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Bermudagrass adaptation in the Mediterranean climate: phenotypic traits of 44 accessions

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Abstract: The use of bermudagrass in the Mediterranean area is increasing for its outstanding tolerance to heat and drought, and its aggressive growth and high recuperative potential make it particularly suited to heavily worn areas and appreciated for sports turfs. However, the overall performance of a given genetic type can be affected by the adaptation to a specific environment. The objective of this research was to determine the variability of a number of phenotypic traits that can affect bermudagrass turf performance on a wide range of bermudagrass accessions grown in two locations in Italy. In May 2010, 44 accessions of bermudagrasses, grouped in "wild", "improved" "hybrid" and "dwarf" types were transplanted in the center of field plots in Pisa and Palermo. In 2011, when the turf was completely established, the following traits were determined: shoot density, horizontal stem density, node density, leaf width, colour, quality, spring green-up, and fall colour retention. Dwarf and hybrid types yielded the best aesthetic characteristics. With respect to colour retention and spring green-up, great variability was recorded within the groups. Dwarf types presented the earliest dormancy, while the hybrid types were in general the ones to green-up first in spring.

1. Introduction

Bermudagrass is still the dominant warm-season turfgrass in warm to temperate climatic regions of the world. It is well adapted to a wide range of soil types, and its drought tolerance, recuperative ability, salt tolerance, wear tolerance, aggressive stoloniferous and rhizomatous growth habit, and overall appearance make bermudagrass an ideal turfgrass in many environments (Taliaferro, 2003; Shearman, 2006).

Bermudagrass includes several taxa of the genus *Cynodon* (L.) Rich. but the two species that represent the genetic pool from which the present cultivars descend are *Cynodon dactylon* (L.) Pers. Var. *dactylon* and *Cynodon transvaalensis* (Burtt-Davy) also known as African bermudagrass (Taliaferro, 2003). *C. transvaalensis* is morphologically distinct from *C. dactylon* due to narrow erect pale leaves producing a fine textured turf with a yellowish-green colour (De Wet and Harlan, 1970; Taliaferro, 1992). *C. dactylon* can be found as far north as 53° N latitude and from sea level to 3000 m altitude (Taliaferro, 2003). Asexual reproduction has played a role in bermudagrass enhancement as well. Remarkable breeding progress has been obtained from inter-specific hybridization and mutation breeding. The inter-specific hybridization of *C. dactylon* and *C. transvaalensis* has been extensively used to obtain sterile cultivars for which clonal propagation is necessary due to a lack of viable seeds. Among hybrid genotypes, a number of cultivars have been selected for plant size and morphology in response to the lower cutting height adopted over the years on golf greens. The more recently released "ultradwarf" cultivars have become routinely adopted thanks to an improved density, a slower vertical leaf extension and an increased dominance of stoloniferous growth relative to rhizomes at low mowing heights (Beard and Sifers, 1996).

Parameters used to evaluate *Cynodon* turf typically include turfgrass quality, colour, percent spring green-up, establishment rates, leaf texture, and density. As the turfgrass industry moves towards more sustainable management practices, the types of parameters potentially related to better stress tolerance are increasingly important (Baldwin and Liu, 2013).

One of the most important parameters is cold tolerance and rapidity of recovery from winter dormancy in the spring (Anderson *et al.*, 2007; Patton *et al.*, 2008). Low-temperature tolerance depends on a combination of sev-

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eral factors, including environmental conditions, cultural practices, and especially genetic factors (Blum, 1988; Anderson and Taliaferro, 2002). Bermudagrass survives the dormancy period using its reserves of nonstructural carbohydrates and nitrogen compounds accumulated during the previous growing season in storage organs such as stolons and rhizomes (Macolino *et al.*, 2010; Volterrani *et al.*, 2012; Giolo *et al.*, 2013; Pompeiano *et al.*, 2013).

In the last two decades several southern European universities have developed research programs to study warm-season turfgrass species, including bermudagrass (Volterrani *et al.*, 2008; Lulli *et al.*, 2011; Lulli *et al.*, 2012; Nikolopoulou *et al.*, 2012; Agati *et al.*, 2013; Gómez de Barreda *et al.*, 2013), and in particular their adaptability to the Mediterranean environment (Volterrani and Magni, 2004).

