Europ.J.Hort.Sci., **79** (3). S. 167–174, 2014, ISSN 1611-4426.

Mixing Warm-Season Turf Species with Red Fescue (*Festuca rubra* L. ssp. *rubra*) in a Transition Zone Environment

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Summary

Turf managers and home lawn owners are often discouraged from using warm-season turf species in the transitional zones of Europe because they undergo dormancy during winter and lose colour up to five months. These issues may be addressed by mixing cool-season species together with warm-season turfgrasses. However, there is a lack of information on performances and dynamics of species succession in such turfgrass mixtures. Therefore, a two-year study was carried out at Padova University (Northeastern Italy) to test the effects of overseeding red fescue in bermudagrass and zoysiagrass cultivars on turf quality and species succession in the mixtures. In September 2011, red fescue 'Corail' (FRR) was overseeded at a 50 g m^{-2} rate on mature turfgrass plots of eight *Cynodon dactylon* (CD) cultivars and *Zoysia japonica* 'Companion' (ZJ). Monostands of CD 'Princess-77' and FRR were established for comparison purposes. Turf quality was estimated visually every other week and the frequencies of species in the mixtures were determined every month using a point-intercept method, by recording species in 10-cm segments of four lines of 1 m each. With the exception of summer, CD 'Princess-77' monostand had the lowest visual turf quality in comparison to all the mixtures tested. Significant differences were also observed among mixtures, with zoysiagrass-red fescue polystand showing the most important decline in turf quality from one year to the next. The two best performing mixtures (CD 'Contessa' + FRR and CD 'Yukon' + FRR) were characterized by high frequency of CD (i.e., average ≥ 82 %) and intermediate frequency of FRR (i.e., average = 82–88 %). The results of this study suggest that the choice of species and cultivar plays a key role for establishing functional mixtures of warm-season grasses with red fescue in a transitional zone environment.

Key words. bermudagrass – lawn – fine fescues – turf quality – water management – zoysiagrass

Introduction

The use of warm-season species (C_4) has been encouraged over the last decade in the transitional zones of Europe in order to reduce cultural inputs required to maintain turfgrasses. In comparison to the more traditionally used cool-season species (C_3), warm-season species generally use water more efficiently (Schiavon et al. 2012) and have higher tolerance to drought (Huang 2008), traffic, and fungal diseases (Beard 1973). Despite these positive aspects, the use of warm-season turfgrasses in the transition zone has been hindered by the extended dormancy period occurring in the colder months (Richardson 2002; Macolino et al. 2010). Dormancy consists of a physiological rest followed by leaf desiccation, resulting in reduced or no colour, which can persist up to five months in the northern regions of Italy (Rimi et al. 2013). Such condition leads to a preferred use of year-round green, cool-season grasses, such as Kentucky bluegrass (*Poa pratensis* L.), perennial ryegrass (*Lolium perenne* L.), and red fescue (*Festuca rubra* L. ssp. *rubra*). To reduce agricultural inputs in transitional zones, mixtures of cool- and warm-season species may be tailored to take advantage of the strengths of two species (Madison 1971; Dunn et al. 1994; Yin et al. 2013).

In transitional environments, a warm-season species, such as bermudagrass (*Cynodon* spp.), might dominate the stand in the summer when mixed with a cool-season species, while the cool-season species would have the best growth in fall and spring (Beard 1973; Dunn et al. 1994). Daniel and Freeborg (1979) reported that various mixtures of bermudagrass 'Midiron' and perennial ryegrasses had balanced frequency of each species and resulted in desirable visual quality for the transition zone. Similarly, Dunn et al. (1994) consistently obtained high visual quality from mixtures composed of bermudagrass and Kentucky blugrasses or Chewings fescues (*Festuca rubra* L. ssp. *commutata*) during a three-year study in Missouri.

