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Performance of turf-type bermudagrass cultivars in the upper and lower limits of the European transition zone

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Abstract

Bermudagrass [*Cynodon dactylon* (L.) Pers.] is one of the most widely cultivated turfgrass species throughout the world. It has several important attributes, such as heat and drought tolerance, and one big disadvantage, which is susceptibility to cold temperatures. Although many seeded bermudagrass cultivars are widely used in Europe, research is warranted on new varieties released in recent decades. Two identical field studies were conducted in Valencia, Spain (39˚ N lat) and Legnaro, Italy (45˚ N lat) to evaluate the turfgrass quality, winter dormancy, and spring green-up of two new bermudagrass releases in Europe ('Arden 15' and 'MBG 002') and three older bermudagrasses ('Blackjack', 'Common', and 'Paul 1'). Even though bermudagrasses were successfully cultivated in the cooler temperature zone (45˚ N lat), cultivars exhibited poorer establishment and longer winter dormancy as a consequence of the lower temperatures compared with those grown in the warmer temperature zone (39˚ N lat). Cultivars Arden 15 and MBG 002 were able to mitigate the effects of low temperature that affected the older cultivars, especially during spring green-up, which is an essential characteristic when growing bermudagrass in the upper limit of the transition zone.

1 | INTRODUCTION

The term "transition zone" does not have a clear, objective definition in climate terms. The turfgrass transition zone is defined by some authors as the region between temperate and subtropical climates (Fu et al., 2004), or as the area between a southern region, where warm-season grasses are adapted, and a northern region, where cool-season grasses are adapted (Dunn & Diesburg, 2004). Bermudagrasses (*Cynodon* spp.) are well adapted to tropical areas (Cui et al., 2021), but they are distributed throughout all of the countries and islands between latitudes 45˚ N and 45˚ S (Esmaili & Salehi, 2012; Tailaferro & McMaugh, 1993) and up to approximately latitude 53˚ N in Europe (Zhang et al., 2018). Bermudagrass began to be established as a turfgrass in the early 1900s (Baxter & Schwartz, 2018) and quickly became one of the most widely used turfgrass species in warm to temperate regions of the world. The turfgrass industry is pushing bermudagrass cultivation toward temperate climates, taking advantage of the species' tolerance to heat and drought (McCarty & Miller, 2002) in warmer months. However, these advantages must be balanced with the risk of cold damage (Richardson

Abbreviations: DOY, day of year; GDD, growing degree days; NDVI, normalized difference vegetation index; NTEP, National Turfgrass Evaluation Program.

et al., 2004) and loss of quality in cooler months. In fact, bermudagrass plants enter dormancy and turn brown when temperatures drop below 10 ˚C, with green-up occurring in spring when average soil temperatures persist above 10 ˚C for several days (Mirabile et al., 2016).

Historically, the highest quality turf-type bermudagrass cultivars have been sterile F_1 hybrid plants from crosses between tetraploid ($2n = 4x = 36$) (*C. dactylon*) and diploid ($2n = 2x = 18$) (*Cynodon transvaalensis* Burtt-Davy) plants (Brosnan & Deputy, 2008). These cultivars are commercially propagated by planting either sprigs or sod, although over the past two decades, there has been a dramatic increase in the number of fertile cultivars (*C. dactylon*) (Morris, 2002). Some of the recently developed fertile bermudagrasses are equal to the sterile cultivars in turfgrass quality and other performance characteristics (Yerramesetty et al., 2005). Normally, new bermudagrass cultivars are selected on the basis of strong self-sterility, turf-type growth form, winter hardiness, and seed production potential (Taliaferro et al., 2003). In the United States, bermudagrass cultivars are tested by the National Turfgrass Evaluation Program (NTEP) in several locations between latitudes 29˚ N (Gainesville, FL) and 40˚ N (West Lafayette, IN). In Mediterranean regions, several studies have evaluated bermudagrass cultivars in single locations (Giolo et al., 2013; Macolino et al., 2010; Mutlu et al., 2020; Pornaro et al., 2019; Volterrani et al., 2012), although there is a lack of information regarding site effects on cultivar performance.

With ongoing climate change and its impact on biological systems through increased temperatures (Hatfield, 2017) and limited water availability, it is possible that cool-season turfgrass species, whose limiting factors are heat, drought, and disease, could be replaced by bermudagrass cultivars at higher latitudes. The objective of this research was to test the performance of five bermudagrass cultivars, including new releases in Europe, in two different Mediterranean locations (latitude 39˚ N in Spain and 45˚ N in Italy), focusing on turf quality over the growing season of the sowing year, winter dormancy, and spring green-up.