The aim of our research was to determine the variability of a number of phenotypic traits and aesthetical characteristics that can affect bermudagrass turf performance in a wide range of bermudagrass accessions grown in two locations in Italy. This information can provide further insight into bermudagrass adaptability in the Mediterranean climate.

2. Materials and Methods

Plant material

With the objective of expanding morphological diversity of the plant material, 44 accessions of bermudagrass [*Cynodon* (L.) Rich.], representative of both wild populations and cultivars, were included in the present study.

Group one included 13 entries that were called "wild types", naturally occurring populations of *C. dactylon* (L.) Pers. collected from contrasting environments supposed to generate a selective pressure. Collection sites were located in Italy (CeRTES-1= warm temperate, salt affected soil; CeRTES-2= warm temperate, fertile soil; CeRTES-3= warm temperate, polluted soil; CeRTES-13= warm temperate, fertile soil), France (CeRTES-4= cool humid, fertile soil), Greece (CeRTES-5, -6 and -7= warm temperate, salt affected soils), Croatia (CeRTES-8= warm temperate, salt affected soil), Argentina (CeRTES-9= warm temperate, salt affected pastureland), United Arab Emirates (CeRTES-10 and -11= warm arid, desert sand), and Maldives (CeRTES-12= tropical humid, salt affected soil).

Group two included 13 entries that were called "improved types". These were experimental or commercial vegetative and seeded improved *C. dactylon* cultivars.

Group 3 included 11 entries called "hybrid types", commercial or experimental inter-specific hybrids (*Cynodon dactylon x transvaalensis* Burtt.-Davy) of which those labelled Tif- were kindly provided by Dr. W. Hanna (University of Georgia, USA).

Group four included seven entries called "dwarf types", commercial interspecific dwarf and ultradwarf hybrid cultivars and two *Cynodon transvaalensis* Burtt.-Davy accessions, one a commercial cultivar (Uganda) and the other (Roma) a line of African bermudagrass that was collected in a turf nursery in Rome (Italy) where the species was first introduced presumably as a weed. African bermudagrasses were included in the "dwarf types" due to their similarity in leaf texture, density and growth habit with the well-known hybrid dwarf bermudagrasses.

2010

Turf establishment

On 15 April 2010 at the University of Pisa, Italy, all the accessions were propagated in the greenhouse (24±5°C) in peat-filled honeycomb seed trays (7 cm^2 area and 25 cm^3 volume each cell). Vegetatively propagated genotypes were planted as single stolon and seeded cultivars were seeded as single seed.

On 13 May 2010 plants in the greenhouse were fertilized (30 kg ha^{-1} N, 10 kg ha^{-1} P, and 10 kg ha^{-1} K) using a soluble fertilizer (Grow More Inc., Gardena, CA, USA).

On 31 May 2010, plants were mown to 5 cm and transplanted into field plots in two locations in Italy: the research station of the University of Pisa (43°40'N, 10°19'E, 6 m a.s.l.) and the research station of the University of Palermo (38°06'N, 13°20'E, 50 m a.s.l.).

Experimental plots were 1.5 by 1.5 m with 0.5 m bare soil pathways arranged in a randomized complete-block design with four replications. One plant of bermudagrass was transplanted in the centre of each plot. Soil type at Pisa was silt-loam (28% sand, 55% silt and 17% clay) with a pH of 7.8 and 18 g kg^{-1} organic matter while at Palermo soil type was sandy clay loam (54% sand, 23% silt and 23% clay) with a pH of 7.6 and 14 g kg^{-1} organic matter. Irrigation was applied as needed to encourage establishment. Plots received 50 kg ha^{-1} N, 10 kg ha^{-1} P, and 40 kg ha^{-1} K per month from June to September 2010. In order to minimize weed competition, from two years before establishment, the experimental areas were treated twice a year with glyphosate [N-(phosphonomethyl) glycine] at 2.88 kg ha^{-1} a.i. The day before planting, oxadiazon [5-tert-butyl-3-(2,4-dichloro-5-isopropoxyphenyl)-1,3,4-oxadiazol-2(3H)-one] was applied at 3.36 kg ha^{-1} a.i. Plots were not mowed during the year of establishment to avoid genotype x mowing interaction. Weeds occurring during the trial period were manually removed, even if it is not a standard cultivation technique, as the accessions could be differently injured by chemical removal. In the trial, no pesticides were applied. Encroachment of stolons into adjacent plots was avoided by using toothpicks that redirected the growing tip back toward the plot centre.