Severmutlu et al. (2005) obtained satisfactorily results in terms of extension of green cover in Nebraska by mixing buffalograss [*Buchloe dactyloides* (Nutt.) Engelm.] with various species of fine fescues (*Festuca* spp.). Recent studies from China (Yin et al. 2013) revealed that perennial mixtures of cool- and warm-season grasses can be successfully maintained in the transition zone using cultivars of zoysiagrass (*Zoysia* spp.) and tall fescue (*Festuca arundinacea* L.). However, major concerns in the development of functional mixtures are related to potential aggressiveness of the species used, which may lead to undesired seasonal shifts in dominance (Beard 1973; Dunn et al. 1994). For example, numerous attempts of mixing bermudagrass with cool-season turfgrasses have been unsuccessful due to the aggressiveness of bermudagrass during the summer (Davis 1958). *Vice versa*, Dunn et al. (1994) reported that Kentucky bluegrass and perennial ryegrass were overly competitive with bermudagrass during fall and spring under trafficked conditions in Missouri.

Competition between species in turfgrass mixtures can be influenced by multiple factors including the choice of cultivar and the cultural practices applied. It has been reported that bermudagrass cultivars having low turf density facilitate the growth of the cool-season grasses in a mixture compared to cultivars with high density (Daniel and Freeborg 1979). In addition, the persistence of species is affected by the growth habit of the cultivars used, with rhizomatous growth often being advantageous for long-term survival (Beard 1973; Severmutlu et al. 2005). Yin et al. (2013) found that turf quality and species succession in zoysiagrass-tall fescue polystands can be effectively manipulated using contrasting N fertilization regimes or mowing heights. Several studies suggested that N applications on turfgrass mixtures in the summer allow the warm-season species to dominate, whereas autumn and spring applications are more advantageous for cool-season grasses (Engel 1973; Hawes 1977; Yin et al. 2013). Mixtures of cool- and warm-season grasses are generally obtained by overseeding cool-season species into mature warm-season stands and the overseeding timing has been noted as a determinant factor for the establishment of fine fescues into buffalograss (Severmutlu et al. 2005).

Bermudagrass, zoysiagrass, and red fescue are drought resistant species (Hanson et al. 1969; Roberts 1990; Rimi et al. 2012) and their characteristics could complement each other in mixtures of warm- and cool-season turfgrasses for low maintenance areas. However, the success of these mixtures may be strongly related to local environmental conditions and there is a lack of information on the performance of such polystands. Therefore, the objective of this study was to evaluate the quality and species succession of mixtures deriving from the combination of various cultivars of bermudagrass and zoysiagrass with a red fescue in a transition zone environment.

Materials and Methods

A field study was conducted from September 2011 to October 2013 at the experimental agricultural farm of Padova University in Legnaro (Italy; 45° 20' 54.46" N, 11° 56' 50.88" E). The area has a humid subtropical climate with an annual rainfall of 826 mm mostly distributed during the warm-season turfgrass growing season from April to November (Table 1). Monthly air temperatures recorded during the experimental period were gen-

Table 1. Monthly mean air temperatures and monthly precipitations from 2011 to 2013 and long-term averages (1963–2009) at the agricultural experimental farm of Padova University, Legnaro, Northeastern Italy.

	Air temperature (°C)				Precipitation (mm)			
Month	2011	2012	2013	1963–2009	2011	2012	2013	1963–2009
January	3.1	1.8	3.9	3.5	18	8	103	52
February	5.0	2.3	4.0	4.8	45	25	78	48
March	9.3	11.5	7.8	8.7	98	1	260	57
April	15.5	12.9	13.7	12.6	5	77	111	70
May	19.5	18.1	16.6	18.1	25	88	131	73
June	22.0	23.3	21.7	21.3	59	30	17	86
July	22.9	25.4	25.0	23.2	88	0	40	73
August	24.6	25.4	23.5	23.3	10	41	76	75
September	22.1	19.9	19.4	18.8	60	95	49	73
October	13.2	14.8	15.1	14.2	90	137	106	78
November	7.8	10.3	10.0	8.7	80	91	102	78
December	4.6	2.6	4.4	4.4	23	37	10	63
Annual	14.1	14.1	13.8	13.5	601	630	1083	826