2 | MATERIALS AND METHODS

Identical field experiments were carried out from May 2020 to June 2021 at two different locations: the experimental agricultural farm of the Polytechnic University of Valencia in Valencia, eastern Spain (39˚48′ N, 0˚34′ W; 5 m asl) and the experimental agricultural farm of the University of Padova in Legnaro, northeastern Italy (45˚20′ N, 11˚57′ E; 8 m asl). According to Reasor et al. (2018), growing degree days (GDD) were calculated for both locations with daily mean air temperature starting from 1 Jan. 2020 and 1 Jan. 2021, using 10 ˚C as base temperature (Berry and Björkman, 1980; Cross and Zuber, 1972; Elmore et al., 2013; McMaster and Wilhelm, 1997). Monthly mean air temperature, precipitation, solar radiation, and GDD for both locations are shown in Tables 1, 2, and 3.

Core Ideas

- Bermudagrasses are distributed throughout a wide range of latitudes.
- At both latitudes, bermudagrasses enter dormancy with different durations.
- Bermudagrass dormancy lasted 4 mo at 45˚ N lat and 1 mo at 39˚ N lat.
- Bermudagrass spring green-up was found quicker at 45˚ N lat than at 39˚ N lat.

2.1 | Treatments and turfgrass management

Five bermudagrass cultivars (Arden 15, Blackjack, Common, MBG 002, and Paul 1) were sown in both locations in mid-May 2020 at a rate of 8 g m^{-2} in 2 by 2 m plots. The soil was plowed at a depth of 20 cm and harrowed before seeding, and seeds were applied by hand without any carrier material; furthermore, no seed fabrics or topdressing were used. All plots were surrounded by a strip of tall fescue (0.5 m in width) [*Schedonorus arundinaceus* (Schreb.) cultivar 'Braveheart']. After full establishment in early July, the following management practices were carried out: (a) sprinkler irrigation at around 80% of local potential evapotranspiration; (b) twice weekly mowing at a height of 50 mm during July and August, and once weekly during the rest of the experimental period; and (c) three applications of a 15:15:15 (N:P_2O_5:K_2O) complex fertilizer (Spain: Fertasol triple [Fertusa Mare Nostrum]; Italy: K-Fert [Adriatica]), 100 kg N ha^{-1} in May 2020 during seed bed preparation, 100 kg N ha^{-1} in mid-July, and 50 kg N ha^{-1} in mid-September.

2.2 | Measurements

The turfgrass was completely established in early July. The following weekly evaluations were made from July 2020 until June 2021: (a) turf quality by subjective visual examination was rated on a scale of 1–9, where 1 is dead turf, 6 is an acceptable turf, and 9 is turf in its best condition (Morris & Shearman, 1998); (b) turf color assessed visually was rated on a scale of 1–9, where 1 is tan or brown turf, 6 is a minimum acceptable color, and 9 an optimal dark-green turf (Karcher & Richardson, 2003); (c) normalized difference vegetation index (NDVI) values were measured using a GreenSeeker

TABLE 1 Monthly mean air temperatures over the study period at the experimental agricultural farm of the University of Padova in Legnaro, northeastern Italy (45°20′ N; 11°57′ E; 8 m asl) and at the experimental agricultural farm of Polytechnic University of Valencia, in Valencia, eastern Spain (39°48′ N; 0°34’ W; 5 m asl)

	Italy			Spain		
Month	2020	2021	36-yr average	2020	2021	22-yr average
	°C					
Jan.	3.3	3.1	3.2	10.6	10.9	9.9
Feb.	7.3	7.1	4.9	14.0	14.0	10.6
Mar.	9.2	8.4	9.0	14.2	12.8	12.7
Apr.	13.9	11.5	13.2	16.1	14.6	15.3
May	18.0	16.0	18.0	20.8	19.6	18.7
June	21.2	23.9	22.0	23.1	23.6	22.8
July	23.9	24.2	23.0	26.2	19.6	25.3
Aug.	24.2	23.3	23.4	26.8	26.2	25.5
Sept.	20.4	20.0	18.9	23.5	24.1	22.4
Oct.	13.3	13.2	14.0	18.9	19.9	18.5
Nov.	8.4	9.3	8.9	15.3	14.3	13.3
Dec.	5.8	3.4	4.1	12.3	13.4	10.4
Year	14.1	13.7	13.6	18.5	17.8	17.1

TABLE 2 Monthly precipitation over the study period at the experimental agricultural farm of the University of Padova in Legnaro, northeastern Italy (45°20′ N; 11°57′ E; 8 m asl) and at the experimental agricultural farm of the Polytechnic University of Valencia in Valencia, eastern Spain (39°48’ N lat; 0°34’ W long; 5 m asl)

	Italy			Spain		
Month	2020	2021	36-yr average	2020	2021	22-yr average
	mm					
Jan.	15	71	43	148	31	33
Feb.	5	16	51	2	16	22
Mar.	60	4	57	55	39	38
Apr.	25	91	73	47	61	35
May	30	132	89	16	22	33
June	142	17	73	38	15	17
July	44	88	72	11	22	11
Aug.	175	47	65	2	21	17
Sept.	19	33	81	25	54	56
Oct.	67	30	84	4	21	56
Nov.	15	95	89	120	39	47
Dec.	106	36	61	2	0	29
Year	702	660	837	470	341	394

handheld crop sensor (Trimble). From full establishment (July 2020) until dormancy (November 2020), grass clippings were collected once per month from each plot in a 0.8 m^2 area using a rotary mower, and dry matter was determined by oven-drying the clippings at 105 °C for 36 h. Once per month, from January to June 2021, turf green cover was measured by digital image analysis, as described by Richardson et al. (2001), to evaluate spring green-up.

