RESEARCH

Tolerance and Recovery of Kentucky Bluegrass Subjected to Seasonal Wear

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ABSTRACT

Kentucky bluegrass (*Poa pratensis* L.) is frequently established on sports fields that receive wear during one or more seasons. Differences exist among Kentucky bluegrass cultivars for seasonal performance characteristics such as spring green-up and summer stress tolerance. The objective of this study was to determine whether the wear tolerance and recovery of Kentucky bluegrass cultivars were dependent on season. Twenty-two Kentucky bluegrass cultivars, representing nine genetically diverse Kentucky bluegrass types, were established in September 2002 in North Brunswick, NJ on a loam. The effects of simulated wear were evaluated during spring, summer, and fall in 2004 and 2005. Generally, Kentucky bluegrass was more tolerant of wear during spring than summer or fall and recovery was more rapid after spring wear. The performance of many cultivars depended on season of wear; however, 'Julia' consistently exhibited the greatest wear tolerance as well as recovery. Compact-Midnight Type cultivars ('Midnight', 'Midnight II', and 'Liberator') had good wear tolerance during fall wear, however were slow to recover after fall wear. 'Cabernet', 'Lakeshore', 'Moon Shadow', 'Limousine', and 'Jefferson' exhibited more rapid recovery from fall wear during the next spring. 'Langara', 'Bedazzled', and 'Touchdown' had poor wear tolerance and recovery during all seasons. The season(s) of play should be considered when selecting Kentucky bluegrass cultivars for sports fields.

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Abbreviations: C_{NW}, fullness of turfgrass canopy under no wear; C_W, fullness of turfgrass canopy after wear; C_W–C_{NW}, canopy loss after wear; NTEP, National Turfgrass Evaluation Program; V_{NW}, verdure under no wear; V_W, verdure after wear; V_W–V_{NW}, verdure loss after wear.

Kentucky bluegrass is widely adapted throughout the cool humid and transitional climates of the world (Schery, 1965) and is one of the most commonly used turfgrass species in sports fields grown in cool-season climates (Puhalla et al., 1999). The vigorous rhizome development of Kentucky bluegrass is well adapted for use on sports fields and other heavily trafficked surfaces (Beard, 1973).

Excessive foot traffic on recreational sites can cause major damage to cool-season turfgrasses (Carrow and Petrovic, 1992), particularly when these sites are frequently used sports fields. Traffic has been cited as the most frequent and damaging stress to sports turfs (Minner et al., 1993). Beard (1973) characterized the stresses of traffic as wear, soil compaction, divoting, and soil displacement. Wear injury on aboveground plant parts results from crushing, tearing, and shearing actions of foot and vehicular traffic (Beard et al., 1974; Shearman, 1988). Soil compaction, soil displacement, and divoting can also contribute to a decline in the quality of sports field surfaces.

Wear can be a greater factor contributing to differences among turfgrass species to traffic stresses than compaction alone. Carrow (1980) determined the relative compaction tolerance among species

Published in Crop Sci. 50:1526–1536 (2010).
doi: 10.2135/cropsci2009.09.0479
Published online 20 Apr. 2010.

was perennial ryegrass (*Lolium perenne* L.) = Kentucky bluegrass > tall fescue (*Festuca arundinacea* Schreb.); however, when wear was applied along with compaction, species were ranked as perennial ryegrass > tall fescue > Kentucky bluegrass (Canaway, 1978; Bourgoin and Mansat, 1979).

Many wear and traffic simulators have been developed (Youngner, 1961; Shearman et al., 1974; Canaway, 1976; Cockerham and Brinkman, 1989; Bonos et al., 2001; Carrow et al., 2001; Shearman et al., 2001; Henderson et al., 2005). While most of these simulators mimic the effects of trampling, which imparts wear and compaction of soil; the simulators described by Shearman et al. (1974), Bonos et al. (2001), and the GA W device described by Shearman et al. (2001) were developed to impart only wear stress. Simulators have been used to evaluate the traffic tolerance of turfgrass species and mixtures (Canaway, 1981; Fushtey et al., 1982; Cockerham and Brinkman, 1989; Minner et al., 1993; Taivalmaa et al., 1998) as well as cultivars within a particular species (Wood and Lwa, 1972; Minner et al., 1993; Park et al., 2004, 2005). Attempting to evaluate both wear and compaction in a single test procedure, while useful, can lead to misleading information; screening procedures that separate these two stresses will allow breeders to better understand and develop wear or compaction tolerance in turfgrass (Carrow and Petrovic, 1992).

Researchers in Massachusetts used the simulator described by Canaway (1976) to evaluate the wear tolerance of cultivars in the 2000 National Turfgrass Evaluation Program (NTEP) Kentucky bluegrass trial in 2002 and 2003 (Brosnan et al., 2005; NTEP, 2009). They used a rapid assessment of damage caused by a single wear event with the differential slip device to avoid confounding factors such as compaction related stresses. From the field results obtained in 2002, Brosnan et al. (2005) identified anatomical and morphological characteristics of 10 wear tolerant and 10 wear intolerant entries within the 2000 NTEP Kentucky bluegrass trial.

