Original article

Performance of various cool-season turfgrasses as influenced by simulated traffic in northeastern Italy

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Summary

Warm-season grasses are known to be more wear tolerant than cool-season grasses, but in northern Italy the latter are generally preferred for ornamental turfgrasses and athletics fields. The Po River valley, in the North of Italy, is a typical transition zone where species and cultivar selection play a very important role in establishing successful turfgrasses with high stress tolerance, including foot traffic.

The aim of this research was to evaluate the traffic tolerance and adaptation of 25 cultivars of three cool-season turfgrass species to transitional growing conditions of Italy.

A study was conducted over a two-year period at the experimental farm of Padova University in Legnaro. The species studied were tall fescue (*Lolium arundinaceum*), kentucky bluegrass (*Poa pratensis*), and perennial ryegrass (*Lolium perenne*). Simulated traffic was applied using a Brinkman traffic simulator at a level equivalent to one soccer game per week. Turfgrass quality and density were assessed every week using a 1 to 9 visual scale during traffic treatments each year. Furthermore, turfgrass canopy height was measured weekly for calculating daily vertical growth rate (mm d⁻¹) in spring, summer, and autumn.

Trafficked plots exhibited lower quality than non-trafficked, primarily as a result of decline in turf density. The effect of traffic on density was more evident in the second year wherein all species exhibited ratings lower than 5.0. Traffic did not affect turf growth for perennial ryegrass and tall fescue, while a drastic decrease in growth rate in the second year of study was observed for kentucky bluegrass. Perennial ryegrass had lower density than tall fescue and kentucky bluegrass, especially in summer and autumn of the first year when it showed ratings lower than 6.0. Different responses occurred among kentucky bluegrass cultivars, while perennial ryegrass and tall fescue cultivars responded similarly. Results indicated a high quality and environmental adaptability of 'Rhambler SRP' tall fescue. Among kentucky bluegrass cultivars, 'Mystere' displayed the best wear tolerance with a decrease of density from 5.5 to 4.3 only during the second year. Perennial ryegrass cultivars were similarly affected by traffic, except for 'Yorktown III' which showed the lower performance in both traffic and non-traffic conditions reaching a turf density rating lower than 5.0 in both years of study.

Keywords

cultivar, wear tolerance, transition zone, turf density, turf quality, turf vertical growth

Significance of this study

What is already known on this subject?

- Perennial ryegrass, tall fescue, and kentucky bluegrass are the most used species for establishing sports fields in the European transition zones. However, the wear tolerance of kentucky bluegrass when compared with perennial ryegrass and tall fescue is reported by different authors with contrasting results. Some studies reported that perennial ryegrass has better wear tolerance than kentucky bluegrass, while others demonstrated that it has similar or lower compaction tolerance.

What are the new findings?

- Results demonstrated that kentucky bluegrass cultivars responded differently to traffic conditions with 'Mystere' displaying the best wear tolerance. In general, perennial ryegrass cultivars performed poorly during warmer months with 'Yorktown III' being the worst performing. Among tall fescue cultivars, 'Rhambler SRP' showed a high quality and environmental adaptability.

What is the expected impact on horticulture?

- The use of wear tolerant cultivars is the best way to reduce the maintenance costs of sports turf areas. Findings from this study will help turfgrass managers in selecting cultivars and improving playability of sport surfaces in northern Italy.

Introduction

The selection of species and cultivars is crucial for establishing high quality turfgrass in transition zones, and especially under traffic conditions. Successful athletic field playing surfaces are defined by high playability and adequate safety for the athletes. Turfgrass function and quality are affected by wear and soil compaction, which have been indicated as the two major components of traffic stress in sports fields (Beard, 1973; Carrow and Petrovic, 1992). As the demand and use of sports fields increases, there is an increasing need for turfgrasses having high wear tolerance and quick recovery under intensive traffic (Hoffman et al., 2010). Wear damage on aboveground plant parts results from the crushing, tearing, and shearing actions of foot and vehicular traffic on the leaves, stems, and crowns (Beard, 1973; Shearman and Beard, 1975a, 1975b; Shearman, 1988; Carrow and Petrovic,

1992; Trenholm et al., 2000). The detrimental effects of soil compaction result in inhibited root system growth, reduced soil drainage capabilities, and a decrease of soil macropores (Feldman, 1984; Unger and Kaspar, 1994; Dest et al., 2009).

