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Traffic Tolerance of Perennial Ryegrass (*Lolium perenne* L.) Cultivars as Affected by Nitrogen Fertilization

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Abstract. **Perennial ryegrass (*Lolium perenne* L.) is one of the most widely used species for sports fields in temperate climates because of its high wear tolerance. However, wear tolerance of cultivars may vary according to local environmental conditions and turfgrass management. In this study, we evaluated the wear tolerance of six perennial ryegrass cultivars (Adagio, Apple SGL, Equate, Firebird, Principal 2, Tetradark) under two fertility treatments (100 or 200 kg N·ha^{-1}·yr^{-1}) over 2 years. The field trial was performed at the Experimental Agricultural Farm at the University of Padova in northeastern Italy in a silty loam soil. Plots were arranged in a randomized complete block with three replications and subjected to three traffic events per week using a sports field wear simulator. Turfgrass quality (TQ), percent green cover (PGC), and normalized difference vegetation index (NDVI) were recorded every 2 weeks and averaged over each month. Although perennial ryegrass cultivars responded differently to wear stress, the higher nitrogen (N) rate positively affected the TQ of them all. 'Tetradrak' and 'Equate' had the lowest TQ, especially during the active growing seasons (spring and autumn). However, 'Tetradark' was particularly negatively affected during the cool fall months. The impact of a higher N fertilization rate on PGC and NDVI appeared to be more pronounced in spring than in fall. Furthermore, slight differences among cultivars and treatments were observed in summer and winter when temperatures were a limiting growth factor.**

Perennial ryegrass (*Lolium perenne* L.) is a dark green, fine-textured, cool-season turfgrass that exhibits rapid establishment after quick germination and extensive shoot tillering (Dunn et al. 2002; Jung et al. 1996; Larsen and Bibby 2005; Thorogood 2003). Heat, drought, and cold tolerance make perennial ryegrass a versatile option for both warm and cool climates, but its ability to endure wear and traffic stress makes it adapted for use as a sports field playing surface (den Haan et al. 2009; Macolino et al. 2004; Pornaro et al. 2016; Stier et al. 2008). Perennial ryegrass is often planted in cooler regions as a monoculture or in combination with Kentucky bluegrass (*Poa pratensis* L.), whereas sports field managers in warmer regions overseed dormant bermudagrass (*Cynodon* spp.) with perennial ryegrass to provide a more resilient surface during cooler months (Haselbauer et al. 2012; Mazur and Rice 1999; Thoms et al. 2011).

Community sports and recreational fields are often established on poorly drained native soils that receive minimal management inputs. Excessive wear from frequent traffic events common to these complexes results in surface hardness and soil compaction (Carrow and Petrovic 1992; Harivandi 2002). Subsequent adverse growing conditions including reduced soil aeration and soil structure may cause further declines in turfgrass growth, quality, and cover (Carrow 1980; O'Neil and Carrow 1983). Simulated traffic aims to replicate the horizontal and vertical forces that affect the canopy and soil profile, ultimately resulting in compaction and shearing of the turfgrass (Aldahir and McElroy 2014; Henderson et al. 2005; Kowalewski et al. 2013).

Previous research investigating the impact of wear stress on perennial ryegrass quality and morphology reported differences among cultivars (Braun et al. 2021; den Haan et al. 2009; Macolino et al. 2004; Pornaro et al. 2016). Varied responses were linked to genotype characteristics associated with vertical leaf angles, wider leaf blades, greater leaf cell wall constituents, increased number of vascular bundles, high root length density, larger intercellular void spaces, and increased leaf antioxidant activity (Brosnan et al. 2005; Glab and Szewczyk 2015; Glab et al. 2015; Han et al. 2008; Pease et al. 2020). More frequent drought events, higher temperatures, and alkaline soils not only limit the perennial ryegrass cultivars adapted for use in northern Italy but also may further influence their response to wear and traffic.

Sports field managers use cultural and chemical practices that affect perennial ryegrass growth, morphology, and competitive response that ultimately influence wear tolerance (Deaton and Williams 2010; Hoffman et al. 2010a; Thoms et al. 2011). Use of the plant growth regulator, trinexapac-ethyl, has been shown to increase tiller density and improve traffic tolerance (Glab et al. 2021), whereas amending soil with Ca and Mg silicates or Si and K can elicit cellular structural resilience (He et al. 2013; Pruyne et al. 2019; Salmén 2015; Trenholm et al. 2001). Fertilizer applications cause increases in turfgrass cover, color, quality, and recovery (Hoffman et al. 2010b; Martiniello 2007). However, higher nitrogen (N) fertilization rates can favor turfgrass canopy growth, resulting in a reduction in the root-to-shoot ratio (Dunn et al. 1995) or overly succulent tissue (Bell 2011; Christians et al. 2016), which both contribute to poor wear resilience.

Identification of wear-tolerant perennial ryegrass is important to maintain sports field integrity. Voids in the turfgrass canopy can reduce field playability and may lead to increased weed colonization. Lack of herbicide options for weed removal in Italy may further exacerbate this phenomenon, eventually compromising field safety. Therefore, the objective of this research was to evaluate the wear tolerance of six perennial ryegrass cultivars maintained under different fertility regimes over 2 years in the field. We hypothesized that wear tolerance would differ among perennial ryegrass cultivars and fertility treatments.

Materials and Methods

Field experiments. The research was conducted at the Experimental Agricultural Farm at the University of Padova in Legnaro, Italy (lat. 45°20′ N, long. 11°57′ E), from 2019 to 2022. The climatic conditions for this northeastern region of Italy are described as humid subtropical (Köppen 1936). Annual minimum, average, and maximum temperatures are 8.9, 13.6, and 18.7°C, respectively, with annual precipitation rates of 83 cm·yr^{-1} (27-year average) (Regional Agency for Environmental Protection of Veneto Region 2023). Monthly precipitation and air temperatures during the investigation period are reported in Table 1. The soil at the site was a coarse-silty,

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Table 1. Monthly mean air temperature and monthly precipitation during 2020, 2021, and 2022, and long-term averages (1994–2021) at the Experimental Agricultural Farm at the University of Padova in Legnaro, northeastern Italy.