erally similar to the long-term averages, with the exception of January, February, and December 2012, which were characterized by below-average temperatures. Precipitations were extraordinary low in the summer of 2012 and above-average in spring 2013 (Table 1). The soil at the site is a silty loam containing 66 % silt, 17 % clay, and 17 % sand, with a pH of 8.3, 2.2 % organic matter, an Olsen extractant P content of 20.6 mg kg^{-1}, an exchangeable K content of 112.7 mg kg^{-1}, and a C to N ratio of 12.8. On 20 September 2011, mature stands of warm-season turfgrasses were overseeded with red fescue 'Corail' (FRR), which was selected because it is widely used in the area of study. Warm-season grasses were seeded in 2005 and included *Cynodon dactylon* (CD) 'Barbados', 'Contessa', 'La Paloma', 'Mohawk', 'NuMex Sahara', 'Princess-77', 'SR9554', and 'Yukon'; and *Zoysia japonica* 'Companion' (ZJ). Prior overseeding, the warm-season grasses were dethatched with a vertical mower and scalped to a height of 20 mm, and the soil was fertilized with 44 kg P ha^{-1} using triple superphosphate (0 N–20 P–0 K). Red fescue was overseeded at a rate of 50 g m^{-2} pure live seed (PLS) and plots were subsequently topdressed with approximately 3 kg m^{-2} of washed river sand. The experiment also included monostands of CD 'Princess-77', a cultivar extensively used in the area, and FRR as controls. Bermudagrass monostands were established in 2005, concurrently with the other warm-season grass plots; and red fescue monostands were seeded on 16 September 2011, at a rate of 35 g m^{-2} PLS. The FRR seeding rate was chosen according to the seed packaging label recommendations, whereas the rate for overseeding was increased of 40 % to counterbalance competition with residual activity of warm-season grasses.

Irrigation was provided after overseeding daily at 5 mm in the absence of natural precipitation to ensure germination and enhance establishment. During the remainder of the study, irrigation was occasionally applied only in July and August 2012 to prevent stress and visual wilt symptoms. For the mixtures, fertilization and mowing regimes were selected to favour the cool-season species and mitigate the advantage of warm-season grass aggressiveness during the summer months (Dunn et al. 1994). A slow-release fertilizer (15.0 N–3.9 P–12.5 K) was applied in March, September, and October at a rate of 67 kg N ha^{-1}, for a total annual rate of 200 kg N ha^{-1}. For CD monostands, fertilizer was applied in May, June, and August at a rate of 67 kg N ha^{-1}, for a total annual rate of 200 kg N ha^{-1}. Plots were mowed weekly with a rotary mower at a height of 38 mm with clippings removed. On 15 September of each year, mixtures were mowed at 20 mm and clippings were removed to facilitate light penetration (Rimi et al. 2011) and stimulate seedlings growth of FRR.

Plots (1.6 × 4.5 m) were visually rated for quality every other week using a 1 to 9 scale, where 1 is dead or brown, 6 is acceptable, and 9 is optimal or ideal (Morris 2013). In addition, single components of turf quality were assessed visually every other week, including colour, uniformity, texture (1 to 9 visual scale, where 9 = optimal), and percentage of turfgrass green cover (0–100 % visual scale; Severmutlu et al. 2005). In the mixtures, the frequency of each species was determined every month using a point-intercept method (Poissonet et al. 1973; Glatzle et al. 1993), by recording species in 10-cm segments of four lines of 1 m each. Equidistant steel needles were perpendicularly put into the soil through the turf canopy to assess whether or not the species were touched by each needle, regardless of the number of contacts (Daget and Poissonet 1971). The four lines were randomly placed within each plot and the frequency of each species was expressed on a percentage basis (0–100 %; i.e., total count/40 × 100).