Turfgrass breeders have developed many distinct cultivars of Kentucky bluegrass that can be classified based on diverse growth and performance characteristics (Murphy et al., 1997). For example, Compact-America and CELA ('Challenger', 'Eclipse', 'Liberty', 'Adelphi') Type cultivars are characterized by moderate winter dormancy and earlier spring green-up compared to the Compact-Midnight Type (Bonos et al., 2004). Mid-Atlantic Type cultivars have good summer stress tolerance and recovery as well as moderate to good winter performance (Bonos et al., 2004). High Density Type cultivars (formerly known as Aggressive Type) have a strong lateral growth habit and high shoot density that can dominate other species or cultivars when used in mixtures and blends (Bonos et al., 2000; Shortell et al., 2009).

A better understanding of wear tolerance and recovery as affected by these seasonal performance differences among Kentucky bluegrass types would provide insight regarding cultivar recommendations on sports fields based on the primary season(s) of play. The objective of this field study was to assess the tolerance and recovery of a diverse group of cultivars, representing nine Kentucky bluegrass types, subjected to wear during spring, summer, and fall.

MATERIALS AND METHODS

This trial used a 4 × 22 factorial combination of seasonal wear and cultivars arranged in a split-plot design with three replications. Whole (main) plots were comprised of four levels of seasonal wear: none, spring, summer, and fall. The subplot factor was comprised of 22 Kentucky bluegrass cultivars, representing a genetically diverse set of elite Kentucky bluegrass cultivars. Cultivars were seeded at 107 kg ha^{-1} into 1.1- by 1.5-m plots in September 2002 on a Nixon loam (fine-loamy, mixed, semiactive, mesic Typic Hapludults) in North Brunswick, NJ.

Kentucky bluegrass cultivars were evaluated for wear tolerance and recovery from spring 2004 through spring 2006. Wear was applied with a simulator (Bonos et al., 2001) operated at 2.4 km h^{-1} across each plot. The noncontact rotational velocity of the paddle axle on the wear simulator was set at 183 rpm. Ninety-six passes of the wear simulator were made during a 6-wk period (16 passes per week) of each treatment-season: spring (30 Mar.–11 May 2004 and 5 Apr.–11 May 2005), summer (21 July–29 Aug. 2004 and 20 July–23 Aug. 2005), and fall (4 Oct.–9 Nov. 2004 and 2005).

Fullness of turfgrass canopy (C_W) was visually rated on a 0 to 100% scale (0% = complete defoliation; 100% = dense and full turfgrass canopy) after each 6-wk wear period to evaluate tolerance and approximately every 2 wk thereafter to evaluate recovery. Plots were visually rated by the same evaluator throughout the study.

To quantitatively assess cultivar performance, one cultivar from each Kentucky bluegrass type was selected for verdure (g m^{-2}) sampling 1 to 2 d after wear: 'Princeton 105' (Compact Type), Midnight (Compact-Midnight Type), Langara (Compact-America Type), Jefferson (CELA Type), Julia (Julia Type), 'Brooklawn' (Shamrock Type), Cabernet (Mid-Atlantic Ecotype), Touchdown (High Density Type), and 'Coventry' (Other Type). Three 24-cm^2 cores per plot were removed from these nine cultivars; verdure was removed from each core, composited into one sample, dried at 60°C for 48 h, and weighed. Annual bluegrass (*Poa annua* L.) encroachment was visually assessed on 20 Apr. and 18 Oct. 2006 using a 1 to 9 scale where 1 equaled severe annual bluegrass encroachment (>75% of the plot area contaminated) and 9 equaled the least annual bluegrass encroachment (<5% of the plot contaminated).

Soil test (Melich 3 extractant) levels of P and K levels were 249 and 208, 247, and 262, and 216 and 271 kg ha^{-1} in March 2004, April 2005, and December 2006, respectively. Lime was applied in September 2004 and April 2005 based on soil tests: soil pH of 5.5, 5.7, and 6.3 in 2004, 2005, and 2006, respectively. Turf was mowed two to three times per week at 3.8 cm. The trial was fertilized with N at 16 kg ha^{-1} every 3 wk from March through November in 2004 and 2005, and March through September 2006 using a spray solution of either $Ca(NO_3)_2$ or NH_4NO_3. Total N applied was 195 kg ha^{-1} in

2004 and 2005 and 128 kg ha^{-1} in 2006. The test was fertilized with K at 27 kg ha^{-1} in April, June, and September of each year providing 81 kg ha^{-1} annually. Plots were irrigated when necessary to avoid drought stress.

