6 = greenup III (GUIII); 7 = greenup II (GUII); 8 = greenup I (GUI); 9 = average internode length (AIL); 10 = second internode length (SIL); 11 = third internode length (TIL); 12 = second internode diameter (SID); 13 = third internode diameter (TID); 14 = first leaf blade width on third node (FLW); 15 = first leaf blade length on third node (FLL); 16 = second leaf blade width on third node (SLW); 17 = second leaf blade length on third node (SLL).

Table 9. Path analysis of direct and indirect effects of seven traits on biomass for 114 Chinese *Cynodon dactylon* accessions.

Trait	Direct effect	Indirect effect via							Correlation coefficient with biomass
		GUI	HNS	SD	SID	WK	HWS	AIL	
Greenup I (GUI)	0.183	–	0.063	0.024	0.040	0.107	−0.047	0.027	0.397
Height without seedhead (HNS)	0.352	0.033	–	0.010	0.005	0.046	−0.191	0.044	0.299
Sod density (SD)	0.135	0.033	0.025	–	−0.012	0.035	−0.014	0.002	0.204
Second internode diameter (SID)	0.179	0.041	0.010	−0.009	–	−0.060	−0.014	0.038	0.185
Winter kill (WK)	−0.207	−0.095	−0.078	−0.023	0.052	–	0.050	0.010	−0.291
Height with seedhead (HWS)	−0.220	0.039	0.303	0.009	0.011	0.047	–	0.043	0.232
Average internode length (AIL)	0.095	0.053	0.163	0.003	0.071	−0.023	−0.099	–	0.263

Highly positive relationships ($r > 0.70$) were respectively found for all pairings of HWS and HNS, GUIII and GUII and GUI, AIL and SIL and TIL, SID and TID, FLW and SLW, and FLL and SLL. Highly negative correlations were found between WK rate and GU descriptors, indicating that accessions with early spring growth had better winter survival. Most of the correlation coefficients between the various morphological traits were significant and substantial, indicating, for instance, that accessions with longer and wider leaves also had internodes that were longer and of greater diameter, and that such accessions were generally taller. The relatively high correlation ($r = 0.57$, $P < 0.0001$) between WA and WK simply reflected the opportunity for weed encroachment in accessions with substantial winter kill. The slime mold and leaf spot occurrence were not correlated ($r = -0.04$, $P = 0.42$), suggesting that simultaneous selection for resistance may be possible.

Biomass yield was significantly ($P \leq 0.05$) positively and negatively correlated with 11 and one trait descriptors, respectively (Table 8). Multiple regression analysis with stepwise selection procedures showed that GUI, HNS, SD, SID, WK, HWS, and AIL were significant ($P < 0.05$) in a model to predict biomass yield, although they collectively accounted for only 29.6% of total biomass variation. Path analysis data for biomass and the seven selected traits are given in Table 9. Among the seven path coefficients (direct effects), the highest value was 0.39 for plant HNS, indicating its large effect on biomass yield. However, GUI, SD, SID, and AIL had similar coefficients in magnitude indicating that they were important contributors to biomass yield. The WK had a predicted negative effect on biomass yield, indicating its importance to adaptation to temperate regions. The HWS contributed to biomass yield via HNS (Table 9). Therefore, selection for taller plants with better winter survival, earlier spring greenup, denser sod, and bigger internodes should improve the biomass yield.

CONCLUSIONS

Substantial genetic variation was found among 114 *C. dactylon* accessions from China for each of 24 adaptive, morphological, and biomass yield descriptor traits. Variation was greatest among tetraploid accessions, which constituted 91% (104) of the collection. Variation among pentaploid (3) and hexaploid (7) accessions for the 24 traits was evident, but of low magnitude compared to the tetraploid accessions. Some accessions exhibited traits either uniquely or rarely expressed in existing bermudagrass collections, such as dark green foliage color. Significant accession × year interactions for many of the descriptor traits indicated the failure of accessions to respond similarly over the two years. Winter kill was positively correlated with weed prolificacy, but negatively with spring greenup and biomass yield. Morphological traits were significantly and positively correlated with each other at varying magnitudes. Biomass yield was significantly associated with numerous traits. Multiple regression and path coefficient analyses both indicated selection for height, adaptation, spring greenup, sod density, and internode size in introduced bermudagrass germplasm should be favorable for increased forage yield. The high degree of polymorphism in *C. dactylon* germplasm indigenous to China is of potential value in breeding improved turf and forage bermudagrass cultivars.

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