In northern Italy, cool-season grasses are generally preferred over warm-season grasses, although it has been demonstrated that warm-season grasses have higher recuperative potential than cool-season grasses (Puhalla et al., 1999). Northern Italy is a typical transition zone, where the winter dormancy of warm-season grasses results in a prolonged loss of turfgrass color (Macolino et al., 2010), leading to the widespread use of cool-season species in the region. Cool-season grasses are also preferred because they perform well during the cooler months (Bertrand et al., 2013), when athletics fields are principally used for soccer and rugby matches. Among cool-season species, perennial ryegrass, kentucky bluegrass and tall fescue are considered to have high wear tolerance (Minner and Valverde, 2005) and they are also the most commonly used turf species for athletics fields in cool climates (Puhalla et al., 1999).

Perennial ryegrass is widely used in northern Italy, since it is best adapted to cool regions that have mild winters and cool, moist summers. It is a non-creeping, bunch-type species that forms a uniform sod of good density if properly established and maintained and it is often used as a constituent of winter sports turfs in moderate temperature regions, because of its high wear tolerance during winter (Beard, 1973). Several studies tested wear stress in perennial ryegrass cultivars (Shearman and Beard, 1975a; Fushley et al., 1983; Den Haan et al., 2009) analysing both quality and morphological variation.

Kentucky bluegrass is one of the most popular species in the Mediterranean countries of Europe for turf use and it is widely adapted throughout the cool humid and transitional climates of the world (Schery, 1965). This species is very suitable for use in sports fields and other heavily trafficked surfaces due to the vigorous rhizomes that encourage rapid recovery from traffic and wear (Beard, 1973). However, there is large cultivar variability within kentucky bluegrass (Evans, 1988; Brosnan et al., 2005) and especially in the transition zone (Abraham et al., 2004).

Tall fescue is usually referred to as a bunch grass with limited ability to spread laterally. However, it has been known that this species produces short rhizomes (Porter, 1958), and recently turfgrass breeders have produced cultivars with more extensive rhizomes than traditional cultivars (Fry et al., 2009). Tall fescue is widely used in transition zones because it is generally considered one of the most drought-tolerant cool-season species (Brede, 2000; Cereti, 2002). Furthermore, in the transition zone, tall fescue has shown good wear tolerance and adaptability in intensively trafficked sports fields and playgrounds (Park et al., 2009), because of its wide leaf blades (Shearman and Beard, 1975c). However, the coarse leaf texture makes tall fescue less desirable than perennial ryegrass or kentucky bluegrass to most athletic turf managers (Miele et al., 2002).

Numerous researchers have investigated the differences in relative traffic tolerance among species (Shearman and Beard, 1975a; Carrow, 1980; Canaway, 1981; Carrow and Petrovic, 1992; Minner and Valverde, 2005) and both tall fescue and perennial ryegrass are known for their tolerance to trafficked sports field in the transition zone of Italy (Macolino et al., 2004; Magni et al., 2004). Fushley et al. (1983) and Macolino et al. (2004) reported that perennial ryegrass has better wear tolerance than kentucky bluegrass, whereas

for Canaway (1978) and Bourgoïn and Mansat (1979) perennial ryegrass and kentucky bluegrass had the same relative compaction tolerance. Moreover, other authors (Minner and Valverde, 2005) have demonstrated that kentucky bluegrass has superior wear tolerance when compared to perennial ryegrass and tall fescue.