2011

In 2011, in the first and second weeks of March at Palermo and Pisa, respectively, scalping was carried out. From the end of April (the end of green-up) to October 2011, the turf was mowed weekly with a reel mower (John Deere 20SR7) at a mowing height of 2.5 cm. The irrigation program was adjusted according to soil temperature and evapotranspiration rate, with supplement irrigations applied as needed to prevent visual wilt of the turf (Croce *et al.*, 2004). Plots received 50 kg ha^{-1} N, 20 kg ha^{-1} P, and 40 kg ha^{-1} K per month from May to August 2011.

Weeds were manually removed inside the plots during the trial period as the accessions could be differently injured by chemical treatments. In the trial, no pesticides were applied. To avoid the encroachment of stolons into adjacent plots, the corridors were treated with glyphosate at 2.88 kg ha^{-1} a.i. every other week. No turf cultivation, or verticutting or phytosanitary treatment was practiced on the plots.

Monthly mean maximum and minimum temperatures recorded at the two trial sites are reported in Table 1. There were 13 days in Pisa with air temperatures below 0°C from November 2010 to March 2011; zero days were recorded in Palermo for the same period.

Table 1 - Monthly mean air temperatures (°C) during the trial period (2011) at Pisa and Palermo

Month	Air temperature (°C)			
	Pisa		Palermo	
	Mean maximum	Mean minimum	Mean maximum	Mean minimum
January	10.6	3.5	14.7	9.3
February	11.8	3.3	13.9	9.3
March	13.9	5.2	16.2	10.4
April	19.2	9.0	19.6	13.1
May	23.8	11.8	21.4	15.9
June	26.2	17.0	25.2	20.2
July	27.6	18.3	28.6	22.9
August	30.2	18.5	29.0	23.0
September	26.7	16.0	26.9	21.0
October	21.8	10.5	22.6	16.5
November	17.5	6.6	20.2	14.5
December	13.3	4.7	16.9	12.6

Assessments

Spring green-up (15 March-15 May 2011) and fall colour retention (15 November 2011-15 January 2012) were estimated and expressed as percentage of green ground cover. In the second week of October at both testing sites a 50 cm^2 core sample per plot was collected and the following parameters determined: leaf width (20 fully expanded leaves per plot measured with a precision Vernier caliper and data reported in millimeters), shoot density (direct counting with data reported as shoot no cm^{-2}), horizontal stem density (stolons and rhizomes collected after soil washing measured with a ruler and data reported as cm cm^{-2}) and node density (nodes of stolons and rhizomes collected from the core samples counted and reported as no cm^{-2}) (Roche and Loch, 2005; Volterrani *et al*., 2008; Volterrani *et al*., 2010; Pompeiano *et al*., 2012).

At the Pisa location two additional parameters were determined: at 30-day intervals throughout the growing season (May-October) colour, with a rating scale of 1=light green and 9=dark green, and quality with a rating scale of 9 = best and 1 = poorest (Morris and Shearman, 2007; Patton *et al*., 2009) were estimated.

Data were subjected to analysis of variance using CoStat software (Monterey, CA, USA). To test the effects of location, accession and their interaction, a factorial combination was used. Significantly different means were separated using Fisher's Least Significant Difference (LSD) at the t-probability level of 0.05.

3. Results

The interaction of treatments was not statistically significant for any of the parameters recorded in Pisa or Palermo. For all the parameters, the location and accession mean effects were statistically significant. Location effect is reported as average across accessions and accession effect is reported as average across locations.