The experimental design was a randomized complete block design with four replicates. The data were averaged every three months and analyzed as four seasons: autumn (October to December), winter (January to March), spring (April to June), and summer (July to September). Prior data analysis, the variance homogeneity was verified visually with panels of Studentized residuals. Turf quality parameters and frequencies of cool-season and warm-season species were subjected to a repeated measures analysis of variance using SAS Proc Mixed (version 9.2; SAS Institute, Cary, NC). Fisher's protected least significant difference test was used at the 0.05 probability level to identify significant differences among means. When appropriate, the differences between mixtures were analyzed separately for each year and studied per specific season using the SLICE option of SAS Proc Mixed (version 9.2; SAS Institute, Cary, NC). Proc Corr and Proc Reg (version 9.2; SAS Institute, Cary, NC) were used to correlate visual turf quality with single components of turf quality. Diagnostics for linear relationships were performed using the Shapiro Wilk test at $P > 0.05$ to ensure that residuals were normally distributed (Shapiro and Wilk 1965).

Results

The ANOVA for visual turf quality revealed significant ($P < 0.001$) main effects of mixture, season, year, and all their two-way and three-way interactions. The differences among mixtures within each season were consistent between years, although there was a difference in magnitude that led to a three-way mixture × season × year interaction (Table 2). All the mixtures tested had higher visual turf quality in comparison to CD 'Princess-77' in autumn 2011, winter and spring 2012, and winter and spring 2013. The monostand FRR had highest quality in autumn 2011, winter 2012, and spring 2013, whereas it fell in the lowest quality group in the summer of each year (Table 2). However, its quality in spring and summer of 2013 was higher in comparison to the previous year. Among the mixtures, CD 'Contessa' + FRR and CD 'Yukon' + FRR were in the highest statistical group in five seasons throughout the study period. The mixtures having CD 'Con-

Table 2. Turf quality (visual ratings on a 1 to 9 scale; where 1 is dead, 6 is acceptable and 9 is optimal) of nine mixtures of warm- and cool-season grasses, a warm-season grass, and a cool-season grass from autumn 2011 through summer 2013.

Turfgrass	2011–2012				2012–2013				Average
	Autumn	Winter	Spring	Summer	Autumn	Winter	Spring	Summer	
CD 'Barbados' + FRR	6.9 ab[§]	5.6 bc	6.3 cd	4.9 de	6.1 bcd	5.3 c	7.0 bcd	6.8 cd	6.1 c
CD 'Contessa' + FRR	6.9 ab	5.6 bc	7.0 ab	6.9 b	6.8 ab	5.3 c	6.9 bcd	7.9 a	6.7 a
CD 'La Paloma' + FRR	7.1 a	5.5 c	6.6 bc	5.1 d	6.6 ab	6.4 a	7.5 ab	7.2 bc	6.5 ab
CD 'Mohawk' + FRR	6.5 b	5.6 bc	6.3 cd	4.7 de	6.5 ab	6.3 a	7.5 abc	6.3 de	6.2 bc
CD 'NuMex Sahara' + FRR	6.8 ab	5.6 bc	6.3 cd	4.8 de	6.1 bcd	6.1 ab	7.3 abcd	6.7 cd	6.2 bc
CD 'Princess-77' + FRR	6.9 ab	5.4 c	6.3 cd	4.6 e	6.4 ab	5.6 bc	6.7 d	6.8 cd	6.1 c
CD 'SR9554' + FRR	6.8 ab	5.5 c	6.2 cd	4.8 de	6.3 abc	5.9 abc	7.2 abcd	6.4 de	6.1 c
CD 'Yukon' + FRR	7.0 ab	6.0 b	7.2 a	7.7 a	6.0 bcd	4.4 d	6.8 cd	7.9 ab	6.6 a
ZJ + FRR	7.0 a	5.9 bc	6.3 cd	5.8 c	5.6 cde	3.8 d	6.7 d	7.2 bc	6.0 c
CD 'Princess-77'	5.5 c	3.9 d	4.2 e	7.8 a	5.3 e	2.8 e	4.8 e	7.4 abc	5.2 d
FRR	7.3 a	6.8 a	6.0 d	3.1 f	5.3 de	6.2 ab	7.7 a	5.8 e	6.0 c

Autumn = October to December; Winter = January to March; Spring = April to June; Summer = July to September
CD = bermudagrass; FRR = red fescue 'Corail'; ZJ = zoysiagrass 'Companion'
[§] Within a column, means values showing the same letter are not significantly different according to Fisher's protected least significant difference test the 0.05 probability level.

tessa', 'Mohawk', 'NuMex Sahara', 'Princess-77', and ZJ fell in the lowest statistical group five times during the study. When the data were pooled across seasons and years, CD 'Contessa' + FRR and CD 'Yukon' + FRR had highest visual quality, together with CD 'La Paloma' + FRR; all the other mixtures and FRR 'Corail' monostand displayed an acceptable quality (i.e., equal or higher to 6.0), which was higher in comparison to CD 'Princess-77' monostand (Table 2).