The use of wear tolerant cultivars is essential to reduce traffic damage and especially if heavy traffic occurs during the cooler months of the year (Taivalmaa et al., 1998). Since there is no ideal turfgrass suitable for the transition zone, turf breeders have focused on improving varieties for transitional environments, developing traffic tolerant cultivars (Minner and Valverde, 2005). The objective of this study was to evaluate environmental traffic tolerance and adaptability of several cultivars of kentucky bluegrass, perennial ryegrass, and tall fescue with a goal to help turf managers in selecting species and cultivars for establishing athletics fields in northern Italy.

Materials and methods

This study was conducted at the experimental agricultural farm of Padova University in Legnaro, northeastern Italy (45°20'N, 11°57'E, 8 m elevation) from March 2010 to February 2012. The area has a humid subtropical climate with a mean annual temperature of 12.3°C and rainfall of 820 mm yr⁻¹. Monthly mean air temperatures and precipitations are reported in Figure 1. The soil was an Oxyaquic Eutrudept, coarse-silty, mixed, mesic containing 66% silt, 18% sand, and 16% clay, with a pH of 8.1, 2.3% organic matter, a C/N ratio of 10.8, 38 mg kg⁻¹ available Olsen P, and 178 mg kg⁻¹ exchangeable K (buffered BaCl₂ method). Grasses were seeded on 10 April 2009 and included perennial ryegrass cultivars 'Crescendo', 'JPR 200', 'JPR 225', 'JPR 250', 'Kokomo', 'New arrival', 'Pavilion', 'Stravinsky', and 'Yorktown III'; kentucky bluegrass cultivars 'Brooklawn', 'Bonaire', 'Concerto', 'Nublu Plus', 'JKB 213', 'JKB 374', 'Julius', 'Larus', and 'Mystere'; and tall fescue cultivars 'Debussy I', 'Escalade', 'JTF 654', 'JTF 655', 'Justice', 'Lucky Selen', and 'Rambler SRP'. These cultivars were chosen on the basis of their current and/or future availability in the Italian turfgrass market.

Cultivar commercial names and distributor are reported in Table 1 and the majority of these cultivars have never been tested for traffic tolerance and also they have not been previously used in cultivar comparisons in the northern Italy. The seeding rates were 25 g m⁻² pure live seed (PLS) for perennial ryegrass, 40 g m⁻² PLS for tall fescue, and 15 g m⁻² PLS for kentucky bluegrass.

Plots were mowed once a week during the growing season (March – November) with a walk-behind rotary mower at an effective height of 58 mm and clippings were removed. Before seeding, the soil was fertilized with a starter fertilizer (8 N–10.4 P–20 K) at a rate of 50 kg ha⁻¹ of N. A fertilizer (15 N–3.9 P–12.5 K), containing 5% of slow released N (isobutylidenediurea) was applied in March, May, September and December at a rate of 62.5 kg ha⁻¹ of N, for a total annual application of 250 kg ha⁻¹ of N. Irrigation was applied daily during the first 30 days after seeding, and subsequently once a week from June to August at a rate of 35 mm, using a sprinkler system. Invading weeds were regularly hand removed during the establishment and treatment periods. During the seeding year, three applications of fungicide (Bumper p : Makhteshim Chemical Works Ltd., a.i. prochloraz + propiconazole) were made to control rust (*Puccinia* spp.) and dollar spot (*Sclerotinia homoeocarpa*) infections which occurred in some kentucky bluegrass and perennial ryegrass plots. Traffic

FIGURE 1. Monthly mean air temperatures (lines) and monthly precipitations (bars) from April 2009 to April 2012 and long-term averages (1963–2007) at the agricultural experimental farm of Padova University, Legnaro, northeastern Italy.

treatments were imposed from April 2010 and included a trafficked and non-trafficked strip across plots. The traffic was applied on fully established plots using a simulator developed by the University of Padova similar to the Brinkman traffic simulator (Cockerham, 1990) to reproduce soccer foot traffic conditions (wear, compaction, and lateral shear). The simulator weighed 350 kg and consisted of two studded rollers with 170 soccer cleats (100 mm diameter and 170 mm long) and an additional smooth roller. Lateral shear was produced by a different gearing causing an unequal speed of the two rollers with cleats. Two passes with this simulator are roughly equivalent to turf damage from one soccer game per week (Zorzanollo, 2003). Therefore, three passes were made across all trafficked plots once a week.