Location mean effect

For the location effect, shoot density and node density were on average higher in Pisa (3.1 shoots cm^{-2} and 2.4 nodes cm^{-2} respectively) compared to Palermo (0.8 and 1.0) (Table 2). Also horizontal stem density was higher in Pisa (4.2 cm cm^{-2}) while leaf width recorded in Pisa was on average less (1.4 mm) compared to Palermo (2.4 mm).

Spring green-up evaluations as average across locations showed green cover percentages (April 14) higher in Palermo (81%) with respect to Pisa (60%), while fall colour retention (December 17) showed higher green cover percentages in Palermo (77%).

Accession mean effect

Shoot density

All wild type entries, with the exception of CeRTES 12 (2.4 shoot cm^{-2}) which produced a density comparable to hybrid and improved types, had a similar shoot den-

Table 2 - Bermudagrass [*Cynodon* (L.) Rich.] shoot density, horizontal stem density, node density, leaf width. Location effect averaged across accessions

	Shoot density (n° cm^{-2})	Horizontal stem density (cm cm^{-2})	Node density (n° cm^{-2})	Leaf width (mm)	Spring green-up (%)	Fall colour retention (%)
Pisa	3.1	4.2	2.4	1.4	60	33
Palermo	0.8	1.9	1.0	2.4	81	77

Means are significantly different at the 0.05 level of probability as determined by Fisher's protected LSD.

sity with values ranging from 0.5 to 1.0 shoots cm^{-2} (Table 3). The most dense improved type was Wintergreen (2.3 shoots cm^{-2}), hybrid type values ranged from 1.7 shoots cm^{-2} (Patriot) to 3.8 shoots cm^{-2} (Tif 00-1), while the most dense dwarf type was Miniverde with 5.1 shoots cm^{-2}.

Horizontal stem density

The highest value was recorded for Miniverde with 5.5 cm cm^{-2} while CeRTES 12 had a slightly lower value (5.1 cm cm^{-2}) (Table 3). The variability within the different groups was high for this parameter with values ranging from 1.5 to 5.1 cm cm^{-2} (respectively for Certes 1 and Certes 3 versus CeRTES 12) for the wild types, from 2.1 to 4.9 cm cm^{-2} (respectively for Scotts R6LA and Yukon versus Bull's Eye) for the improved types, from 2.7 to 4.3 cm cm^{-2} (for Tif 00-18 compared to Santa Ana and Tif 00-1) for the hybrid types, and from 1.6 to 5.1 cm cm^{-2} (respectively for Tifdwarf and Miniverde) for the dwarf types.

Node density

CeRTES 3 and Miniverde were the entries with the lowest and the highest node density with 0.6 and 5.5 nodes cm^{-2}, respectively (Table 3). The variability within the groups was high for this parameter, with the exception of the hybrid types that had values ranging from 1.6 to 2.5 nodes cm^{-2} (respectively for Tif 00-18 and Santa Ana).

Leaf width

Coarser leaves were found in the wild types with values ranging from 2.1 mm (CeRTES 10) to 3.0 mm (CeRTES 5, 6, 7) with CeRTES 12 (1.1 mm) the exception (Table 3). Improved *Cd* types had a leaf width ranging from 1.6 mm (Wintergreen and Yukon) to 2.2 mm (Scotts R6LA and Sovereign). For hybrid types values ranged from 1.3 mm (Tif 00-10) to 1.9 mm (Tif 00-27), while for dwarf types values ranged from 1.0 mm (Roma) to 1.5 mm (Uganda).

Spring green-up

Green cover percentage evaluated in mid-April showed accessions scoring values above 80% and not statistically different from each other in each group (Table 4). In more detail, the accession with the best score was CeRTES 5 (93%); the lowest score was found in Sovereign (24%).

Fall colour retention

Green colour retention evaluated in mid-December showed a great variability within the groups (Table 4). The highest value was recorded for Tif 00-2, with the lowest for three dwarf types, Miniverde, Tifdwarf and Tifeagle (11%).