Data Analysis

Loss of turfgrass canopy and verdure relative to nonworn plots was calculated for cultivars within replications using the equations: $C_W - C_{NW}$ and $V_W - V_{NW}$, respectively, where C_W and V_W represent fullness of turfgrass canopy and verdure, respectively, assessed after wear; C_{NW} and V_{NW} represent fullness of canopy and verdure, respectively, simultaneously measured on nonworn plots. Relative recovery (R) was assessed as the fullness of canopy ratings transformed to a percentage of the nonworn plots using the equation: $R = (C_W/C_{NW}) \times 100$. Thus, a greater percentage represented better recovery by a cultivar. Recovery data were analyzed at mean recovery levels (across all cultivars) of approximately 33%, 67%, and full (>95%). Recovery data were assessed at 1 yr after initiation of wear when the mean recovery had not achieved full recovery (summer 2004 wear: 1-yr recovery assessed on 19 July 2005; and fall 2005 wear: 1-yr recovery assessed on 27 Sept. 2006).

Data for fullness of turfgrass canopy, verdure, and canopy and verdure loss were subjected to analysis of variance as a 3 × 22 factorial arranged as split-plot design with three replications; season of wear (spring, summer, and fall) was the main plot and cultivar was the subplot. Recovery data (fullness of canopy transformed to a percentage of nonworn plots) for each season of wear were analyzed using a randomized complete block design with three replications. Analysis of variance was performed on annual bluegrass encroachment data designed as a 4 × 22 split-plot design with three replications; season of wear (none, spring, summer, and fall) was the main plot and cultivar was the subplot. Means were separated using Fisher's protected least significant difference ($p \leq 0.05$).

RESULTS AND DISCUSSION

Wear Tolerance

Season affected fullness of turfgrass canopy, both C_{NW} and C_W, as well as canopy loss in 2004 and 2005 (Table 1). A significant season × cultivar interaction indicated that cultivar response to wear depended on the season. Interaction effects that were consistent and had biological significance are discussed; others were considered as random effects.

Fullness of Turfgrass Canopy (C_{NW}, C_W)

Kentucky bluegrass had greater C_{NW} during spring and fall than summer; whereas, Kentucky bluegrass maintained the greatest C_W during spring compared to both summer and fall in both years (Table 1). There was no significant season × cultivar interaction for C_{NW} in 2004 (Table 1); thus, C_{NW} data were pooled across seasons (Table 2). Moreover, there was greater separation among cultivars for C_W during spring (Tables 2 and 3). Not unexpected, Kentucky bluegrass had low to intermediate potential to maintain C_W during the summer when growing conditions were more stressful.

Julia was always among the cultivars with the greatest C_W and had the greatest C_W of all cultivars in spring 2004 and 2005 and summer 2004 (Tables 2 and 3). During the seasons (summer and fall) when Kentucky bluegrass consistently had lower tolerance to wear (Table 1), Midnight II, Liberator, Limousine, Moon Shadow, and 'Brunswick' were among the cultivars with the greatest C_W in fall of both years and 'Brilliant', Midnight, and Cabernet were among the cultivars with greater C_W in summer of both years (Tables 2 and 3).

Langara had a similar C_W during all seasons in 2004 (Table 2) as did Touchdown during 2005 (Table 3); both cultivars were among cultivars with the lowest C_W during five out of the six seasons evaluated (Tables 2 and 3). Bedazzled, Brooklawn, and 'Eagleton' were very susceptible to wear damage during summer and fall in both years, ranking among the cultivars with the lowest C_W (Tables 2 and 3).

Canopy Loss (C_W–C_{NW})

Interestingly, the canopy loss of Kentucky bluegrass from wear was greater, averaged across all cultivars, during fall than either spring or summer even though the potential for producing a full turfgrass canopy (C_{NW}) was greatest during fall as well as spring (Table 1). Brilliant and Coventry were the only cultivars that had a lower canopy loss during both spring and summer than fall over both years (Tables 2 and 3). Julia, Moon Shadow, 'P-707', Princeton 105, 'Champlain', and 'Avalanche' had a lower canopy loss during spring compared to fall and Touchdown had a lower canopy loss during summer compared to fall over both years (Tables 2 and 3).

Julia either had or was among the cultivars with the least canopy loss during each season of both years (Tables 2 and 3). Julia, Limousine, Princeton 105, Midnight II, 'Moonlight', and Liberator were among the cultivars with the least canopy loss during fall of both years when the potential for canopy loss was greatest (Tables 2 and 3). Brilliant, Princeton 105, and Cabernet had lower canopy loss than other cultivars (aside from Julia) during summer of both years. Coventry, Limousine, Moon Shadow, Princeton 105, and Champlain had lower canopy loss than other cultivars during spring of both years. Lakeshore, Eagleton, Bedazzled, Langara, and Touchdown had the greatest canopy loss during five out of six seasons evaluated (Tables 2 and 3).

Verdure (V_{NW}, V_W) and Verdure Loss (V_W–V_{NW})

Verdure of nonworn plots and V_W and the loss of verdure were affected by season during both years (Table 4). The cultivar effect on V_W was dependent on season (interaction) during both years (Table 4). The loss of verdure was affected by cultivar in 2004 (Table 4). Loss of verdure data during 2004 corroborate canopy loss data that indicated

Table 1. Fullness of turfgrass canopy for Kentucky bluegrass as affected by season of wear and cultivar during 2004 and 2005.