When the data were averaged among mixtures (Table 3), turf quality was lowest in winter and summer 2012, and in winter 2013, whereas highest quality occurred in spring and summer 2013. Single components of turf quality (colour, uniformity, texture, and green cover) were influenced by mixtures similarly to visual turf quality (data not reported) and were likely related to environmental differences that occurred within and between years (Tables 1 and 3). Correlation analyses revealed that

Table 3. Turf quality, colour, leaf texture, uniformity (visual ratings on a 1 to 9 scale; where 1 is lowest and 9 is optimal), and turfgrass green coverage (0 to 100 % visual assessment) of turfgrasses as affected by seasons and years. Data were collected on nine mixtures of warm- and cool-season grasses, a warm-season grass, and a cool-season grass over four replicates.

Season	Turf quality	Colour	Texture	Uniformity	Green cover
	1 to 9 visual rating				%
Autumn 2011	6.8 b[§]	7.0 a	7.1 c	6.8 cd	86 b
Winter 2012	5.6 d	5.5 d	6.1 g	5.8 g	63 f
Spring 2012	6.2 c	6.5 b	7.0 cd	6.4 e	88 a
Summer 2012	5.5 d	5.9 c	6.8 e	6.0 f	83 c
Autumn 2012	6.1 c	6.6 b	7.4 a	7.0 bc	78 e
Winter 2013	5.3 e	5.4 e	6.7 f	6.8 d	63 f
Spring 2013	6.9 ab	7.0 a	7.3 b	7.8 a	86 ab
Summer 2013	7.0 a	7.0 a	6.9 de	7.1 b	81 d

Autumn = October to December; Winter = January to March; Spring = April to June; Summer = July to September
[§] Within a parameter, means values showing the same letter are not significantly different according to Fisher's protected least significant difference test the 0.05 probability level.

visual turf quality, colour, leaf texture, uniformity and turfgrass green cover were positively correlated (Table 4), yielding correlation coefficients that ranged from 0.34 (i.e., uniformity *vs.* green cover) to 0.88 (i.e., turf quality *vs.* colour). When colour, leaf texture, uniformity and turfgrass green cover were averaged over mixtures (Table 3), the lowest values were observed in the winter of each year. During the winter, turfgrass green cover was lower in comparison to the other seasons, averaging 63 % green cover in both years of study (Table 3). During the first year (2011–2012), turfgrasses were characterized by dark colour in the autumn and by light colour and coarse leaf texture in the winter (Table 3). In 2012 and 2013, turfgrasses had light colour, poor uniformity and coarse leaves in the winter; dark colour and good uniformity in the spring; and dark colour in the summer (Table 3).

The interaction mixture × season × year was significant for the species frequency in the mixtures of both warm- ($P < 0.001$) and cool-season grass ($P < 0.05$). The frequencies of the two grasses in the mixtures were also affected by each single effect and all their possible two-way interactions ($P < 0.001$). ZJ + FRR was characterized by high presence of warm-season grass in the mixture and fell in the top statistical group during the entire study, with zoysiagrass frequency ranging between 44 and 100 % (Table 5). Among the other mixtures, CD 'Contessa' + FRR and CD 'Yukon' + FRR fell in the top statistical group on seven and six seasons, respectively. CD 'NuMex Sahara' + FRR had low presence of warm season grass, being in the lowest statistical group throughout the study period, with bermudagrass frequency ranging between 37 and 66 % (Table 5). When the data were pooled across seasons and years, the frequency of warm-season grass in CD 'Contessa' + FRR, CD 'Yukon' + FRR, and ZJ + FRR was higher compared to the other mixtures (Table 5). When the data were averaged among mixtures, the frequency of warm-season grass decreased between autumn and winter in both years of study (Fig. 1). Moreover, a significant reduction of warm-season grass frequency occurred between the winter and spring of 2013. In 2012, the frequency of warm-season grass increased from 41 % to 70 % between winter and spring, whereas in 2013 it increased from 57 % to 74 % between spring and summer (Fig. 1).