	Air temp (°C)				Precipitation (mm)			
Month	2020	2021	2022	27-yr avg	2020	2021	2022	27-yr avg
January	3.3	3.1	3.0	3.2	15	71	20	44
February	7.3	7.1	6.2	5.0	5	16	10	50
March	9.2	8.4	8.2	9.0	60	4	14	55
April	13.9	11.5	12.0	13.2	25	91	40	74
May	18.0	16.0	20.0	17.9	30	132	33	90
June	21.2	23.9		22.0	142	17		71
July	23.9	24.2		23.9	44	88		73
August	24.2	23.3		23.4	175	47		64
September	20.4	20.0		19.0	19	33		79
October	13.3	13.2		14.0	67	30		82
November	8.4	9.3		8.9	15	95		89
December	5.8	3.9		4.0	106	36		60
Year	14.1	13.7		13.6	702	660		830

mixed, mesic, Oxyaquic Eutrudept (Morari 2006) containing 27.5% clay, 28.8% silt, and 43.7% sand, with a pH of 8.2, organic matter content of 2.7%, a carbon (C)/N ratio of 12.0, a total N content of 1.3 mg·g^{-1} (combustion method), an Olsen P content of 5.6 mg·kg^{-1}, and an exchangeable K content of 162.7 mg·kg^{-1} (buffered $BaCl_2$ method).

Seedbed preparation consisted of cultivating the site with a tractor mounted roto-tiller (Lamborghini R70; Cento, Ferrara, Italy) to a depth of 30 cm and grading to provide a smooth planting bed of the desired contour. Plots measured 2 × 5 m and were arranged in a randomized complete block design with three replications. Six perennial ryegrass cultivars (Adagio, Apple SGL, Equate, Firebird, Principal 2, Tetradark) were chosen within the cultivars currently available on the European market and were seeded by hand at a rate of 25 g·m^{-2} on 27 Sep 2019. Cultivars were selected based on commercial turfgrass availability (high frequency of use or new introduction into the Italian market). Fertilizer (8N–24P_2O_5–24K_2O; Adriatica SpA, Loreo RO, Italy) was applied at seeding with a rotary spreader at a rate of 50 kg N·ha^{-1}. Surface irrigation was provided through a sprinkler system that applied ~0.5 cm of water every other day for 3 weeks until full establishment was reached. Grass weeds were manually removed, whereas broadleaf weeds were controlled using the selective herbicide dicamba at 1 L·ha^{-1} (Joker; Chimiberg SpA, Caravaggio BG, Italy).

Table 2. Results of the ANOVA of the effects of cultivar, nitrogen (N) rate, and sampling date on perennial ryegrass TQ, PGC, and NDVI at the University of Padova in Legnaro, northeastern Italy.

Source	TQ	PGC	NDVI
Cultivar (C)	***	***	***
N rate (N)	***	***	***
Sampling date (D)	***	***	***
C × N	*	**	*
N × D	***	*	NS
C × D	***	***	NS
C × N × D	NS	NS	NS

*Significant at $P \leq 0.05$; **Significant $P \leq 0.01$; ***Significant at $P \leq 0.001$.

NDVI = normalized difference vegetation index; NS = not significant; PGC = percent green cover; TQ = turfgrass quality.

Once established, plots were mowed weekly at 4.5 cm with a walk-behind HRD 536 rotary mower (Honda Europe Power Equipment, Orleans, France) with clippings collected and removed. Mowing began 4 weeks after planting. Irrigation was applied weekly at 80% reference evapotranspiration from June to August of each year, whereas plots only received natural rainfall during the remaining months. Fertility treatments (100 or 200 kg N·ha^{-1}·yr^{-1}) were initiated on 22 Mar 2020 and arranged in a split-plot design with perennial ryegrass cultivar as the main plot and N rate as the sub-plot (2 × 2.5 m). Fertilizer (18N–7P_2O_5–9K_2O; Ferti Go NPK, Padana Sementi, Tombolo, Italy) was applied incrementally by hand in March (30%), May (20%), September (30%), and December (20%).

Traffic treatments were initiated in March of each year using a sports field wear simulator developed by the University of Padova that is similar to the Brinkman traffic machine (Cockerham et al. 1990) to replicate soccer foot traffic conditions (wear, soil compaction, and lateral shear). The simulator weighed 350 kg and consisted of two studded rollers (diameter, 10 cm length, 17 cm) with 170 soccer cleats evenly spaced (5 cm) apart plus an additional smooth roller. Lateral shear was produced through differential gearing that caused unequal speed of the two cleated rollers. Two passes with this simulator are approximately equivalent to turf damage observed from one soccer game per week (Zorzanello 2003). Therefore, to impose the level of stress similar to what is observed on amateur and most professional leagues in Italy, three passes were made across all trafficked plots once per week. The traffic simulator was pulled by an Iseki TM3160 tractor equipped with turf tires to minimize ground pressure by dispersing the weight (595 kg) over the grass surface. Research was conducted on the same plots in consecutive years.

Data collection and analysis. Turfgrass quality (TQ), percent green cover (PGC), and