Colour

In Pisa, the highest and lowest values, Barazur (score 8.4) and Riviera (score 6.0) respectively, were recorded within the improved type group. In the wild type group, the values ranged from 6.1 (CeRTES 1) to 7.4 (CeRTES 4 and 9) (Table 4). With the exception of Barazur, the highest values were recorded within the hybrid type group with values ranging from 7.1 (Tifsport) to 8.2 (Patriot), while

Table 3 - Bermudagrass [*Cynodon* (L.) Rich.] accessions. Shoot density, horizontal stem density, node density and leaf width. Accession effect averaged across locations

Accessions	Shoot density (n° cm^{-2})	Horizontal stem density (cm cm^{-2})	Node density (n° cm^{-2})	Leaf width (mm)
Wild types (Cd)				
CeRTES-1	0.8	1.5	0.7	2.8
CeRTES-2	0.7	1.7	0.8	2.8
CeRTES-3	0.9	1.5	0.6	2.8
CeRTES-4	0.8	2.9	1.8	2.5
CeRTES-5	0.9	1.9	0.9	3.0
CeRTES-6	1.0	3.1	1.7	3.0
CeRTES-7	0.6	2.1	0.9	3.0
CeRTES-8	0.5	1.8	0.8	2.9
CeRTES-9	0.9	2.3	0.9	2.8
CeRTES-10	0.9	2.1	0.9	2.1
CeRTES-11	1.0	2.5	1.1	2.7
CeRTES-12	2.4	5.1	3.0	1.1
CeRTES-13	0.7	1.9	1.1	2.8
Improved types (Cd)				
Argentina	1.0	4.0	1.8	2.1
Barazur	2.0	3.1	2.1	1.7
Bull's Eye	1.9	4.9	2.4	1.9
Celebration	1.3	2.5	1.3	1.9
Grand Prix	2.2	2.9	1.6	1.8
Princess 77	2.1	3.6	1.9	1.8
Riviera	1.1	2.3	0.9	1.9
Scotts R6LA	1.3	2.1	1.0	2.2
Sovereign	0.9	3.3	1.4	2.2
SR 9554	1.3	2.2	0.7	2.0
Veracruz	1.3	3.4	1.6	1.8
Wintergreen	2.3	2.9	1.5	1.6
Yukon	1.2	2.1	1.1	1.6
Hybrid types (Cdxt)				
Patriot	1.7	3.9	2.0	1.8
Santa Ana	3.1	4.3	2.5	1.4
Tifsport	2.3	3.4	1.7	1.8
Tifway	2.6	3.8	2.0	1.4
Tif 00-1	3.8	4.3	2.3	1.5
Tif 00-2	3.2	3.3	2.1	1.5
Tif 00-7	3.2	3.2	2.2	1.5
Tif 00-10	3.5	3.7	2.0	1.3
Tif 00-18	2.7	2.7	1.6	1.4
Tif 00-24	2.0	3.7	1.9	1.4
Tif 00-27	2.3	3.6	2.1	1.9
Dwarf types (Cdxt/Ct)				
Champion	2.2	4.0	2.0	1.2
Miniverde	5.1	5.5	5.5	1.3
Tifdwarf	2.6	1.6	1.0	1.3
Tifeagle	3.1	4.4	4.2	1.1
Tifgreen	2.7	1.9	1.5	1.2
Roma	4.1	3.7	2.2	1.0
Uganda	3.0	4.7	2.6	1.5
LSD 0.05	0.7	1.6	1.2	0.3

Table 4 - Bermudagrass [*Cynodon* (L.) Rich.] accessions. Spring green-up (April 14 2011) and fall colour retention (percentage of green colour) (17 December 2011). Accession effect averaged across locations. Colour (visual estimation based on a 1-9 scale) and quality (visual estimation based on a 1-9 scale) refer only to the Pisa location (mean values May-October 2011)