2.3 | Experimental design and statistical analyses

Both trials had plots arranged in a randomized block design with three replicates. An ANOVA was performed using a linear mixed effects model to test the effects of site, cultivar, sampling date, and their interactions on the parameters measured (turfgrass visual quality, color, NDVI, clipping production, and green cover during the spring green-up). The blocks within sampling date and the main plots within blocks were included as random effects to account for the clustering of observations. Day of the year (DOY) and associated GDD at which 50, 75, and 95% of green cover was reached were calculated. A sigmoidal model (Leinauer et al., 2010) was identified to best describe spring green-up and used to predict DOY and GDD for each plot in both locations. An ANOVA was performed using a linear mixed effects model to test the effects of site, cultivar, and their interaction on the DOY and associated GDD at 50, 75, and 95% of green cover. The blocks were included as random effects to account for the clustering of observations. A LSD test with Bonferroni correction at a probability of 0.05 was used to identify significant differences among means. All statistical analyses were performed in R version 4.0.2 (R core team, 2020).

3 | RESULTS

The ANOVA revealed a significant three-way interaction between cultivars, sites, and sampling dates for turf quality, color, and NDVI (Table 4). The evolution of these parameters is, therefore, presented separately for each experimental site in Figures 1–3.

In Italy, the bermudagrass cultivar MBG 002 achieved its highest turf quality rating in August and September 2020, higher than the other cultivars (Figure 1). There were no differences in turf quality between cultivars in Spain during the same months, although MBG 002 tended to be higher than all other cultivars, except Arden 15. As temperatures started to drop, all cultivars underwent a gradual decline in turf quality at both sites, although in Italy it was quicker and all cultivars entered complete dormancy sooner than in Spain. At both sites, the cultivar MBG 002 maintained better turf quality than some of the other cultivars as quality declined. Winter dormancy was shorter in Spain than in Italy, and by the middle of March, the cultivars Arden 15 and MBG 002 had reached an acceptable level of turf quality while all

TABLE 3 Cumulative monthly solar radiation and cumulative monthly growing degree days (base temperature 10 ˚C) over the study period at the experimental agricultural farm of the University of Padova in Legnaro, northeastern Italy (45˚20′ N; 11˚57′ E; 8 m asl) and at the experimental agricultural farm of the Polytechnic University of Valencia in Valencia, eastern Spain (39˚48′ N; 0˚34′ W; 5 m asl)

Month	Cumulative solar radiation						Growing degree days			
	Italy			Spain			Italy		Spain	
	2020	2021	5-yr average	2020	2021	5-yr average	2020	2021	2020	2021
	MJ m^{-2}									
Jan.	175	148	165	206	226	221	0	0	42	76
Feb.	266	241	226	308	250	271	0	4	116	112
Mar.	412	483	430	315	397	389	17	17	129	87
Apr.	632	530	553	391	400	421	124	64	182	138
May	691	665	638	570	547	552	247	186	336	298
June	693	746	749	574	546	583	337	414	393	407
July	736	704	747	584	597	587	432	442	502	491
Aug.	633	688	676	541	494	513	439	412	521	503
Sept.	506	518	475	434	421	409	311	301	404	423
Oct.	285	352	304	344	329	334	103	101	276	307
Nov.	199	173	157	208	232	223	16	17	160	128
Dec.	95	132	124	219	202	198	3	0	74	82
Year	5,322	5,379	5,244	4,694	4,641	4,704	2,029	1,958	3,135	3,052

TABLE 4 Results of the ANOVA testing the effects of cultivar, site, sampling date and their interactions on turfgrass quality, color, normalized difference vegetation index (NDVI), clipping production rate, and turf green cover of five bermudagrass cultivars (Arden 15, Blackjack, Common, MBG 002, and Paul 1) established at the experimental agricultural farm of the University of Padova in Legnaro, northeastern Italy (45˚20′ N; 11˚57′ E; 8 m asl) and at the experimental agricultural farm of the Polytechnic University of Valencia in Valencia, eastern Spain (39˚48′ N; 0˚34′ W; 5 m asl)

Source	Turf quality	Turf color	NDVI	Dry matter	Turf green cover
Cultivar (C)	***	***	***	***	***
Site (S)	***	***	***	***	***
Sampling date (Da)	***	***	***	***	***
C × S	**	**	***	ns[†]	***
C × Da	***	***	***	***	***
S × Da	***	***	***	***	***
C × S × Da	***	***	***	ns	***

*Significant at the .05 probability level.
**Significant at the .01 probability level.
***Significant at the .001 probability level.
[†]ns, nonsignificant at the .05 probability level.

other cultivars were still greening-up, a pattern that was also observed later in Italy (May and June).