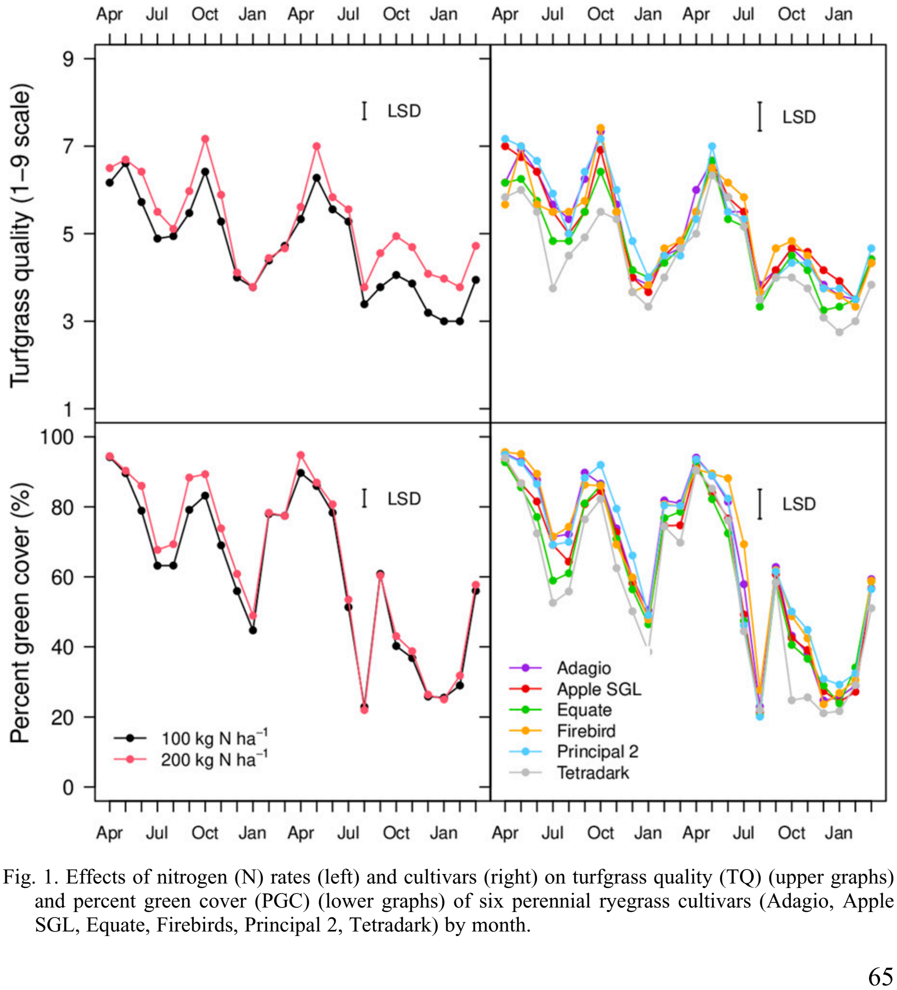

Fig. 1. Effects of nitrogen (N) rates (left) and cultivars (right) on turfgrass quality (TQ) (upper graphs) and percent green cover (PGC) (lower graphs) of six perennial ryegrass cultivars (Adagio, Apple SGL, Equate, Firebirds, Principal 2, Tetradark) by month.

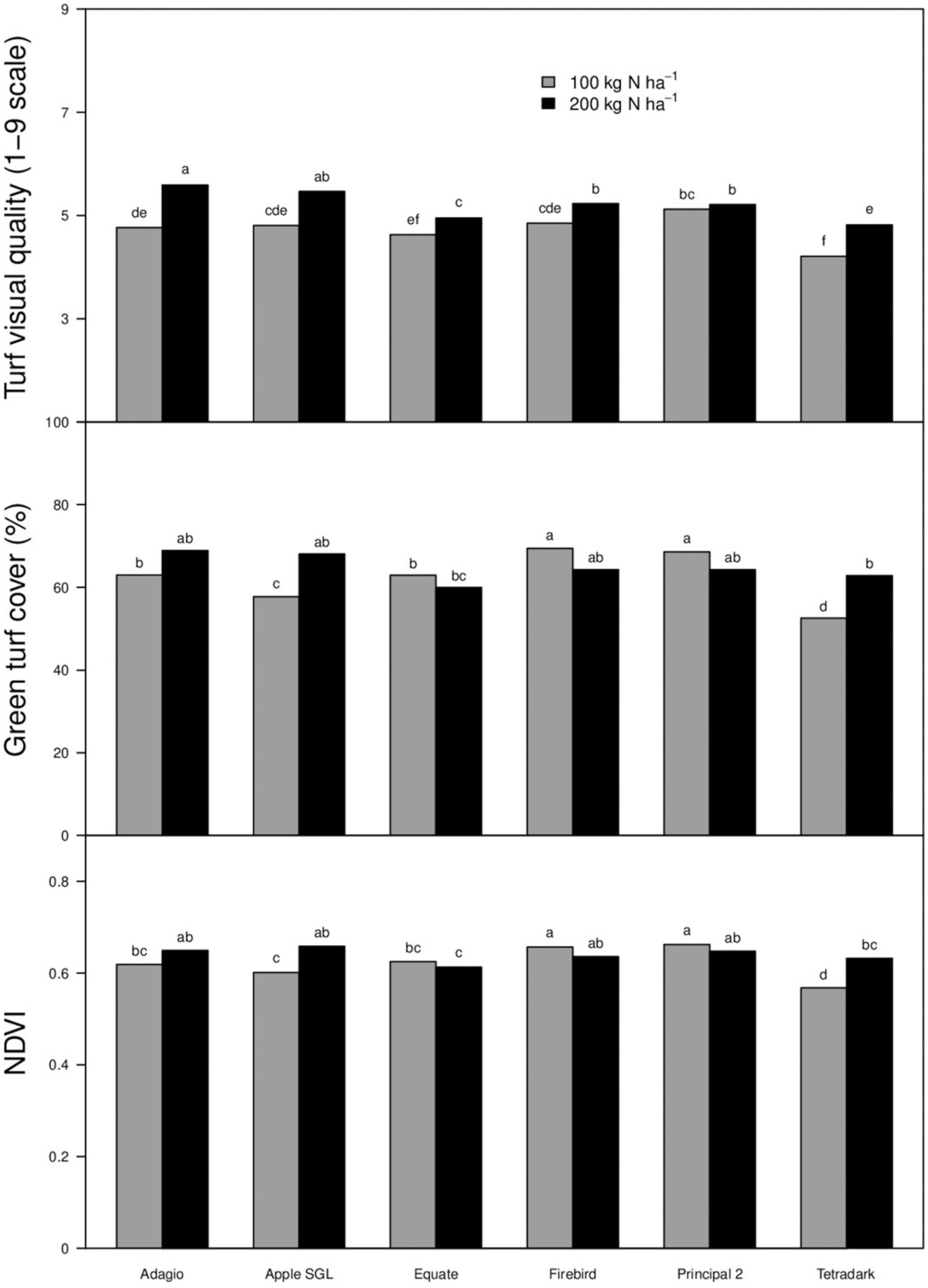

Fig. 2. Effects of nitrogen (N) rates (100 and 200 kg N·ha^{-1}) on turfgrass quality (TQ), percent green cover (PGC), and normalized difference vegetation index (NDVI) of six perennial ryegrass cultivars (Adagio, Apple SGL, Equate, Firebirds, Principal 2, Tetradark).