Season of wear	2004			2005		
	C_{NW}†	C_W‡	C_W- C_{NW}§	C_{NW}	C_W	C_W- C_{NW}
	%					
Spring	99.6	28.3	–71.4	96.8	27.8	–68.9
Summer	97.4	19.6	–77.8	85.6	15.8	–69.8
Fall	98.9	8.0	–90.9	97.0	19.8	–77.8
LSD (0.05)	1.0	1.8	2.1	1.8	1.3	2.3
			ANOVA			
Source of variation						
Season	*	**	**	**	**	*
Cultivar	**	***	***	***	***	***
Season × cultivar	ns¶	***	***	***	***	***
CV, %	2.8	28.5	–7.6	5.6	18.0	–9.4

* Significant at $p \leq 0.05$.

** Significant at $p \leq 0.01$.

*** Significant at $p \leq 0.001$.

†Fullness of turfgrass canopy on nonworn turf; 100% = full canopy

‡Fullness of turfgrass canopy after wear

§Loss of turfgrass canopy; more negative number represents greater canopy loss

¶ns, nonsignificant.

Table 2. Fullness of turfgrass canopy of Kentucky bluegrass as affected by cultivar (C_{NW}) and season of wear and cultivar (C_W and C_W- C_{NW}) and during 2004.

Cultivar	C_{NW}†	C_W‡			C_W- C_{NW}§		
		Spring¶	Summer#	Fall††	Spring	Summer	Fall
	fullness of turfgrass canopy, %						
Julia JL‡‡	95.7	51.2	57.7	17.3	–48.8	–32.3	–79.7
Brilliant CA	98.7	36.5	34.3	17.7	–63.5	–61.7	–82.3
Coventry OT	97.6	35.9	15.7	4.3	–64.1	–79.3	–93.3
Brunswick HD	99.7	34.2	15.0	8.3	–65.8	–84.0	–91.7
Jefferson CL	98.4	32.6	17.3	8.0	–67.4	–80.3	–89.7
Limousine HD	99.2	31.7	16.3	9.7	–68.3	–81.3	–90.3
Moon Shadow CT	99.8	31.7	18.3	9.0	–67.7	–81.7	–91.0
P-707 CT	98.7	30.4	22.0	8.0	–68.9	–74.7	–92.0
Princeton 105 CT	94.2	28.7	22.3	6.7	–70.0	–70.3	–84.7
Champlain SH	99.2	28.7	15.0	6.3	–70.7	–83.3	–93.7
Brooklawn SH	100.0	28.4	10.0	6.3	–71.6	–90.0	–93.7
Avalanche JL	99.4	27.7	19.0	5.7	–72.3	–79.3	–94.3
Midnight CM	99.7	27.7	24.3	7.3	–72.3	–74.7	–92.7
Midnight II CM	99.8	27.7	23.7	12.3	–71.7	–76.3	–87.7
Lakeshore SH	99.7	27.7	11.0	7.0	–72.3	–88.0	–93.0
Cabernet MA	100.0	26.3	29.0	4.3	–73.7	–71.0	–95.7
Bedazzled CA	99.8	24.5	7.0	6.7	–74.9	–93.0	–93.3
Moonlight CT	98.2	24.4	21.0	6.3	–74.9	–77.3	–90.7
Liberator CM	98.2	21.7	24.0	11.0	–77.6	–73.3	–87.0
Eagleton MA	98.8	21.1	5.0	3.7	–78.3	–93.0	–95.3
Langara CA	97.3	14.0	4.3	5.7	–84.0	–89.7	–94.3
Touchdown HD	98.2	9.1	19.7	4.3	–90.9	–76.0	–94.7
LSD (0.05)	2.6		10.3			11.1	

†Fullness of turfgrass canopy on nonworn turf; 100% = full canopy.

‡Fullness of turfgrass canopy after wear.

§Loss of turfgrass canopy; more negative number represents greater canopy loss.

¶Rated 14 May 2004.

#Rated 1 Sept. 2004.

††Rated 16 Nov. 2004.

‡‡CL CELA Type CTCompact Type; CA Compact-America Type; CM Compact-Midnight Type; HD High Density Type; JL Julia Type; MA Mid-Atlantic Ecotype; OT Other Type; SH Shamrock Type.

Table 3. Fullness of turfgrass canopy of Kentucky bluegrass as affected by season of wear and cultivar during 2005.