In autumn 2011, the frequency of red fescue was higher when mixed with CD 'Yukon' than when mixed with CD 'Barbados', 'Contessa', 'La Paloma', 'Mohawk', 'Princess-77', and with ZJ (Table 5). CD 'Contessa' + FRR and CD 'La Paloma' + FRR had 8–9 % more red fescue than ZJ + FRR in summer 2012. The red fescue frequency was lowest in ZJ + FRR compared to all the other mixtures throughout the second year of study, ranging between 9 and 63 % (Table 5). When the data were pooled across seasons and years, ZJ + FRR had the lowest frequency of red fescue in the mixture, followed by CD 'Yukon' + FRR. In the overall average, the frequency of red fescue in CD 'Barbados' + FRR and CD 'Contessa' + FRR was not different than other mixtures with CD (Table 5). When the data were averaged among cultivars (Fig. 1), an increase of red fescue was observed from autumn 2011 to spring 2012, followed by a reduction from summer 2012 to summer 2013.

Discussion

Mixing warm- and cool-season turfgrasses in a transitional environment requires careful selection of species and cultivars to prevent undesired seasonal shifts in species dominance and detriment of turf quality (Daniel and Freeborg 1979; Dunn et al. 1994; Severmutlu et al. 2005). In this study, overseeding a red fescue cultivar on warm-season grasses led to an extended improvement of turf quality in comparison to a bermudagrass monostand. These findings are in agreement with those of Severmutlu et al. (2005), who found that overseeding fine-leaved fescues on buffalograss enhanced quality and extended the duration of green cover. In addition, most of the mixtures performed better than the red fescue monostand during the summer months. Such results were expected, since the mixtures were designed to take advantage of the winter coloration of red fescue and the resistance to summer stress of warm-season species (Dunn et al. 1994; Yin et al. 2013). In addition, wide differences in turf quality were observed among mixtures within and between years, which may be ascribed to morphological and/or physiological features of the warm-season grasses (Beard 1973; Daniel and Freeborg 1979). It was interesting to note an

Table 4. Correlation coefficients relating turf quality, colour, leaf texture, uniformity (visual ratings on a 1 to 9 scale), and turfgrass green coverage (0 to 100 % visual assessment) for turfgrasses. Data were collected on nine mixtures of warm- and cool-season grasses, a warm-season grass, and a cool-season grass over four seasons, two years, and four replicates (n = 352). Correlations were significant at P = 0.001.

Parameter	Colour	Texture	Uniformity	Green cover
Turf quality	0.88	0.60	0.62	0.76
Colour		0.66	0.52	0.87
Texture			0.52	0.58
Uniformity				0.34

Table 5. Specific frequency (%) of warm-season and cool-season grass in nine mixtures of warm- and cool-season grasses from autumn 2011 through summer 2013.