From March 2010, turfgrass quality was rated weekly using a visual scale from 1 to 9, where 1 represented dead turf, 9 optimum quality, and 5 minimal acceptable quality. Turfgrass quality is a combination of several characteristics, including density, color, uniformity and texture. Similarly, turf density was visually assessed on a scale from 1 (bare soil) to 9 (very high density) where 5 represented acceptable density. Weekly turf ratings were averaged over three months to be analysed as seasons: March, April and May (spring), June, July and August (summer), September, October and November (autumn), and December, January and February (winter). During the growing period, turfgrass canopy height was measured before each mowing using a rising grass plate meter (Sanderson et al., 2001; Rimi et al., 2013). Five randomly selected measurements were taken within each plot (1.2 by 2.5 m). Daily vertical growth was calculated for spring, summer, and autumn as the sum of the vertical growth occurring in the inter-mowing periods divided by the number of days of each respective season.

The experimental design was a strip plot split block with species as the whole plot (2.4 by 22.5 m for perennial ryegrass and kentucky bluegrass, 2.4 by 17.5 m for tall fescue) and cultivars within species as subplots (2.4 by 2.5 m),

TABLE 1. Cultivars tested in the trial and their associated distribution company.

Cultivar	U.S.A. distributor
<i>Lolium perenne</i>	
Crescendo	Turf Merchants, Inc.
JPR200	J. R. Simplot Company
JPR225	J. R. Simplot Company
JPR250	J. R. Simplot Company
Kokomo	DLF International Seeds
New arrival GLR	Turf Merchants, Inc.
Pavilion	Blue Moon Farms
Stravinsky	DLF International Seeds
Yorktown III	Loft's seed, Inc.
<i>Poa pratensis</i>	
Brooklawn	Turf Merchants, Inc.
Bonaire	Turf Merchants, Inc.
Concerto	Turf Merchants, Inc.
NuBlue Plus	J. R. Simplot Company
JKB213	J. R. Simplot Company
JKB374	J. R. Simplot Company
Julius	DLF International Seeds
Larus	Lantmännen SW Seed
Mystere	Pro Seeds Marketing
<i>Lolium arundinaceum</i>	
Debussy I	DLF International Seeds
Escalade	Oregro Seeds, Inc.
JTF654	J. R. Simplot Company
JTF655	J. R. Simplot Company
Justice	Pennington Seeds
Lucky Selen	Pennington Seeds
Rambler SRP	Turf Merchants, Inc.

with plots split by traffic application. All treatments were replicated three times in the study. Turf quality, density and vertical growth were subjected to a repeated measures analysis of variance (ANOVA) using a compound symmetry covariance structure in SAS Proc Mixed (version 9.2; SAS Institute, 2008). The different number of subplots within each whole plot was taken into account by the ANOVA structure in SAS Proc Mixed. The main effect of cultivar was partitioned into terms corresponding to species and cultivars within species. Fisher's protected least significant difference test was used at the 0.05 level of probability to identify significant differences between means.

Results and discussion

There were large and significant differences in data collected between years. Therefore, the data are presented for each year individually. The analysis of variance revealed a significant three-way interaction between species, traffic and season for visual quality, density and vertical growth in both years (Table 2). Significant two-way interactions between cultivars within species and traffic and between cultivars within species and season were found for turf density and for turf vertical growth respectively. These interactions are examined and discussed below. To simplify the discussion, results of three-way interactions between cultivars within species, traffic and season and two-way interactions between cultivars and season, when significant, are not shown but simply summarized in the text.