Cultivar MBG 002 had significantly darker green color than Blackjack, Common, and Paul 1 during the growing period at both sites (Figure 2). Cultivar Arden 15 rated similarly to MBG 002 from establishment until the autumn temperature drop (Figure 2). In Spain, Arden 15 and MBG 002 resulted in greater turf color during spring green-up in mid-March compared with other cultivars, whereas this phenomenon occurred 2 mo later in Italy.

Normalized difference vegetation index values measured at both sites are shown in Figure 3. These are objective measurements based on light reflectance (Zhang et al., 2019), and they match the changes of the turf quality and color of the cultivars at both sites. In Italy, there were larger differences in NDVI between cultivars in summer than during winter and spring green-up, whereas in Spain, the greater differences between cultivars mostly occurred in autumn and during spring green-up. At both sites, MBG 002 generally had the highest NDVI values, followed by Arden 15 and then by the other cultivars.

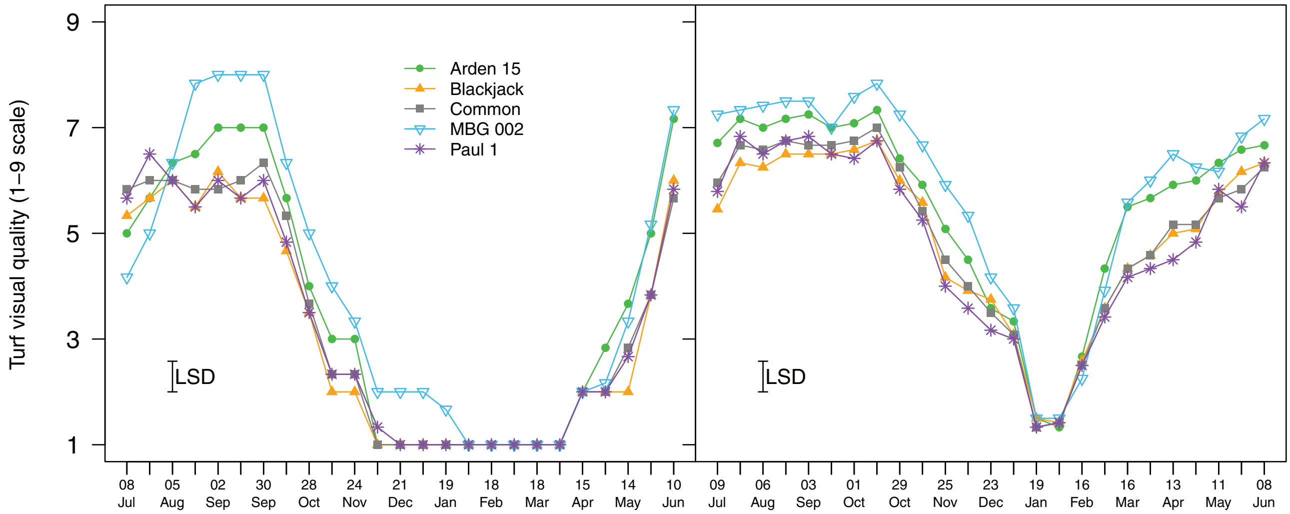

FIGURE 1 The effects of site and sampling date on turfgrass visual quality of five bermudagrass cultivars (Arden 15, Blackjack, Common, MBG 002, and Paul 1) established at (a) the experimental agricultural farm of the University of Padova in Legnaro, northeastern Italy (45˚20′ N; 11˚57′ E; 8 m asl) and at (b) the experimental agricultural farm of the Polytechnic University of Valencia in Valencia, eastern Spain (39˚48′ N; 0˚34′ W; 5 m asl) (on the right). Vertical bars represent the least significant differences (*P* = .05) for comparing means