	2011–2012				2012–2013				Average
Turfgrass	Autumn	Winter	Spring	Summer	Autumn	Winter	Spring	Summer	
Warm-season grass									
CD 'Barbados' + FRR	73 ab[§]	40 b	66 bc	69 b	79 bcd	71 bc	58 bc	74 bc	66 b
CD 'Contessa' + FRR	73 ab	40 b	84 a	90 a	91 abc	81 ab	70 b	87 ab	77 a
CD 'La Paloma' + FRR	74 ab	46 ab	68 b	64 b	65 de	50 def	39 d	58 d	58 bc
CD 'Mohawk' + FRR	78 ab	41 b	61 bc	49 c	57 e	40 f	37 d	53 d	52 c
CD 'NuMex Sahara' + FRR	66 b	37 b	58 bc	47 c	55 e	43 ef	38 d	52 d	49 c
CD 'Princess-77' + FRR	73 ab	54 a	55 c	48 c	65 de	56 de	42 d	66 cd	57 bc
CD 'SR9554' + FRR	75 ab	34 b	67 bc	67 b	77 cd	61 cd	47 cd	75 bc	63 b
CD 'Yukon' + FRR	70 ab	33 b	86 a	96 a	94 ab	89 a	86 a	96 a	81 a
ZJ + FRR	82 a	44 ab	81 a	89 a	100 a	94 a	91 a	100 a	85 a
Cool-season grass									
CD 'Barbados' + FRR	70 c[§]	87	99	96 ab	90 a	87 ab	91 a	63 b	85 ab
CD 'Contessa' + FRR	76 bc	89	98	98 a	96 a	89 ab	87 a	68 ab	88 ab
CD 'La Paloma' + FRR	78 bc	86	99	99 a	98 a	96 a	94 a	79 a	91 a
CD 'Mohawk' + FRR	73 bc	82	100	98 ab	97 a	94 a	94 a	73 ab	89 a
CD 'NuMex Sahara' + FRR	80 ab	86	99	95 ab	94 a	94 a	94 a	71 ab	89 a
CD 'Princess-77' + FRR	78 bc	85	99	94 ab	93 a	91 a	92 a	79 a	89 a
CD 'SR9554' + FRR	78 ab	87	100	97 ab	95 a	96 a	95 a	73 ab	90 a
CD 'Yukon' + FRR	86 a	89	99	93 ab	90 a	74 b	62 b	60 b	82 b
ZJ + FRR	73 bc	83	99	90 b	63 b	56 c	42 c	9 c	64 c

Autumn = October to December; Winter = January to March; Spring = April to June; Summer = July to September
CD = bermudagrass; FRR = red fescue 'Corail'; ZJ = zoysiagrass 'Companion'
[§] Within a column, means values showing the same letter are not significantly different according to Fisher's protected least significant difference test at the 0.05 probability level.

increase of turf quality for FRR monostand from the first to the second year, which may be explained by high precipitation in spring of 2013 (Table 1).

The turf quality of zoysiagrass-red fescue polystand declined from one year to another as a consequence of a steady decrease of red fescue abundance in the mixture. Therefore, overseeding red fescue on zoysiagrass appeared not effective for the establishment of a perennial mixture in northern Italy. Rimi et al. (2012) compared ZJ to CD 'La Paloma', 'Princess-77', and 'Yukon', and found that zoysiagrass had earlier spring green-up and more prolonged fall colour retention than bermudagrasses. According to this, zoysiagrass would be more competitive than bermudagrass in the mixtures during spring and autumn, in which the cool-season grasses are growing more actively (Turgeon 2004). In the same study, it was pointed out that zoysiagrass has smaller root system than bermudagrass and it has less ability to expand in the deeper soil layers. Root exploration in the deeper soil layers during drought stress has been reported in turf species as an adaptation mechanism to improve efficiency of plant water uptake (Sharp and Davies 1985; Huang and Gao 2000). In this case study, lower efficiency in water uptake from the deep soil would equate to higher competitiveness with cool-season grasses, which are mostly characterized by shallow root systems (Youngner et al. 1981; Huang 2008). Various attempts of mixing zoysiagrass with tall fescue have been successful in the transition zone (Brede 1991; Li and Han 2008; Yin et al. 2013) and this may be due to higher aggressiveness of tall fescue in comparison to red fescue. However, the large physiological and morphological variability that exists within *Zoysia* spp. (Patton and Reicher 2007; Trappe et al. 2011) suggests that more research is needed to assess a potential functionality of zoysiagrass-red fescue polystands.