Turf quality and density

There was a significant decrease in the quality of perennial ryegrass and kentucky bluegrass in both traffic and non-traffic conditions (Figures 2a and 2b) during the first year of the study. Except for spring, under non-traffic conditions, tall fescue showed better quality, reaching ratings higher than 6.0 compared with perennial ryegrass that never displayed ratings higher than 5.0. Significant differences between tall fescue and kentucky bluegrass occurred only in the winter, when a drastic decrease of kentucky bluegrass quality was observed. The overall turf quality for autumn and winter was 5.9 and 3.8 respectively. These findings support those of Fiorio et al. (2012), who also demonstrated that various cultivars of tall fescue perform satisfactorily in northern

Italy, especially during the winter conditions of the first year. Under traffic conditions, tall fescue showed higher quality ratings (1 unit) than kentucky bluegrass in autumn and winter (Figure 2b). As expected, perennial ryegrass performed better under traffic than kentucky bluegrass in winter (Macolino et al., 2004). The lowest ratings for tall fescue (4.0) occurred in winter under traffic conditions, which could be the consequence of the low temperature hardness of this species (Dernoeden et al., 1993). Under non-traffic conditions, the quality of tall fescue was constant throughout seasons in both years ranging from 5.7 to 7.1. These results agree with Bremer et al. (2006) who found that 'Dynasty' tall fescue had high visual quality across seasons in a transition zone environment.

In the second year of the trial, tall fescue reached quality ratings about 1 unit higher than perennial ryegrass in all seasons, except winter, under non-traffic conditions. Under traffic conditions, perennial ryegrass and tall fescue performed similarly (Figures 2c and 2d), as found by Cereti et al. (2005) in a study conducted in central Italy with different cultivars. Greater differences between trafficked and non-trafficked plots were observed in the second year compared with the first year, when very low ratings were observed only in the winter. In the second year, quality ratings of trafficked plots were constantly lower than 5.0; however no decline was observed throughout the year. This stronger influence of traffic in the second year occurred probably because in the first year the traffic effect was mostly due to lateral tearing and holes through the turfgrass canopy, while in the second one soil compaction was progressively added to wear, reducing the ability of the turf to recover (Puhalla, 1999).

Observing the interaction between species, traffic and season for turf density (Figure 3), the trends were similar to what was observed for turfgrass quality (Figure 2), consistently with a significant correlation detected for the two parameters ($P < 0.001$; $r = 0.75$, data not shown). Perennial ryegrass often had lower density than tall fescue and kentucky bluegrass, and these differences were most noticeable in the summer (5.7, 7.2, and 7.0 for perennial ryegrass, tall fescue and kentucky bluegrass respectively) and autumn (5.6, 7.7, and 7.5 for perennial ryegrass, tall fescue and kentucky bluegrass respectively) of the first year. The effect of traffic on density was more evident in the second year, when

TABLE 2. Results of analysis of variance testing the effects of species, traffic, cultivar within species, season, and their interactions on turf visual quality, turf density and turfgrass vertical growth rate.

Effect	Visual quality		Density		Vertical growth	
	2010–11	2011–12	2010–11	2011–12	2010–11	2011–12
Species (Sp)	***	***	***	***	***	***
Traffic (Tr)	*	**	**	**	ns	*
Sp × Tr	*	**	***	***	*	***
Cultivar within species [Cv(Sp)]	***	***	***	***	**	***
Cv(Sp) × Tr	ns	***	**	***	ns	ns
Season (Se)	***	***	***	***	***	***
Sp × Se	***	***	***	***	***	***
Cv(Sp) × Se	***	***	***	***	***	***
Tr × Se	***	***	***	***	***	***
Sp × Tr × Se	***	***	***	***	***	***
Cv(Sp) × Tr × Se	ns	*	ns	ns	ns	ns

*, **, ***: Significant at the 0.05, 0.01, and 0.001 probability level, respectively.

ns: Not significant at the 0.05 probability level.

FIGURE 2. Effect of species $\times$ traffic $\times$ season on turf quality ratings of perennial ryegrass (*Lolium perenne*), kentucky bluegrass (*Poa pratensis*) and tall fescue (*Lolium arundinaceum*) recorded during 2010–11 (a and b: April 2010 – February 2011) and 2011–12 (c and d: April 2011 – February 2012). Data were averaged over cultivars; the error bar represents the least significant difference ($P=0.05$) and can be used to determine differences between traffic treatments, species and seasons.