Cultivar	C_{NW}†			C_W‡			C_W- C_{NW}§		
	Spring¶	Summer#	Fall††	Spring	Summer	Fall	Spring	Summer	Fall
	fullness of turfgrass canopy, %								
Julia [JL‡‡]	95.7	73.3	89.3	43.0	17.0	24.0	–52.7	–56.3	–65.3
Brilliant [CA]	100.0	84.7	100.0	35.0	19.7	19.0	–65.0	–65.0	–81.0
Coventry [OT]	100.0	65.0	90.0	35.7	17.0	13.3	–64.3	–48.0	–76.7
Brunswick [HD]	98.3	88.3	99.0	30.3	20.0	23.0	–68.0	–68.3	–76.0
Jefferson [CL]	99.0	79.0	97.0	29.0	22.0	20.0	–70.0	–57.0	–77.0
Limousine [HD]	100.0	74.0	98.0	35.7	16.7	26.7	–64.3	–57.3	–71.3
Moon Shadow [CT]	92.3	88.3	98.3	33.3	13.0	24.3	–59.0	–75.3	–74.0
P-707 [CT]	93.3	92.3	100.0	25.7	19.0	17.0	–67.7	–73.3	–83.0
Princeton 105 [CT]	85.7	83.3	93.3	27.3	19.0	18.0	–58.3	–64.3	–75.3
Champlain [SH]	96.7	84.0	96.3	33.0	21.7	15.7	–63.7	–62.3	–80.7
Brooklawn [SH]	100.0	83.3	93.3	31.0	14.3	14.3	–69.0	–69.0	–79.0
Avalanche [JL]	100.0	93.3	100.0	34.3	8.3	21.7	–65.7	–85.0	–78.3
Midnight [CM]	90.7	93.7	99.0	25.3	18.3	25.7	–65.3	–75.3	–73.3
Midnight II [CM]	96.0	96.3	100.0	27.7	15.7	26.3	–68.3	–80.7	–73.7
Lakeshore [SH]	100.0	90.0	96.3	24.3	15.7	16.3	–75.7	–74.3	–80.0
Cabernet [MA]	100.0	90.7	98.3	28.3	21.7	19.0	–71.7	–69.0	–79.3
Bedazzled [CA]	99.0	91.7	99.0	20.0	8.3	15.0	–79.0	–83.3	–84.0
Moonlight [CT]	95.0	88.3	96.3	22.3	11.7	20.0	–72.7	–76.7	–76.3
Liberator [CM]	92.3	89.0	97.3	21.0	13.3	28.3	–71.3	–75.7	–69.0
Eagleton [MA]	100.0	88.3	95.7	20.3	13.0	12.7	–79.7	–75.3	–83.0
Langara [CA]	98.3	83.0	97.3	17.0	12.3	20.0	–81.3	–70.7	–77.3
Touchdown [HD]	96.7	84.0	100.0	12.3	10.3	14.3	–84.3	–73.7	–85.7
LSD (0.05)		9.9			6.8			11.8	

†Fullness of turfgrass canopy on nonworn turf; 100% = full canopy

‡Fullness of turfgrass canopy after wear

§Loss of turfgrass canopy; more negative number represents greater canopy loss

¶Rated 14 May 2005

#Rated 29 Aug. 2005

††Rated 15 Nov. 2005

‡‡[CL] CELA Type [CT]Compact Type; [CA] Compact-America Type; [CM] Compact-Midnight Type; [HD] High Density Type; [JL] Julia Type; [MA] Mid-Atlantic Ecotype; [OT] Other Type; [SH] Shamrock Type.

Julia was more tolerant of wear, while Langara and Touchdown were more susceptible to wear injury (Table 5).

Similar to fullness of turfgrass canopy ratings, Kentucky bluegrass maintained greater V_W during spring compared to summer and fall in both years (Table 4). This occurred despite greater verdure loss due to wear in spring compared to summer and fall in 2004 and 2005 (Table 4). Thus, the better wear tolerance of Kentucky bluegrass during the spring appears to be at least partly related to greater shoot biomass at that time of year. Vigorous shoot growth during spring is a characteristic of the annual growth cycle of cool season turfgrasses (Turgeon, 1999). Greater shoot biomass has been associated with better turf performance under wear for species mixtures (Youngner, 1961) and seashore paspalum (*Paspalum vaginatum* Swartz.) (Trenholm et al., 2000). While the loss of verdure to wear during summer and fall was not as great during spring, the initially lower verdure during summer and fall apparently resulted in a lower V_W (Table 4). Thus, shoot biomass (verdure) would appear to be useful selection criteria for turfgrass breeders working to improve tolerance.

All cultivars except Touchdown had better V_W during spring compared to summer during both years (Table 6). The V_W of Midnight, Langara, and Touchdown during spring was similar to V_W during fall of both years, while other cultivars had greater V_W during spring compared to fall of both years (Table 6). There were more differences in V_W among cultivars during spring than summer or fall of both years. When cultivar differences were evident, Julia either had or was among cultivars with the greatest V_W and Touchdown was always among cultivars with the least V_W (Table 6).

Julia was among the most traffic (wear and compaction stresses) tolerant cultivars in the 1985 and 2000 NTEP Kentucky bluegrass trials (Cockerham and Brinkman, 1989; Minner et al., 1993; Park et al., 2004). Among Julia Type entries comprising the 2000 NTEP Kentucky bluegrass trial (Bonos et al., 2004), Julia and Avalanche were the best performing cultivars under traffic in 2002 and 2003 (Park et al., 2005). In the current study, Avalanche and Julia had similar C_W only during fall 2005 (Table 3). It is possible that the additional compaction and season-long application of traffic in the 2000 NTEP trial equalized performance of Julia relative to Avalanche.

Table 4. Verdure response of Kentucky bluegrass as affected by season of wear and cultivar in 2004 and 2005.