normalized difference vegetation index (NDVI) were recorded every 2 weeks until the conclusion of the trial. Visual ratings of TQ were based on a scale from 1 (worst) to 9 (best), with a rating of 6 being considered acceptable TQ (Morris and Shearman 2007). The PGC was determined using a digital image analysis in accordance with Richardson et al. (2001). Digital images were captured using a digital camera (Canon Powershot G12; Canon, Tokyo, Japan) and the JPEG (joint photographic experts group) format with image resolution of 2736 × 3648 pixels. Proper exposure was supplied by selecting an aperture of f/4.0. The camera was mounted to the top of a light box (50 × 55 × 60 cm) internally equipped with four incandescent light bulbs (550 lumens; TCP Inc., Aurora, OH, USA) to provide a consistent light source. Digital images were analyzed and processed using SigmaScan Pro software (SPSS, Inc., Chicago, IL, USA). Turfgrass vigor was recorded with Rapid SCAN CS-45 (Holland Scientific Inc., Lincoln, NE, USA). Measurements of the whole plot were obtained by directing the instrument in the central area of the plot. The Rapid SCAN CS-45 is an active meter with an internal polychromatic light source that has three fixed wavebands covering red (670 nm), red edge (730 nm), and near-infrared (780 nm) regions. Biweekly data were subsequently averaged over each month. Data from April 2020 to March 2021 and from April 2021 to

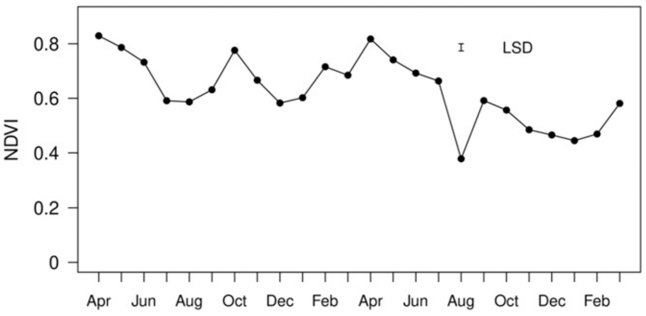

Fig. 3. Effects of the sampling date on the normalized difference vegetation index (NDVI) of six perennial ryegrass cultivars (Adagio, Apple SGL, Equate, Firebirds, Principal 2, Tetradark).

March 2022 represented the first (year 1) and second (year 2) years of experimentation, respectively.

An overall analysis of variance (ANOVA) of the 2-year data was performed using a linear mixed effect model to test the effects of cultivar, N rate, sampling date, and their interactions on the parameters measured (TQ, PGC, and NDVI). Two additional ANOVAs were performed for spring and fall data averaged over the 2 years to obtain a better understanding of cultivar behavior during the period of most active growth. The effects of cultivar, N rate, sampling date, and their interactions on TQ, PGC, and NDVI were tested. All statistical analyses were performed using R (R Core Team 2021) as well as the "nlme" package for fitting mixed models and "multcomp" for post hoc comparisons. Normality and homoscedasticity of residuals were checked by using graphical analyses. When appropriate, a least significant difference (LSD) test with Bonferroni correction with a probability of 0.05 was used to identify significant differences among means.

Results

The ANOVA revealed a significant interaction between the cultivar × N rate, between the N rate × sampling date, and between the cultivar × sampling date for TQ and PGC (Table 2), whereas NDVI was affected by the significant interaction between the cultivar × N rate.

Table 3. Results of ANOVA testing the effects of cultivar, nitrogen (N) rate, and sampling date on perennial ryegrass TQ, PGC, and NDVI during spring and fall, at the University of Padova in Legnaro, northeastern Italy.

	Spring			Fall		
Source	TQ	PGC	NDVI	TQ	PGC	NDVI
Cultivar (C)	***	***	***	***	***	***
N rate (N)	***	***	***	***	*	*
Sampling date (D)	**	***	***	**	***	***
C × N	NS	***	NS	NS	*	NS
N × D	NS	**	*	NS	NS	NS
C × D	NS	NS	***	NS	NS	NS
C × N × D	NS	NS	NS	NS	NS	NS

*Significant at $P \leq 0.05$; **Significant at $P \leq 0.01$; ***Significant at $P \leq 0.001$.

NDVI = normalized difference vegetation index; NS = not significant; PGC = percent green cover; TQ = turfgrass quality.

Perennial ryegrass TQ was generally high in spring and fall, with the exception of fall in the second year (Fig. 1) when ratings were less than 5, but higher than the summer and winter ratings of the same year. Differences between lower and higher N rates were observed in October of the first year, May of the second year, and from September of the second year until the end of the experiment, revealing that plots treated with higher N rates performed best (Fig. 1). Differences among cultivars were markedly greater during the first year of the experiment (Fig. 1); however, during the second year, differences were limited to only a few dates. 'Tetradark' reached a TQ rating ≥6 only in May of both years, whereas other cultivars displayed a TQ rating >5 in the spring of both years and during fall of the first year (Fig. 1). 'Equate' did not significantly differ from 'Tetradark', with better TQ only observed in July of the first year, whereas 'Adagio' and 'Principal 2' received