FIGURE 3. Effect of species $\times$ traffic $\times$ season on turf density ratings of perennial ryegrass (*Lolium perenne*), kentucky bluegrass (*Poa pratensis*) and tall fescue (*Lolium arundinaceum*) recorded during 2010–11 (a and b: April 2010 – February 2011) and 2011–12 (c and d: April 2011 – February 2012). Data were averaged over cultivars; the error bar represents the least significant difference ($P=0.05$) and can be used to determine differences between traffic treatments, species and seasons.

all species achieved very low ratings, with values not exceeding 5.0 (Figure 3d). Traffic treatments had a similar negative effect on turf quality and density, confirming the relevant impact of density on the estimation of overall turf quality (Macolino et al., 2004).

For both turf quality and density, the two-way interaction between cultivars and season (Table 2) revealed highest ratings in the spring of the first year (data not shown). Perennial ryegrass cultivars showed a similar trend through the year, while kentucky bluegrass cultivars displayed a different behaviour among seasons: 'Nublu Plus' and 'JKB 374' maintained an acceptable rating (>7.0) for both quality and density during all seasons except winter, while other cultivars such as 'Concerto', 'Julius' and 'Larus' achieved high

ratings in spring, but displayed a significant decrease in the cooler months (autumn and winter). Among tall fescue cultivars, 'Rhambler SRP' had best performance, achieving the highest ratings in spring and autumn, and maintaining good turfgrass quality ratings throughout the winter.

The interaction between cultivars and traffic for density showed a greater traffic effect in the second than in the first year for all species (Figure 4). In the first year only four perennial ryegrass cultivars ('Pavillion', 'JPR 225', 'JPR 200' and 'JPR 250') were significantly affected by simulated traffic. In the second year, all perennial ryegrass cultivars had low density under traffic conditions (i.e., <5.0), and unlike the first year, significant differences between traffic and non-traffic conditions were observed for 'Crescendo', 'Kokomo', 'Stravinsky'

FIGURE 4. Effect of cultivar $\times$ traffic on turf density ratings of perennial ryegrass (*Lolium perenne*, a and b), kentucky bluegrass (*Poa pratensis*, c and d) and tall fescue (*Lolium arundinaceum*, e and f) recorded during 2010–11 (from April 2010 to February 2011) and 2011–12 (from April 2011 to February 2012). Data were averaged over seasons; the error bar represents the least significant difference ($P=0.05$) and can be used to determine differences between traffic treatments and cultivars.

sky' and 'Yorktown III' (Figures 4a and 4b). Among kentucky bluegrass cultivars, high density ratings were observed for 'Julius', 'Larus', 'Nublu Plus', and 'JKB 374' under non-traffic condition (Figures 4c and 4d). However, 'Julius' and 'Larus' exhibited a severe reduction of density in consequence of simulated traffic in both years, indicating poor traffic tolerance. 'Mystere' appeared to be less affected by traffic than the other kentucky bluegrass cultivars, with no differences between traffic and non-traffic in the first year, and only minimal difference between traffic treatments in the second year.

The tall fescue cultivars were similarly affected by traffic, however, 'Rambler SRP' showed a superior density than all the other tall fescue cultivars in both traffic and non-traffic conditions (Figures 4e and 4f). The enhanced performance of 'Rambler SRP' in northern Italy was also observed by Macolino et al. (2014) in a study comparing four mixtures of tall fescue and kentucky bluegrass under different mowing heights.