Season of wear	2004			2005		
	V_{NW}†	V_W‡	V_W–V_{NW}§	V_{NW}	V_W	V_W–V_{NW}
	g m^{-2}					
Spring	293.2	97.0	–196.2	260.1	106.1	–154.0
Summer	78.2	21.5	–56.7	153.1	30.8	–122.2
Fall	235.5	61.6	–173.9	145.0	44.5	–100.4
LSD (0.05)	17.8	9.3	20.9	20.6	13.1	23.8
	ANOVA					
Source of variation						
Season	**	**	**	***	***	**
Cultivar	ns¶	***	*	ns	**	ns
Season × cultivar	ns	***	ns	ns	**	ns
CV, %	16.0	28.4	–26.9	20.3	39.6	–34.6

* Significant at $p \leq 0.05$.

** Significant at $p \leq 0.01$.

*** Significant at $p \leq 0.001$.

†Verdure on nonworn turf.

‡Verdure after wear.

§Loss of verdure; more negative number represents greater verdure loss.

¶ns, nonsignificant.

Table 5. Loss of verdure of nine Kentucky bluegrass cultivars subjected to wear in 2004, pooled across all seasons of wear.

Cultivar	V_{NW}†	V_W–V_{NW} ‡
	g m^{-2}	
Julia [JL]§	179.5	–109.6
Coventry [OT]	212.6	–140.4
Jefferson [CL]	162.4	–130.8
Princeton 105 [CT]	187.2	–126.8
Brooklawn [SH]	197.2	–154.0
Midnight [CM]	185.6	–134.5
Cabernet [MA]	178.6	–142.9
Langara [CA]	202.6	–165.0
Touchdown [HD]	168.8	–176.4
LSD (0.05)		36.3

†Verdure on nonworn turf.

‡Loss of verdure calculated as V_W–V_{NW}, where V_W and V_{NW} represent verdure assessed after wear and on nonworn plots, respectively; sampled 13 May, 31 Aug., and 11 Nov. 2004.

§[CL] CELA Type [CT] Compact Type; [CA] Compact-America Type; [CM] Compact-Midnight Type; [HD] High Density Type; [JL] Julia Type; [MA] Mid-Atlantic Ecotype; [OT] Other Type; [SH] Shamrock Type.

Limousine, Princeton 105, Julia, Bedazzled, Brilliant, and Midnight were among the most wear tolerant entries comprising the 2000 NTEP Kentucky bluegrass trial in Massachusetts during 2002, 2003, and averaged across 2002 and 2003 (NTEP, 2009). These cultivars, with the exception of Bedazzled, exhibited the highest C_W and/or least canopy loss in our trial in one or more seasons. Langara was among the least wear tolerant during 2002 in the Massachusetts test (NTEP, 2009) and performed consistently poor in our trial. The poor performance of Bedazzled in our trial compared to its strong performance in the Massachusetts trial may be attributable to differences in wear simulators and/or environmental stresses associated with trial locations.

Our data corroborates with previous reports that Langara (Brosnan et al., 2005) and Touchdown (Minner et al., 1993) are very susceptible to damage caused by traffic stresses. Among the Compact-America Type cultivars in this research, Brilliant had better wear tolerance than Langara and Bedazzled. Among the High Density Type cultivars, Limousine had better wear tolerance than Touchdown. This agrees with a previous report (Park et al., 2005) of variable performance, under traffic, among cultivars within Types. This trial and that of Park et al. (2005) suggest the wear tolerance among Compact-Midnight Type cultivars is relatively consistent.

Recovery from Wear

Approximately Thirty-three Percent Mean Relative Recovery

Not unexpected, the time to reach approximately 33% mean relative recovery for Kentucky bluegrass was considerably greater when wear was applied during fall (≥186 d) than spring (22–34 d) or summer (41–46 d) (Table 7). Julia had the best relative recovery from wear during spring and summer among all cultivars in both years (Table 7). Julia, Cabernet, Lakeshore, and Moon Shadow had the best recovery from wear during fall 2004; Julia, Limousine, and Jefferson had the best recovery from wear during fall 2005 (Table 7). Cabernet, Lakeshore, Jefferson, and Julia have moderate to good winter performance and spring green-up (Bonos et al., 2003, 2004; Shortell et al., 2005). Better winter performance and early spring green-up probably aided in the recovery of these cultivars after wear was applied during the previous fall season. These cultivars may be useful on sports fields needing recovery from fall wear injury (play).

Table 6. Verdure of Kentucky bluegrass after wear (V_W) as affected by the interaction of season and cultivar in 2004 and 2005.

Cultivar	Season of wear 2004			Season of wear 2005		
	Spring†	Summer‡	Fall§	Spring	Summer	Fall
	g m^{-2}					
Julia JL¶	162.1	62.2	81.0	152.5	43.8	56.4
Coventry OT	149.7	16.1	41.3	148.3	34.3	43.9
Jefferson CL	96.8	15.4	58.6	139.2	24.6	46.4
Princeton 105 CT	107.6	20.4	58.8	121.0	42.1	31.8
Brooklawn SH	107.3	11.3	37.3	100.6	20.8	36.4
Midnight CM	89.4	27.9	101.4	80.7	22.8	68.3
Cabernet MA	72.9	23.0	42.9	105.4	31.0	41.1
Langara CA	55.8	7.5	81.2	76.8	29.3	45.1
Touchdown HD	31.3	9.9	52.4	30.5	28.9	31.1
LSD (0.05)		41.0			39.7	

†Sampled 11 May 2004 and 12 May 2005.