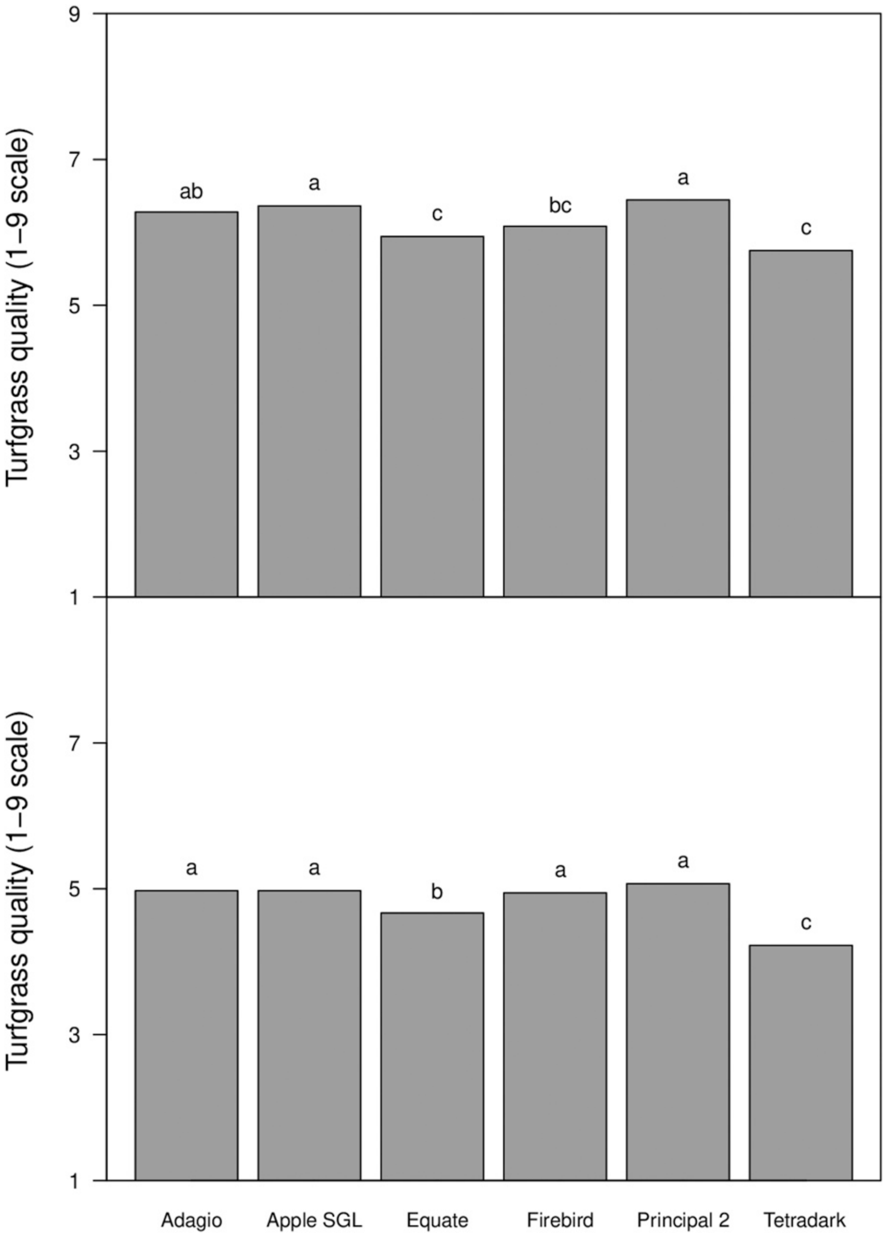

Fig. 4. Turfgrass quality (TQ) of six perennial ryegrass cultivars (Adagio, Apple SGL, Equate, Firebirds, Principal 2, Tetradark) during spring (top: April–June) and fall (bottom: October–December) averaged over the two nitrogen (N) rates.