Turfgrass vertical growth

The interaction between species, traffic and season showed higher vertical growth rates for tall fescue cultivars, especially in spring and summer, compared to both kentucky bluegrass and perennial ryegrass (Figure 5). These results are in agreement with Beard (1973), who indicated tall fescue as a well-adapted species for transitional zones even under traffic. The lowest growth rate for tall fescue was recorded in summer 2010 and in autumn of both years (i.e., <2.0 mm d⁻¹). With the exception of these instances, the growth rate of tall fescue was constantly higher than perennial ryegrass and kentucky bluegrass. Similar findings were observed by Bremer et al. (2006) who compared 'Dynasty' tall fescue and 'Apollo' kentucky bluegrass in Kansas. However, in the autumn of the second year, there were no differences in vertical growth between the three species when traffic was applied (Figure 5). This may be due to the low tempera-

tures occurred in November of the second year (Figure 1). During this time period, there were 11 consecutive days with mean air temperature lower than 5°C, which is considered the minimum growth temperature for tall fescue (Ju et al., 2006). In contrast, perennial ryegrass was not affected by these weather conditions, achieving the same growth rate as in summer, and this resulted in high visual quality ratings during the fall season. The effect of traffic was generally more evident starting from the summer of the first year and was more pronounced on tall fescue than for perennial ryegrass (Figure 5).

In the first year of the experiment, differences in vertical growth rate among perennial ryegrass cultivars occurred only in spring (Table 3), with 'Yorktown III' reaching the highest growth rate (3.1 vs 2.2–2.6 mm day⁻¹). Interestingly, this cultivar had the lowest ratings for both quality and density in the trial, suggesting that growth rate is not correlated to the overall performance. Among kentucky bluegrass cultivars, 'Bonaire', 'Concerto' and 'Mystere' had the highest growth rate in spring. Similarly to 'Yorktown III' perennial ryegrass, those high-growth kentucky bluegrass cultivars showed low quality and density ratings in spring. On the contrary, 'Nublu Plus', 'JKB 374', 'Julius' and 'Larus', which performed well for visual quality and density between summer and autumn of the first year, displayed a vertical growth lower than the others, especially in spring. 'Rambler SRP' tall fescue, the cultivar performing better in both years of investigation, had the lowest growth rates in spring of the first year and maintained low rates in summer and autumn.

During the second year of investigation (Table 3), all cultivars of perennial ryegrass displayed the same trend observed in the first year, with lower growth rates in summer and autumn. As in the first year, the cultivar with the highest growth rates in spring was 'Yorktown III' (2.7 mm day⁻¹). As found by Park et al. (2010), who studied the response of kentucky bluegrass to seasonal wear, differences among ken-

FIGURE 5. Effect of species × traffic × season on vertical growth rates of perennial ryegrass (*Lolium perenne*), kentucky bluegrass (*Poa pratensis*) and tall fescue (*Lolium arundinaceum*) recorded during 2010–11 (a and b: April 2010 – February 2011) and 2011–12 (c and d: April 2011 – February 2012). Data were averaged over cultivars; the error bar represents the least significant difference ($P=0.05$) and can be used to determine differences between traffic treatments and cultivars.

TABLE 3. Turfgrass vertical growth rates (mm d⁻¹) of perennial ryegrass, kentucky bluegrass and tall fescue cultivars recorded during the first year (April 2010 – February 2011) and the second year (April 2011 – February 2012) of experimentation. Data were averaged over traffic treatments.