In this study, the turf quality of bermudagrass-red fescue polystands was strongly influenced by the CD cultivar used in the mixture. Overseeding red fescue on CD 'Contessa' and 'Yukon' resulted in acceptable turf quality along with sustained frequency of both species across two years. These two mixtures were characterized by high frequency of bermudagrass in winter and spring relative to the other

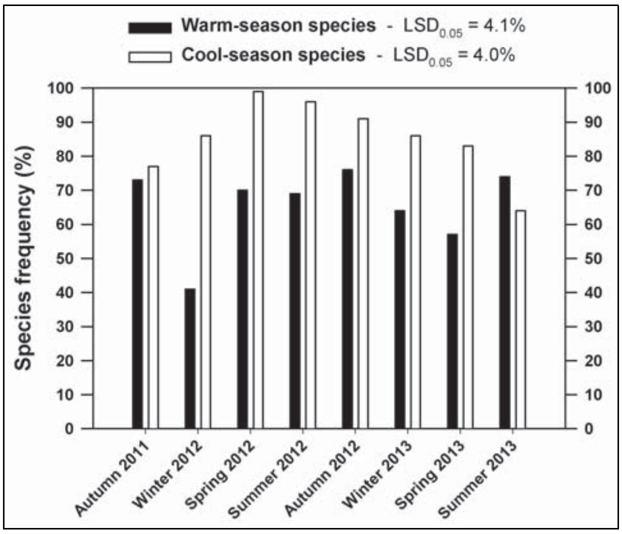

Fig. 1. Species frequency of warm-season and cool-season species in mixtures of warm- and cool-season turfgrasses as affected by seasons and years. Data were averaged over nine mixtures and four replicates. For each species separately, $LSD_{0.05}$ indicates Fisher's protected least significant difference at P = 0.05 and can be used to determine statistical differences between seasons within any year.

bermudagrass-red fescue polystands. Winter hardiness and spring regrowth are determinant factors for bermudagrass persistence (Anderson et al. 2002; Patton et al. 2008) and previous research from northeastern Italy revealed that CD 'Contessa' greened up significantly later than 'Yukon' and responded differently to low cutting in the spring (Rimi et al. 2011). As such, no similarities between the two cultivars can be substantiated from the literature in terms of plant morphology or spring vegetation. However, the results of the current study are supported by Patton et al. (2008), who reported that CD 'Contessa' and 'Yukon' have higher winter hardiness in comparison to most of the commercial seeded bermudagrasses. Overseeding time, fertilization, and mowing regimes in this research were selected to favour the cool-season species in the mixtures and different management strategies may have led to different outcomes (Dunn et al. 1994; Severmutlu et al. 2005; Yin et al. 2013). Under a similar management regime, using the two abovementioned mixtures can be recommended for lawns, parks, and other turf areas with low water availability for irrigation.

The differences among mixtures for turf quality were likely related with differences in terms of colour, leaf texture, uniformity, and green cover. Among these aspects, colour and turfgrass green cover were the most determinant quality components for obtaining a mixture of warm- and cool-season grasses with satisfactorily turf quality. Our findings are similar to those of Severmutlu et al. (2005) and suggest that cultivars characterized by dark colour should be highly considered for further studies attempting to mix warm- and cool-season grasses. The turf quality of mixtures was generally acceptable in autumn and spring; whereas it was poorest in winter, concurrently with a decline of warm-season species frequency. The decline of warm-season species frequency in the winter is likely due to leaves necrosis and reduction of turf density (Turgeon 2004). According to this, the winter aspect of warm-season grasses (e.g., leaf discolouration, density reduction) had detrimental effects on the turf quality of mixtures during the colder months of the year. During the summer, red fescue had similar effects on the turf quality of the mixtures, but different in nature. In fact, red fescue had reduced turf quality during summer, which hindered the performance of mixtures, especially under the drought conditions of the first investigative year. Similarly to previous studies (Johnson 2003; Severmutlu et al. 2005), the high frequency of fine fescues caused some concern for the long-term survival of balanced mixtures and their management. However, this study demonstrated that an appropriate cultivar choice of bermudagrass plays a primary role for its survival in bermudagrass-red fescue polystands.

Acknowledgements

The authors gratefully acknowledge Aurora Defrancesco, Simone Parro, and Valentina Maron, who assisted with the technical work required for this project. This study was supported by the Italian Ministry of Instruction, University and Research (MIUR).

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Received 01/14/2014 / Accepted 03/22/2014

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