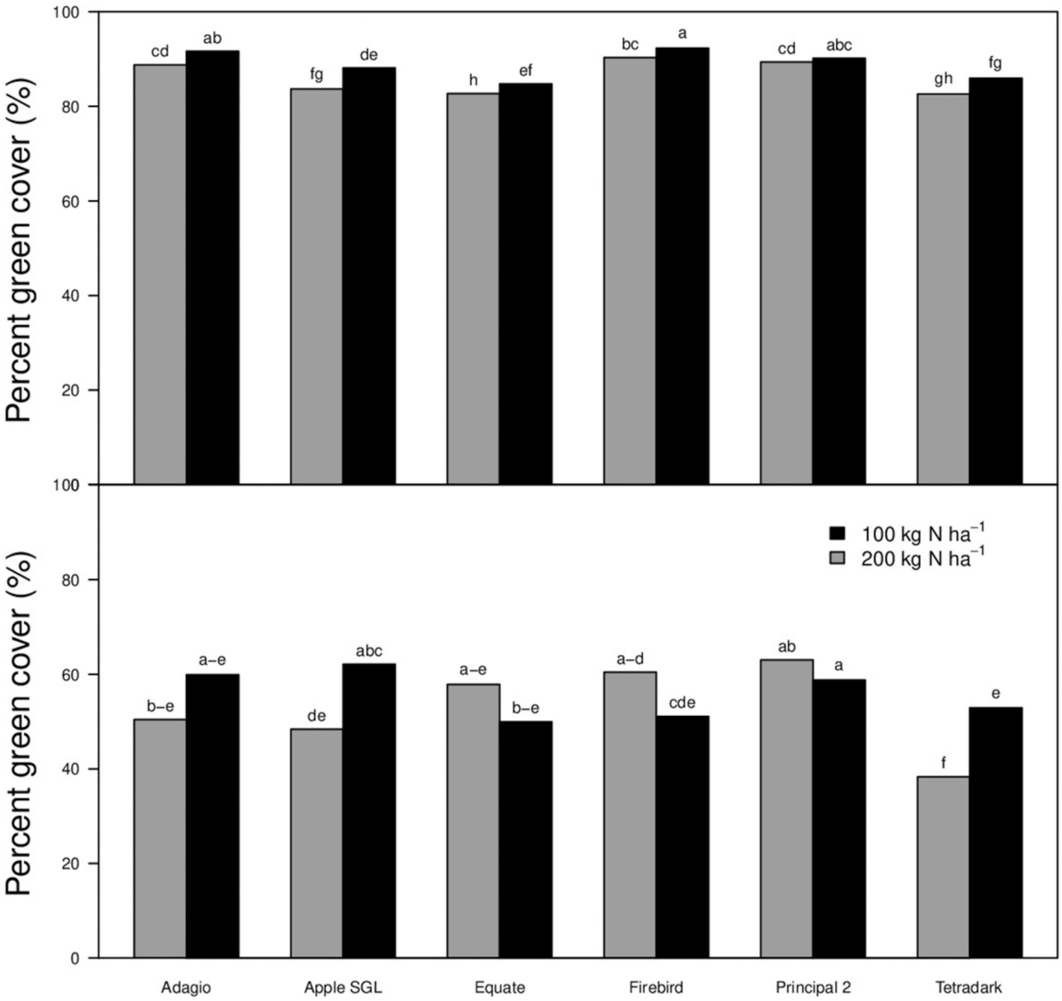

Fig. 5. Effects of nitrogen (N) rates (100 and 200 kg N·ha^{-1}) on percent green cover (PGC) of six perennial ryegrass cultivars (Adagio, Apple SGL, Equate, Firebirds, Principal 2, Tetradark) during spring (top: April–June) and fall (bottom: October–December).

higher ratings than ‘Tetradark’ during all of spring and in October of the first year. ‘Apple SGL’ was rated better than ‘Tetradark’ for most of the first year (April–October) and during autumn of the second year. Visual TQ of all cultivars benefited from the higher N rates (Fig. 2), with ‘Adagio’ fertilized with 200 kg N·ha^{-1} exhibiting higher TQ than all other cultivar/N rate combinations. ‘Equate’ and ‘Tetradark’ showed the lowest TQ when considering each N rate level alone. ‘Adagio’ was observed to perform better than ‘Firebird’ and ‘Principal 2’ when fertilized at 200 kg N·ha^{-1}, whereas no differences from ‘Apple SGL’, ‘Firebird’, and ‘Principal 2’ were found when fertilized at 100 kg N·ha^{-1}.

Similar to TQ, PGC was highest in the spring of both years and fall of the first year (Fig. 1). Except for Sep 2021 and Mar 2022, lower PGC was observed in the second year, with a marked drop occurring in the summer. The impact of the N rate on PGC was only apparent in September of the first year. Differences among cultivars were found from May to September of the first year, with ‘Tetradark’ and, in some cases, ‘Equate’ displaying lower PGC than ‘Adagio’, ‘Firebird’, and ‘Principal 2’ (Fig. 1). Further differences were observed in November and December of the first year, with ‘Principal 2’ having higher PGC than ‘Tetradark’. In June and July of the second year, ‘Firebird’ maintained higher PGC than ‘Tetradark’, ‘Equate’, and ‘Apple SGL’. In October and November of the second year, major differences were observed between ‘Tetradark’ and all other cultivars. A cultivar response to the N rate was only observed for ‘Apple SGL’ and ‘Tetradark’ (Fig. 2), which maintained higher PGC when fertilized with 200 kg N·ha^{-1}.

Perennial ryegrass cultivars ‘Adagio’, ‘Apple SGL’, ‘Firebird’, and ‘Principal 2’ fertilized with 200 kg N·ha^{-1} exhibited higher NDVI values than ‘Apple SGL’ and ‘Tetradark’ at the lower N rate and ‘Equate’ at the higher N rate. The highest NDVI values were recorded in April, May, and October of the first year and April of the second year (Fig. 3), whereas the lowest values were observed in August of the second year. During September of the second year, NDVI values never exceeded 0.6.

The ANOVAs of spring and fall data revealed significant main effects for TQ, PGC, and NDVI, but no significant interactions for TQ during either season and no significant interactions for NDVI during fall (Table 3). During spring, PGC was significantly affected by the interaction between the cultivar × N rate and between the N rate × sampling date; however, during fall, a significant interaction was observed between the cultivar × N rate. During spring, the NDVI was affected by a significant interaction between the N rate × sampling date and between the cultivar × sampling date.

Averaged over cultivars, perennial ryegrass plots exhibited greater TQ ratings in spring in response to lower N than those receiving higher N (6.4 and 6.0, respectively), whereas the same treatments resulted in TQ of 5.1 and 4.5, respectively, in the fall (data not shown). Averaged over fertilization rates, TQ ratings in May were higher (6.7) than those in April and June (5.9 for both months); however, during fall, the highest TQ value was observed in October (5.7), followed by November (5.0) and December (3.8) (data not shown). Cultivars Apple SGL and Principal 2 displayed higher TQ ratings than Equate, Firebird, and Tetradark during spring, whereas Tetradark reached the lowest rating, followed by Equate during fall (Fig. 4).

During spring, Adagio, Firebird, and Principal 2 exhibited higher PGC than the other