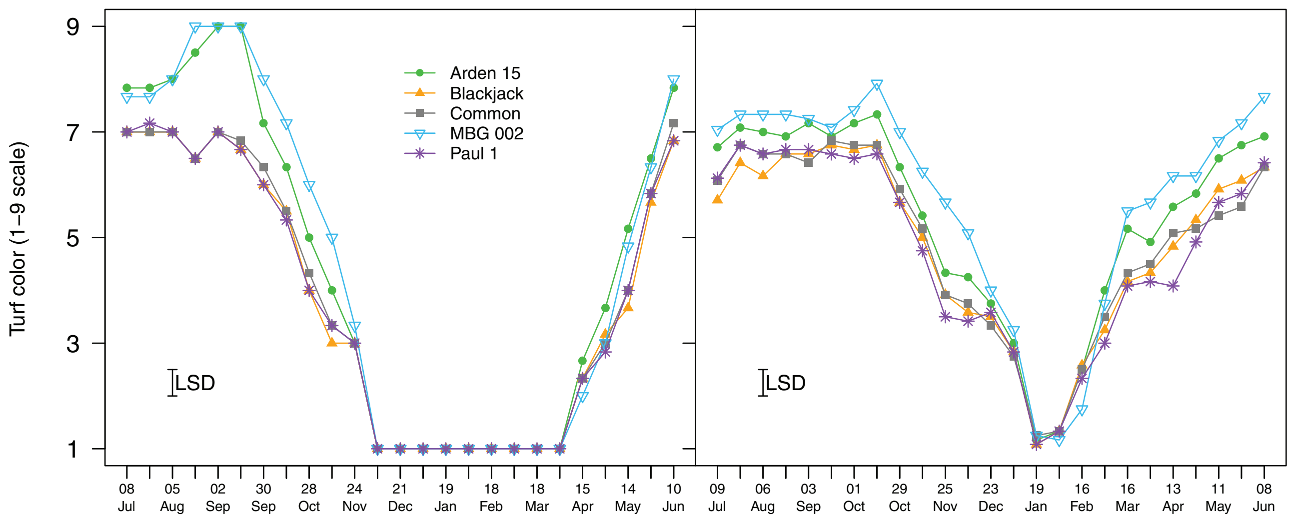

FIGURE 2 Effects of site and sampling date on the turfgrass color of five bermudagrass cultivars (Arden 15, Blackjack, Common, MBG 002, and Paul 1) established at (a) the experimental agricultural farm of the University of Padova in Legnaro, northeastern Italy (45˚20′ N; 11˚57′ E; 8 m asl) and at (b) the experimental agricultural farm of the Polytechnic University of Valencia in Valencia, eastern Spain (39˚48′ N; 0˚34′ W; 5 m asl). Vertical bars represent the least significant differences (*P* = .05) for comparing means

Clipping yield was affected by the interaction between cultivar and sampling date, and by the interaction between site and sampling date (Table 4). When the data were averaged by site (Figure 4a), clipping yield values were found to be high and constant in Spain during the summer (July–September), whereas values in Italy were only similar to Spain in August. Furthermore, in November, clippings were produced only in Spain. When the data were averaged by cultivar (Figure 4b), important differences in clipping yields between cultivars were revealed. During the best bermudagrass growing season (summer), MBG 002 always produced fewer clippings than Blackjack, Common, and Paul 1. Cultivar Arden 15 had similar values to MBG 002 from July to September, and lower values than Blackjack, Common, and Paul 1 in July and September. However, the clipping production of Blackjack, Common, and Paul 1 dropped sharply in autumn to values equal to the less productive cultivars.

The percentage of green cover during spring green-up was also affected by a three-way interaction between cultivar, site, and sampling date (Table 4). In Spain, green-up started

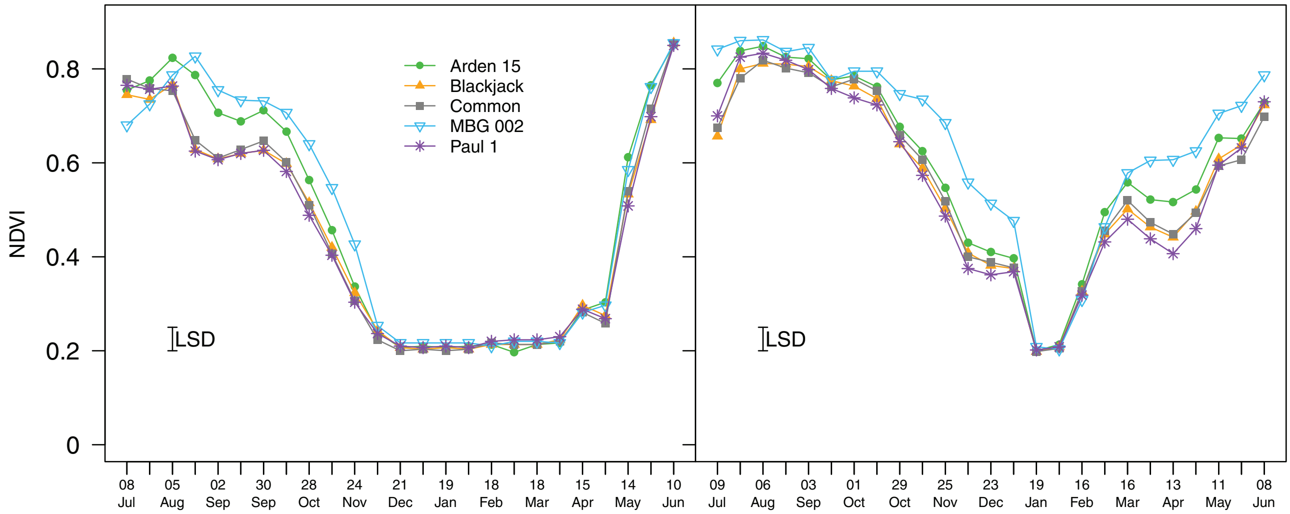

FIGURE 3 Effects of site and sampling date on the normalized difference vegetation index (NDVI) of five bermudagrass cultivars (Arden 15, Blackjack, Common, MBG 002, and Paul 1) established at (a) the experimental agricultural farm of the University of Padova in Legnaro, northeastern Italy (45°20′ N; 11°57′ E; 8 m asl) and at (b) the experimental agricultural farm of the Polytechnic University of Valencia in Valencia, eastern Spain (39°48′ N; 0°34′ W; 5 m asl). Vertical bars represent the least significant differences (P = .05) for comparing means