‡Sampled 31 Aug. 2004 and 24 Aug. 2005.

§Sampled 11 Nov. 2004 and 10 Nov. 2005.

¶CL CELA Type CT Compact Type; CA Compact-America Type; CM Compact-Midnight Type; HD High Density Type; JL Julia Type; MA Mid-Atlantic Ecotype; OT Other Type; SH Shamrock Type.

Table 7. Relative recovery of Kentucky bluegrass cultivars at approximately 33% mean relative recovery from wear during spring, summer, and fall in 2004 and 2005.

Parameter	Relative recovery†					
	2004			2005		
	Spring	Summer	Fall	Spring	Summer	Fall
Mean relative recovery	37%	36%	31%	34%	29%	39%
Days after wear‡	34	46	186	22	41	203
Date of rating	14 June 2004	14 Oct. 2004	14 May 2005	2 June 2005	3 Oct. 2005	31 May 2006
Cultivar	%					
Julia JL§	75.0	85.0	45.5	63.7	48.9	54.9
Brilliant CA	30.5	43.3	25.7	30.1	27.9	28.1
Coventry OT	60.3	25.0	23.0	39.2	30.5	36.6
Brunswick HD	28.9	28.3	30.9	29.0	26.1	37.5
Jefferson CL	48.2	39.4	34.0	37.6	32.6	49.8
Limousine HD	50.0	34.3	34.3	42.3	31.4	47.0
Moon Shadow CT	33.3	36.3	43.3	33.6	23.4	43.7
P-707 CT	30.0	39.8	31.4	27.0	29.0	34.9
Princeton 105 CT	29.4	41.7	29.4	30.9	28.5	33.1
Champlain SH	29.3	31.3	27.3	33.3	31.1	30.8
Brooklawn SH	51.7	27.0	30.0	44.8	28.2	41.5
Avalanche JL	40.6	36.8	29.3	36.4	21.7	43.3
Midnight CM	31.7	44.5	25.8	28.1	26.1	33.5
Midnight II CM	33.3	42.9	29.6	31.0	24.6	36.8
Lakeshore SH	38.3	27.7	38.3	37.2	32.3	41.7
Cabernet MA	55.3	57.8	38.3	43.0	38.1	42.1
Bedazzled CA	25.0	20.7	24.3	25.0	24.5	30.7
Moonlight CT	26.4	40.6	30.7	24.4	24.8	37.0
Liberator CM	33.9	41.2	30.0	27.6	23.7	36.1
Eagleton MA	30.0	21.3	23.3	26.5	29.1	39.2
Langara CA	22.0	15.6	30.3	22.7	26.6	38.5
Touchdown HD	17.0	16.8	27.9	23.7	23.1	35.8
LSD (0.05)	8.1	11.8	8.2	8.9	10.7	8.4
CV, %	13.2	19.7	16.0	16.2	22.7	13.1

†Relative recovery = $(C_W/C_{NW}) \times 100$; where C_W represents fullness of canopy after wear and C_{NW} represents represents fullness of canopy on nonworn plots.

‡Days after wear treatment was terminated when approximately a 33% mean relative recovery was achieved.

§CL CELA Type CT Compact Type; CA Compact-America Type; CM Compact-Midnight Type; HD High Density Type; JL Julia Type; MA Mid-Atlantic Ecotype; OT Other Type; SH Shamrock Type.

Bedazzled and Touchdown were among cultivars with the poorest relative recovery from wear during all seasons in both years and Langara was among the poorest in five of the six seasons (Table 7). The poor recovery of Langara and Bedazzled is consistent with a previous report of other Compact-America Type cultivars, where this type exhibited poor recovery in spring, approximately 5 mo after wear (Park et al., 2005). Compact-America Type cultivars typically have moderate winter dormancy (Bonos et al., 2004); thus, better spring recovery after fall wear should have been expected in the current trial. It is possible that the slower recovery of the Compact-America Type cultivars in this trial was due, in part, to the more severe, initial canopy loss of these cultivars (Tables 2 and 3).

Midnight and Liberator (Compact-Midnight Type cultivars) were among cultivars with the poorest recovery from fall wear in both years; Midnight II was among the poorest in 2004 (Table 7). This response was probably due to the long winter dormancy and late spring green-up characteristic of this type (Bonos et al., 2004).

Approximately Sixty-seven Percent Mean Relative Recovery

Kentucky bluegrass achieved approximately 67% mean relative recovery from wear during spring in <70 d in both years (Table 8). Conversely, it required more than 220 d to achieve approximately 67% mean relative recovery from wear during summer 2004 and fall 2004 and 2005 (Table 8). Relative recovery at a mean level of 67% after wear applied during summer 2005 were not reported due to annual bluegrass encroachment confounding that data. Vigorous shoot growth during spring through early summer probably accounts for the excellent recuperative ability of Kentucky bluegrass from spring wear compared to recovery from wear in summer and fall.