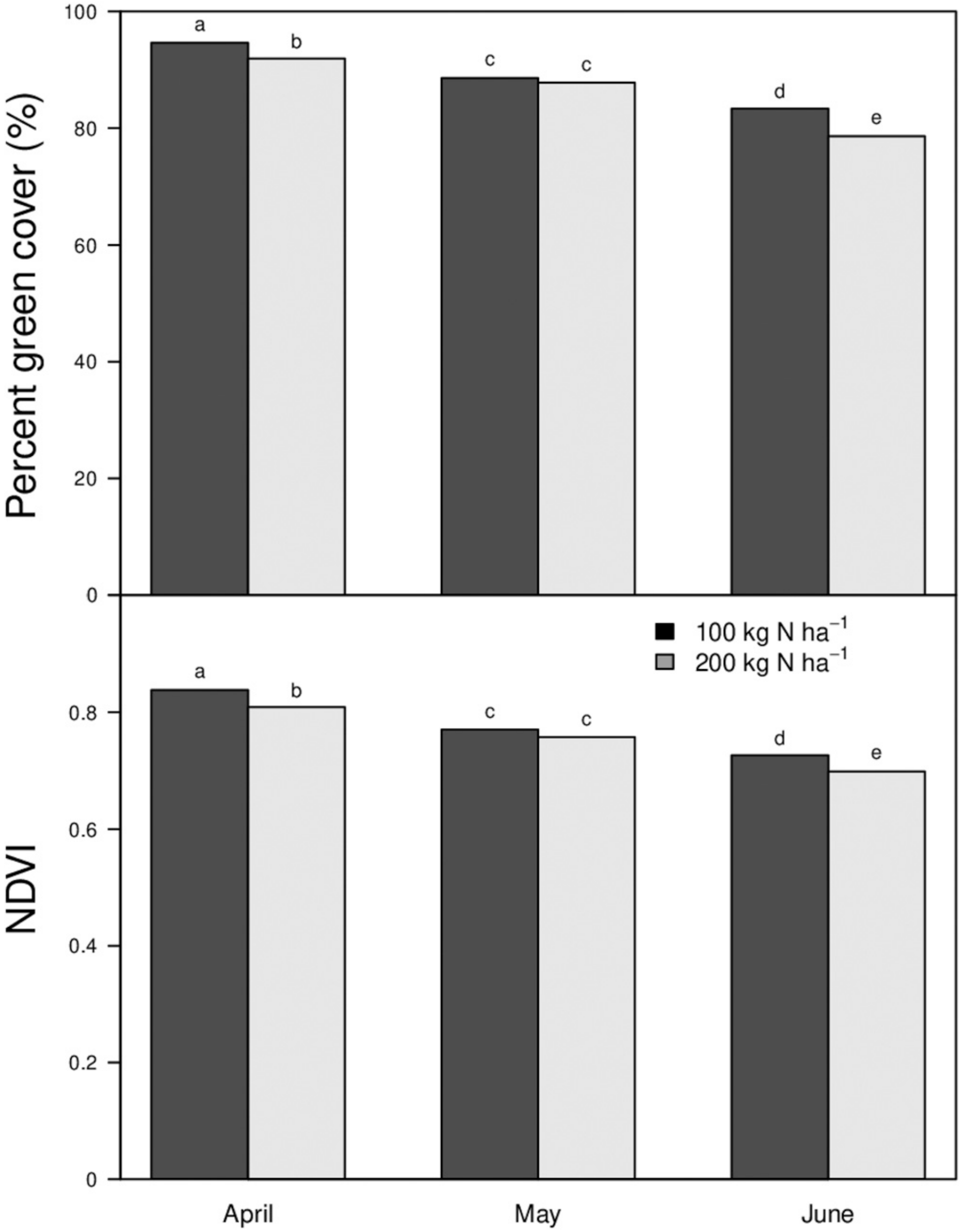

Fig. 6. Effect of nitrogen (N) rates (100 and 200 kg N·ha^{-1}) on percent green cover (PGC) and normalized difference vegetation index (NDVI) averaged over six perennial ryegrass cultivars (Adagio, Apple SGL, Equate, Firebirds, Principal 2, Tetradark) during spring (April–June).

cultivars, regardless of the N rate (Fig. 5). Moreover, 'Principal 2' and 'Tetradark' showed no differences in the response to the two N rates. During fall, Apple SGL and Tetradark were the only cultivars that showed a differential PGC response to the two N rates (Fig. 5). During spring, PGC was higher in April, followed by May and June, with a significant N rate effect in April and June (Fig. 6), whereas PGC decreased during fall from October to November (October, 65%; November, 55%; December, 42%).

During spring, NDVI was higher in April, followed by May and June, with a significant N rate effect in April and June (Fig. 6). In April, Principal 2 displayed a higher NDVI than Apple SGL, whereas in May and June Principal 2, Adagio, and Firebird displayed higher NDVI than all other cultivars (Fig. 7). Moreover, the NDVI ratings for 'Principal 2', 'Adagio', and 'Firebird' in May were not different from the 'Apple SGL', 'Equate', and 'Tetradark' NDVI ratings recorded in June. All cultivars maintained the highest NDVI values in April and the lowest NDVI values in June. During fall, NDVI ratings were worse for plots receiving the lower N rate (0.58) and greater for those receiving the higher N rate (0.60), with the highest value observed in October (0.67), followed by November (0.58) and December (0.52) (data not shown). The cultivar Principal 2 had the highest NDVI, although it was statistically similar to that of Apple SGL, whereas Tetradark displayed the lowest NDVI value (Fig. 8).

Discussion

Perennial ryegrass cultivars examined during this research exhibited dissimilar responses to wear stress, with the greatest differences occurring in spring and fall. We observed that the cumulative effect of temperature stress (low or high) and wear stress that occurred during the summer and winter of both years resulted in the largest differences among cultivars because turfgrasses deteriorate faster when exposed to multiple stresses simultaneously (Braun et al. 2021). In particular, high temperatures and limited rainfall during summer of 2021 (Table 1) resulted in turfgrass decline that extended to the conclusion of the experiment (Fig. 1), which was more severe than that observed in Summer 2020. In agreement with Pornaro et al. (2016), we found a stronger influence of traffic during the second year, most likely because of accumulation of soil compaction over time in addition to wear. Loamy soil present at the experimental site is particularly prone to compaction, which may have exacerbated this phenomenon (Boekel 1980; Stewart 2004). Additional studies