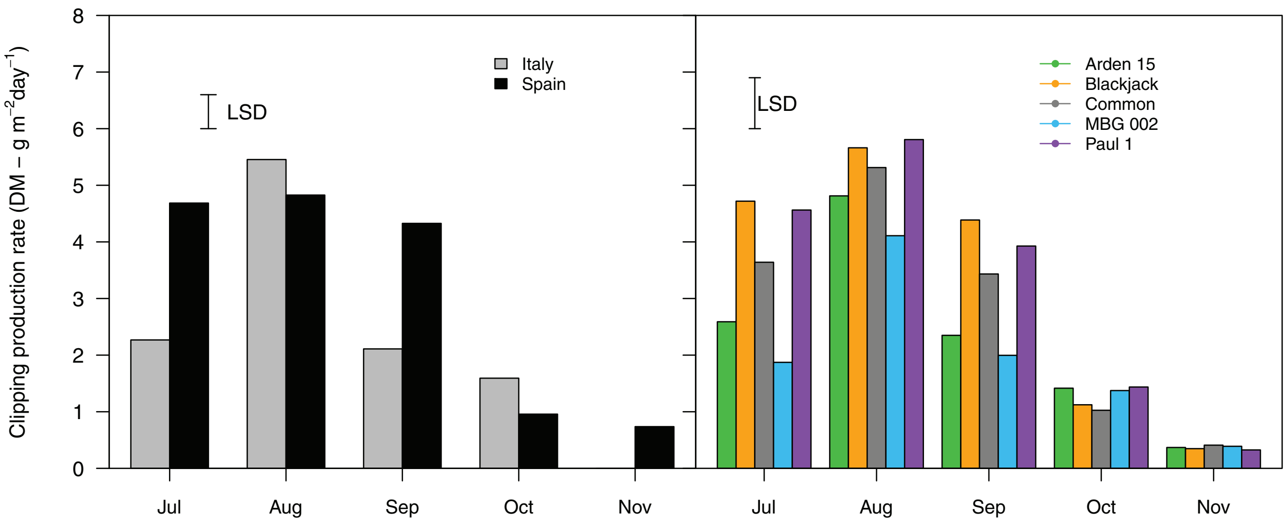

FIGURE 4 Effects of (a) site and sampling date, and of (b) cultivar and sampling date on the clipping production rate of bermudagrass cultivars established at the experimental agricultural farm of the University of Padova in Legnaro, northeastern Italy (45°20′ N; 11°57′ E; 8 m asl) and at the experimental agricultural farm of the Polytechnic University of Valencia in Valencia, eastern Spain (39°48′ N; 0°34′ W; 5 m asl). Vertical bars represent the least significant differences (P = .05) for comparing means

earlier than in Italy (late January vs. early March). Cultivar MBG 002 reached 60% green cover in mid-March with values higher than all the other cultivars, whereas Arden 15 had higher values than Paul 1 (Figure 5). In Italy, differences in green cover between cultivars were not observed until May, when Arden 15 and MBG 002 reached 80%, compared with 60% green cover exhibited by the other cultivars. Despite the different rates of green-up between the two sites and among the different cultivars, all cultivars reached full green-up in June at both sites.

The ANOVA revealed a significant two-way interaction between cultivars and sites for DOY and GDD at which 50 and 75% of green cover was reached (Table 5).

In Italy, no differences were found within cultivars for DOY necessary to reach 50% of green cover (Table 6), whereas MBG 002 in Spain showed the lowest value, followed by Arden 15, and then by Blackjack, Common, and Paul 1. Furthermore, cultivars seeded in Italy displayed the lowest GDD values to reach 50% of green cover, whereas Blackjack, Common, and Paul 1 seeded in Spain the highest (Table 6).

TABLE 5 Results of the ANOVA testing the effects of cultivar, site, and their interaction on day of the year (DOY) and associated growing degree days (GDD) at which 50, 75, and 95% of green cover was reached in comparison of five bermudagrass cultivars (Arden 15, Blackjack, Common, MBG 002, and Paul 1) established at the experimental agricultural farm of the University of Padova in Legnaro, northeastern Italy (45˚20′ N; 11˚57′ E; 8 m asl) and at the experimental agricultural farm of the Polytechnic University of Valencia in Valencia, eastern Spain (39˚48′ N; 0˚34′ W; 5 m asl)

Source	DOY 50%	DOY 75%	DOY 95%	GDD 50%	GDD 75%	GDD 95%
Cultivar (C)	***	***	*	**	***	ns[†]
Site (S)	***	ns	***	***	***	***
C × S	***	***	ns	*	**	ns

*Significant at the .05 probability level.
**Significant at the .01 probability level.
***Significant at the .001 probability level.
[†]ns, nonsignificant at the .05 probability level.