Cultivar	2010–2011			2011–2012		
	Spring	Summer	Autumn	Spring	Summer	Autumn
<i>Lolium perenne</i>						
Crescendo	2.2 ^z	0.9 ^z	0.8 ^z	1.9 ^y	1.0 ^y	0.8 ^y
JPR200	2.3	0.5	1.0	1.9	0.9	0.8
JPR225	2.2	0.7	0.9	1.8	0.8	0.8
JPR250	2.3	0.8	1.1	1.8	1.0	0.9
Kokomo	2.6	0.8	0.9	2.3	1.0	1.0
New arrival	2.2	0.6	0.7	1.8	0.8	0.7
Pavilion	2.3	0.5	0.9	1.9	0.9	0.8
Stravinsky	2.5	0.5	0.9	2.2	1.0	1.0
Yorktown III	3.1	0.7	0.8	2.7	1.2	0.9
<i>Poa pratensis</i>						
Brooklawn	2.4 ^x	1.4 ^x	0.8 ^x	1.1 ^w	1.1 ^w	0.3 ^w
Bonaire	2.8	1.3	0.8	1.1	1.0	0.4
Concerto	2.7	1.3	0.8	1.3	1.1	0.4
NuBlue Plus	1.8	1.1	0.9	0.6	1.0	0.4
JKB213	2.0	1.1	0.9	0.7	1.1	0.4
JKB374	2.0	1.0	0.9	0.9	1.2	0.4
Julius	2.3	1.4	0.7	0.6	0.9	0.2
Larus	1.9	1.5	0.9	0.5	1.1	0.3
Mystere	2.8	1.2	1.0	1.8	1.0	0.4
<i>Lolium arundinaceum</i>						
Debussy I	3.5 ^v	1.8 ^v	1.9 ^v	3.1 ^u	2.0 ^u	1.1 ^u
Escalade	3.6	1.7	1.6	2.7	1.9	1.1
JTF654	3.3	2.0	1.6	2.8	2.3	1.1
JTF655	3.6	2.0	1.7	3.1	2.3	1.2
Justice	3.6	1.8	1.6	2.9	2.0	0.9
Lucky Selen	3.6	1.9	1.8	2.9	2.3	1.2
Rhambler SRP	3.0	1.6	1.4	2.6	1.5	0.7

^z Least significant difference ($\alpha=0.05$) to compare *Lolium perenne* cultivars in 2010–11=0.3.

^y Least significant difference ($\alpha=0.05$) to compare *Lolium perenne* cultivars in 2011–12=0.2.

^x Least significant difference ($\alpha=0.05$) to compare *Poa pratensis* cultivars in 2010–11=0.4.

^w Least significant difference ($\alpha=0.05$) to compare *Poa pratensis* cultivars in 2011–12=0.3.

^v Least significant difference ($\alpha=0.05$) to compare *Lolium arundinaceum* cultivars in 2010–11=0.4.

^u Least significant difference ($\alpha=0.05$) to compare *Lolium arundinaceum* cultivars in 2011–12=0.4.

tucky bluegrass cultivars occurred only in spring. ‘Mystere’ had the highest growth rate probably as the result of its high traffic tolerance, as reflected by the visual quality ratings. In the second year, tall fescue cultivars displayed, as in the first year, a high vertical growth ranging from 1.5 mm d⁻¹ in autumn to 2.9 mm d⁻¹ in spring. ‘Rhambler SRP’ maintained a low vertical growth also in the second year, however this was not significantly lower than all the other cultivars.

Turfgrass vertical growth was well correlated with both turfgrass quality and turfgrass density ($P<0.001$, $r=0.39$ and $P<0.001$, $r=0.22$ respectively; data not shown). These results suggests that cultivars well adapted to local environmental condition also displayed better quality and density.

Conclusion

The study revealed that damage from traffic is not immediate but occurs after repeated traffic events, probably as the combined effects of wear and soil compaction become significant. Traffic did not have a strong effect on growth rates

for perennial ryegrass and tall fescue, known for their high tolerance to soil compaction. However, kentucky bluegrass showed a drastic decrease in growth rate in the second year, likely due to the effects of wear injury on its shallow root system.

The decrease of turf quality due to traffic was mainly related to a decline in turf density. A wide response to traffic was observed among kentucky bluegrass cultivars, while perennial ryegrass and tall fescue cultivars responded similarly. ‘Mystere’ had the highest traffic tolerance in comparison to the other kentucky bluegrass cultivars tested. Among tall fescues, ‘Rhambler SRP’ showed the best traffic tolerance and a high adaptation to the local environmental conditions. Among perennial ryegrass cultivars, ‘Yorktown III’ was the worst performing regardless of the traffic treatment applied. These results demonstrated that in the transition zone of northeastern Italy proper cultivar selection is essential for trafficked sports fields, and is especially important for kentucky bluegrass.

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