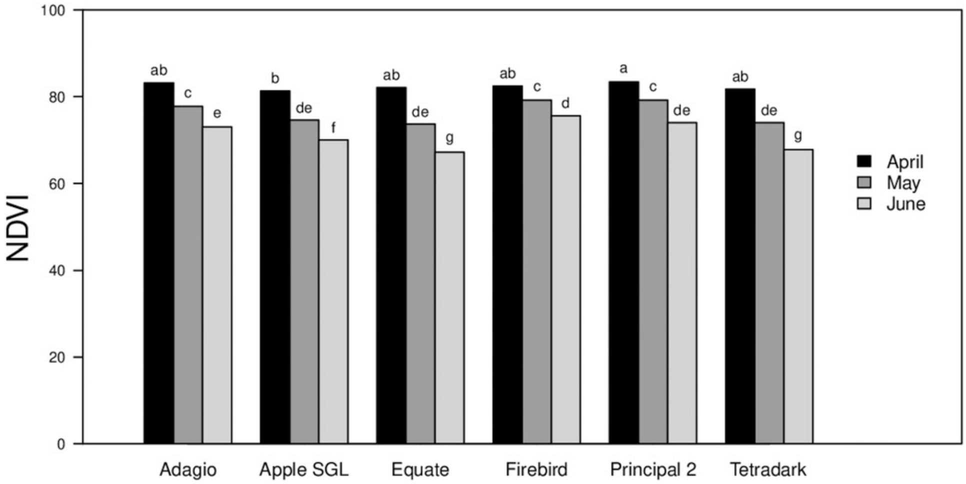

Fig. 7. Normalized difference vegetation index (NDVI) of six perennial ryegrass cultivars (Adagio, Apple SGL, Equate, Firebirds, Principal 2, Tetradark) during spring (April–June) averaged over the two nitrogen (N) rates.

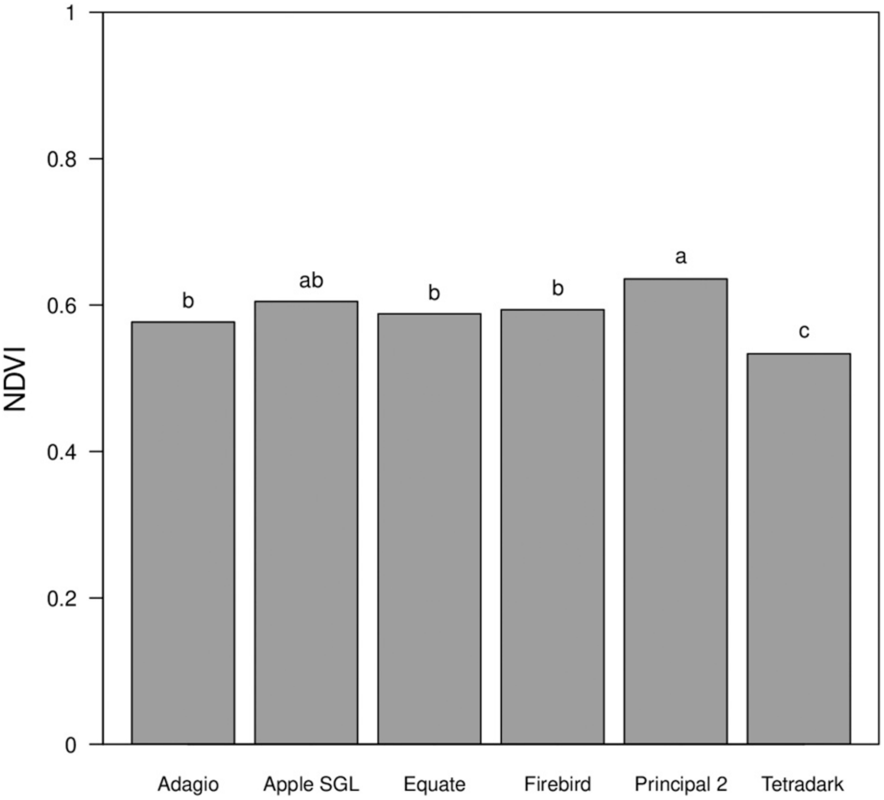

Fig. 8. Normalized difference vegetation index (NDVI) of six perennial ryegrass cultivars (Adagio, Apple SGL, Equate, Firebirds, Principal 2, Tetradark) during fall (October–December) averaged over the two nitrogen (N) rates.

reported a decrease in TQ from 7 in spring to 4 in winter as a consequence of traffic within the first year (Puhalla et al. 2020). However, TQ remained below 4 during the entire second year of the experiment. On the contrary, our results showed an increase in TQ during the spring of the second year, before summer decline.

Several studies (Bell 2011; Braun and Patton 2022; Christians et al. 2016; Dunn et al. 1995) reported that higher N fertility levels cause an increase in perennial ryegrass shoot growth and density and make plant tissue more succulent, especially in spring, when temperatures are optimal for growth. This enhanced growth should make perennial ryegrass plants more resistant to traffic stress. We reported that higher fertility increased TQ and PGC only in spring and fall (Fig. 1), when temperatures were optimal for perennial ryegrass growth. However, our results are in contrast with those indicating that fertilizer applications increased turfgrass cover, color, quality, and recovery during simulated wear (Hoffman et al. 2010a; Martiniello 2007). Dissimilarities in results may be attributed to differences in fertilization rates examined. Excessive turfgrass vigor and growth can reduce perennial ryegrass wear tolerance because plants receiving high levels of N (400 and 625 kg N·ha^{-1}) can deteriorate faster in response to wear (Canaway 1985). Hoffman et al. (2010a) found a significant reduction in perennial ryegrass wear tolerance when plants were fertilized at rates exceeding 245 kg N·ha^{-1}·yr^{-1}, whereas no differences were detected when fertility was between 49 and 245 kg N·ha^{-1}·yr^{-1}. Results from our research suggest that fertility adjustments at rates less than 245 kg N·ha^{-1}·yr^{-1} may still influence perennial ryegrass wear tolerance, but outcomes may be cultivar-dependent and differences may be observed only when temperature is not a limiting growth factor.

Higher fertility induced an increase in TQ for all cultivars examined during our research (Fig. 2). However, the influence of fertility on PGC and NDVI was only observed for 'Apple SGL' and 'Tetradark'. The cultivar Tetradark performed worst in terms of TQ, PGC, and NDVI, which was also reported by Vines et al. (2018) to be a poor-quality cultivar when compared with other cultivars, including Apple SGL. It is likely that the cultivars examined during our research exhibit poor tolerance to heavy traffic and, therefore, benefitted from higher fertility. The impact of a higher fertilization rate on PGC and NDVI was more evident in spring than in fall. Future research examining the response of new perennial ryegrass cultivars to wear and traffic stress may become even more important as climate change continues to increase the temperature and intensity of rainfall events of northern Italy, thus lengthening the periods of time that limit perennial ryegrass growth.

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