Cultivar MBG 002 in Spain was the fastest cultivar to reach 75% of green cover in terms of DOY, whereas MBG 002 seeded in Italy did not differ for all other cultivars (Table 6). Growing degree days necessary to reach 75% of green cover were found lower for cultivars seeded in Italy, followed by MBG 002 seeded in Spain, Arden 15 seeded in Spain, and then Blackjack and Common seeded in Spain (Table 6). Day of the year and GDD necessary to reach 95% of green cover were affected by sites, with Spain showing higher values than Italy (166 vs. 149 DOY; 992 vs. 224 GDD). Furthermore, DOY necessary to reach 95% varied also within cultivars, with Blackjack and Paul 1 reaching a value of 161 d (Table 6) and MBG 002 showing the lowest value (153).

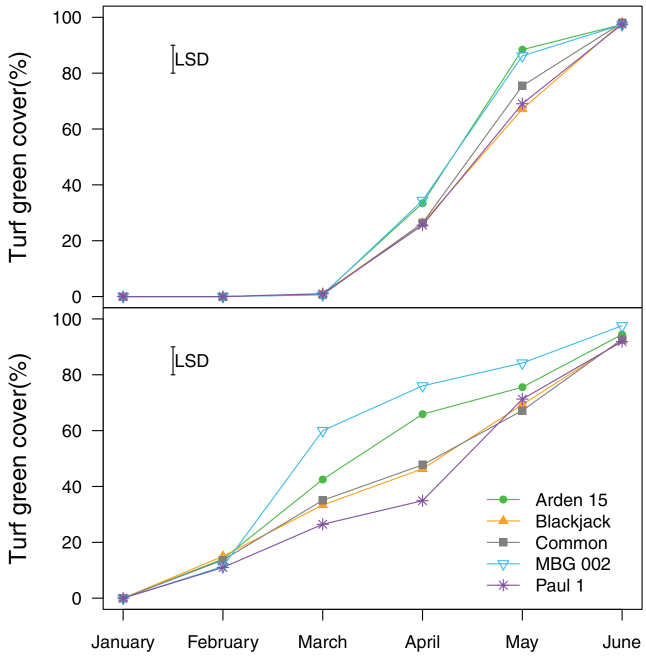

FIGURE 5 Effects of site and sampling date on the percentage green cover of five bermudagrass cultivars (Arden 15, Blackjack, Common, MBG 002, and Paul 1) established at (a) the experimental agricultural farm of the University of Padova in Legnaro, northeastern Italy (45˚20′ N; 11˚57′ E; 8 m asl) and at (b) the experimental agricultural farm of the Polytechnic University of Valencia in Valencia, eastern Spain (39˚48′ N; 0˚34′ W; 5 m asl). Vertical bars represent the least significant differences (P = .05) for comparing means

4 | DISCUSSION

Although the definition of transition zone is somewhat vague, it is widely recognized that, in this zone, warm-season grasses enter into dormancy and lose their color in winter, whereas cool-season grasses suffer during summer. Accordingly, both types of grasses have a nonstressful growing period during the year (Magni et al., 2017). To our knowledge, this is the only study that has tested the performance of five bermudagrass cultivars established at very different latitudes (45˚ N in Italy and 39˚ N in Spain). Within this 6˚ span of latitude, bermudagrass cultivars fell into dormancy at both sites, although with very different durations. In Spain, total dormancy lasted less than 1 mo, whereas in Italy, it lasted almost 4 mo. The average turf quality values of the bermudagrass cultivars remained above 6 for 8 mo in Spain and for 5 mo in Italy. In Turkey, in a Mediterranean climate with temperatures reported to be in the middle between Valencia and Legnaro, Severmutlu et al. (2011) found similar results, with sufficient turf quality values maintained for 6 mo but with a spring green-up starting in February. Temperatures were likely the responsible factor as shown by the effects of temperature reductions on turfgrass color (Figure 2; Table 1), NDVI (Figure 3; Table 1), and clipping yield (Figure 4; Table 1). However, solar radiation is also influencing bermudagrass growth and color (Bunnell et al., 2005; Burton et al., 1988). Cumulative solar radiation from May to September in Legnaro (Italy) is 3,259 MJ m^{-2}, whereas in Valencia (Spain), cumulative solar radiation is 2,703 MJ m^{-2} (Table 3), which explains a slightly better performance of Arden 15 and MBG 002 during late summer in Legnaro than in Valencia (Figures 1 and 2).