Accessions	Spring green-up (%)	Fall colour retention (%)	Colour (1-9)	Quality (1-9)
Wild types (Cd)				
CeRTES-1	55	16	6.1	4.3
CeRTES-2	75	32	7.0	5.7
CeRTES-3	66	38	6.3	5.8
CeRTES-4	65	38	7.4	6.8
CeRTES-5	93	76	6.4	6.0
CeRTES-6	73	49	7.2	6.4
CeRTES-7	74	37	7.1	6.2
CeRTES-8	59	33	6.6	6.2
CeRTES-9	85	63	7.4	6.7
CeRTES-10	51	53	6.7	5.9
CeRTES-11	72	68	6.2	5.6
CeRTES-12	79	54	6.8	7.0
CeRTES-13	60	41	6.7	5.9
Improved types (Cd)				
Argentina	66	45	6.4	6.1
Barazur	55	43	8.4	7.7
Bull's Eye	76	59	7.9	7.7
Celebration	49	59	7.5	6.4
Grand Prix	77	78	6.8	6.9
Princess 77	72	73	6.9	6.9
Riviera	57	50	6.0	5.8
Scotts R6LA	73	57	6.9	6.4
Sovereign	24	56	6.4	6.3
SR 9554	67	56	6.8	6.5
Veracruz	71	61	6.8	6.9
Wintergreen	83	69	7.1	6.5
Yukon	70	35	7.3	7.1
Hybrid types (Cdxt)				
Patriot	75	33	8.2	8.1
Santa Ana	77	73	7.4	7.9
Tifsport	79	68	7.1	7.2
Tifway	87	83	7.9	8.1
Tif 00-1	86	77	7.9	7.5
Tif 00-2	89	86	7.2	7.6
Tif 00-7	62	75	7.9	6.8
Tif 00-10	82	81	8.1	7.8
Tif 00-18	84	80	8.0	8.0
Tif 00-24	74	79	7.7	7.0
Tif 00-27	87	81	7.4	7.6
Dwarf types (Cdxt/Ct)				
Champion	86	76	7.7	8.0
Miniverde	53	11	7.9	8.4
Tifdwarf	63	11	7.8	7.9
Tifeagle	52	11	7.4	8.1
Tifgreen	72	31	7.0	7.9
Roma	75	56	7.4	8.0
Uganda	84	78	7.8	7.9
LSD 0.05	17	7	0.5	0.7

for the dwarf types the values ranged from 7.0 (Tifgreen) to 7.9 (Miniverde).

Quality

In Pisa, the highest quality was recorded for the dwarf type Miniverde with a score of 8.4, however no significant differences were recorded within this group (Table 4). Wild types ranged in quality from 4.3 (CeRTES 1) to 7.0 (CeRTES 12), while improved types ranged from 5.8 (Riviera) to 7.7 (Barazur and Bull's Eye); the variability of ratings within both these groups is worthy of note.

The hybrid types scored from 6.8 (Tif 00-7) to 8.1 (Patriot and Tifway).

4. Discussion and Conclusions

The study carried out on a pool of genetically and morphologically different entries belonging to the genus *Cynodon* has highlighted a wide variability of aesthetic and morphological traits.

Morphological characteristics such as shoot density, node density, and horizontal stem density highlighted the better quality of the majority of dwarf and hybrid type cultivars, with improved types showing performances similar to those of wild types; CeRTES 12 was the exception.

The genetic differences among groups are reflected more clearly with regard to leaf width, with values getting lower going from wild to dwarf types, with the exception of CeRTES 12.

Recovery from winter dormancy in the spring, expressed as spring green up, showed a great variability within and among the groups. This parameter is associated with carbohydrate reserves accumulated in storage organs as observed by Macolino *et al*. (2010). Other studies (Volterrani *et al*., 2012) focused on carbohydrates in stolons in the first year of establishment and the relationship with growth and establishment rate.

Cold tolerance, expressed as fall colour retention, highlighted the better performances of the hybrid types with the dwarf types being the first cultivars in which dormancy begins.

The parameters representing turf aesthetic quality (colour and turf quality), although they indicate a great variability within groups, showed improving mean values from wild to dwarf types and confirmed what Patton *et al*. (2009) observed concerning the differences between improved and hybrid types.

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