In Italy, the spring green-up was reported to occur in general in April and May (Macolino et al., 2010; Schiavon et al., 2016), whereas in Spain, the green-up depended on winter

TABLE 6 Effects of site on the day of the year (DOY) and associated growing degree days (GDD) necessary to reach 50, 75, and 95% of green cover of five bermudagrass cultivars (Arden 15, Blackjack, Common, MBG 002, and Paul 1) established at the experimental agricultural farm of the University of Padova in Legnaro, northeastern Italy 45˚20′ N; 11˚57′ E; 8 m asl) and at the experimental agricultural farm of the Polytechnic University of Valencia in Valencia, eastern Spain (39˚48′ N; 0˚34′ W; 5 m asl)

	DOY 50%		DOY 75%		GDD 50%		GDD 75%		
Cultivar	Italy	Spain	Italy	Spain	Italy	Spain	Italy	Spain	DOY 95%
Arden 15	122a	94c	129cd	127d	98c	301b	136d	544b	155bc
Blackjack	127a	112b	138bc	144ab	123c	425a	184d	717a	161a
Common	125a	112b	135cd	146ab	112c	400a	167d	742a	159ab
MBG 002	123a	82d	131cd	106e	101c	273b	147d	364c	153c
Paul 1	127a	121ab	138bc	150a	122c	470a	184d	770a	161a

Note. Mean values of each parameter (DOY 50%, DOY 75%, GDD 50%, GDD75%, DOY 95%) with the same letters are not statistically different at a probability level of 0.05.

temperature (especially in February) (De Luca and Gómez de Barreda, 2021). We found that, in Italy, the GDD to achieve any green cover threshold is generally lower than in Spain (Table 6) due to a faster spring green-up. Few studies evaluated the relationship between spring green-up and GDD. Rimi et al. (2013) reported 449, 456, 488, and 612 GDD to reach 80% of green coverage during spring green-up for the 'Yukon', 'Riviera', 'SWI 1014', and 'Princess 77' respectively. However, these data cannot be compared with our results as GDD was calculated using a 5 ˚C base temperature.

Our results show that bermudagrass can be cultivated as a turfgrass species at 45˚ N latitude, where the summer is wetter (Table 2), obviating the need for irrigation systems, and day length in summer is long compared with lower latitudes. Another advantage of growing bermudagrass at 45˚ N over 39˚ N is the lower clipping yield during early and late summer, which means less time-consuming mowing and fewer C emissions (Law et al., 2016; Pirchio et al., 2018). Furthermore, at the Italian site at latitude 45˚ N, bermudagrass was in its best condition for a short time in summer, followed by a reduction in quality in early autumn and a long dormancy (Figure 1). However, the spring green-up was found to be quicker there than at the Spanish site at 39˚ N (Figure 5) due to a higher solar radiation from April onward (Table 3).

If the appropriate cultivar is selected, bermudagrass can retain optimal visual quality for longer, or green-up faster in spring, as demonstrated by Arden 15 and MBG 002. However, the high-quality cultivars that we tested did not reach optimal quality until mid-August in Legnaro, whereas at the lower latitude (Valencia), they exhibited good performances more than a month earlier (Figures 1–3). The improvements in turfgrass quality in Valencia resulting from cultivar selection varied from cultivars exhibiting a slower loss of quality in autumn (i.e., MBG 002) to those exhibiting a more rapid green-up in spring (i.e., Arden 15 and MBG 002) than the other cultivars tested. More recently released cultivars in Europe have also been shown to grow less quickly than the older cultivars (Figure 4); again, the differences are even greater just before and after reaching maximum growth in August. The bermudagrass cultivars Arden 15 and MBG 002 have been tested by the NTEP in the United States over the last years. Cultivar MBG 002 matches the best seeded-type cultivars in the 2013–2017 NTEP final report, testing cultivars in 17 locations from Jay, FL (30˚ N) to West Lafayette, IN (40˚ N) (Morris, 2018), with low ratings (4.7) in College Park, MD (39˚ N) only. Cultivar Arden-15 (codified as SWI-1070 in the 2007-2012 NTEP final report [Morris, 2013]) in the same locations displayed good turf quality rates (6.7, first out of 25 cultivars), spring green-up (second out of 25 cultivars), and frost tolerance–winter kill (first out of 25 cultivars). These NTEP reports suggest that winter kill in Valencia (Spain) at 39˚ N should never occur, due also to the influence of the Mediterranean Sea. On the contrary, in Legnaro (Italy) at 45˚ N, winter kill could occur as the minimum temperature during the study period reached −6 ˚C, which according to Anderson et al. (2002), falls within the freeze tolerance range from −5.6 to −7.4 ˚C.

In conclusion, latitude is a decisive factor for bermudagrass cultivation, with higher latitudes conferring important disadvantages, such as the risk of incomplete establishment during a short growing season, long dormancy, and delayed green-up. However, low water consumption and low growing rates make bermudagrass a species for low-input management turfgrasses. Selection of an appropriate bermudagrass cultivar is paramount when cultivating this species in the higher latitude of the transition zone, and new bermudagrass releases in Europe, such as Arden 15 and MBG 002, show potential for such conditions.

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AUTHOR CONTRIBUTIONS

Diego Gómez de Barreda: Conceptualization, Methodology, Project administration, Supervision, Writing – original draft, Writing – review & editing; Carlos Azcárraga: Data curation; Investigation. Cristina Pornaro: Data curation; Formal analysis; Investigation; Software; Validation; Visualization; Writing – review & editing. STEFANO MACOLINO: Conceptualization; Funding acquisition; Project administration; Resources; Supervision; Writing – review & editing.

CONFLICT OF INTEREST

The authors report no conflicts of interest.

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