Julia was among the cultivars with the best relative recovery during all seasons in both years (Table 8). Julia has exhibited good recovery from traffic stresses in other trials (Minner et al., 1993; Park et al., 2005) and cultivars within the Julia Type were among the best Kentucky bluegrasses for recovery (Park et al., 2005). Limousine, Lakeshore, Moon Shadow, Midnight II, Jefferson, P-707, and Midnight were among the best cultivars for recovery during fall 2004 and 2005 (Table 8).

Bedazzled was among the poorest recovering cultivars during all five reported seasons. Similarly, Langara was among the poorest recovering cultivars during four of the five reported seasons and Touchdown and Moonlight were among the poorest during three of five reported seasons (Table 8). Touchdown and Langara have exhibited poor recovery from traffic stresses (Minner et al., 1993; Park et al., 2005).

Midnight and Midnight II were among cultivars that exhibited the best recovery after fall wear in both years and Liberator was among the best after fall wear in 2005 (Table 8). Thus, while these Compact-Midnight Type cultivars exhibit poor spring green-up and subsequently poor recovery in May (approximately 33% mean relative recovery after fall wear), rapid recovery occurred once these cultivars had achieved green-up during June and July. Bonos et al. (2004) noted the good heat tolerance of cultivars within this Type. The ability of these cultivars to exhibit good growth/recovery in the summer months is an indication of that this Type has strong summer performance.

Full Recovery

Full recovery (>95% mean relative recovery) of Kentucky bluegrass was reached after spring wear in 2004 and 2005 (326 and 188 DAW, respectively) and fall wear in 2004 (307 DAW). Mean relative recovery after fall 2005 wear reached a maximum of 85% at 322 DAW; the cultivar effect was not significant at this rating date. Recovery from wear applied during summer 2004 only achieved 85% mean relative recovery by 325 d after wear treatment was stopped and the cultivar effect was significant which indicated the poor recovery of Langara and Bedazzled (data not shown).

Annual Bluegrass Encroachment

Annual bluegrass encroachment was relatively severe during the winter of 2005–2006 and was greater when wear was applied in summer compared to spring and fall and nonworn plots (Table 9). Annual bluegrass is opportunistic and can ingress into the voids of turfs caused by stress including wear (Beard, 1970). Kaminski and Dernoeden (2005) observed that the most aggressive emergence of annual bluegrass in Maryland occurred during a 3 to 4 wk period between September and mid-October. Thus, canopy defoliation caused by summer wear in our trial provided ideal conditions for annual bluegrass to encroach when Kentucky bluegrass had yet to fully recover during late summer and fall. Interestingly, there was less annual bluegrass encroachment into Kentucky bluegrass plots receiving wear during fall compared to spring, summer, and the check (Table 9). It is plausible that wear during fall damaged emerging annual bluegrass seedlings and disrupted encroachment.

An interaction indicated that cultivar differences were more evident when wear was applied during summer; only a few, small differences were found at other times of wear and under nonworn conditions. On 20 Apr. 2006, cultivars with the most severe annual bluegrass encroachment after summer wear included Liberator, Bedazzled, Langara, Avalanche, Coventry, Limousine, and Touchdown (Table 10). After summer wear in 2005, Liberator, Bedazzled, Langara, Avalanche, and Touchdown were among cultivars with the lowest C_W and poorest recovery at 33% mean relative recovery (Tables 3 and 7).

Table 8. Relative recovery of Kentucky bluegrass cultivars at approximately 67% mean relative recovery from wear during spring, summer, and fall 2004 and spring and fall 2005. Recovery data for wear during summer 2005 not shown due to confounding by weed encroachment.

	Relative recovery†				
	2004			2005	
Parameter	Spring	Summer	Fall	Spring	Fall
Mean relative recovery	61%	66%	65%	71%	64%
Days after wear‡	69	277	221	56	245
Date of Rating	19 July 2004	2 June 2005	20 June 2005	6 July 2005	12 July 2006
Cultivar	%				
Julia JL§	92.7	89.3	73.3	94.3	74.1
Brilliant CA	53.3	73.0	62.3	64.7	51.2
Coventry OT	88.8	65.8	52.8	82.5	64.3
Brunswick HD	44.2	62.3	63.7	70.7	63.1
Jefferson CL	74.2	73.0	66.0	71.0	68.8
Limousine HD	69.6	69.0	68.3	85.7	74.0
Moon Shadow CT	65.0	66.2	77.4	77.4	66.3
P-707 CT	58.0	72.3	74.0	68.3	68.1
Princeton 105 CT	51.0	63.3	59.3	71.2	59.0
Champlain SH	55.5	57.3	61.7	77.3	63.0
Brooklawn SH	83.7	66.3	64.3	84.0	66.3
Avalanche JL	79.9	72.4	62.2	82.7	67.3
Midnight CM	57.0	64.1	65.7	64.0	65.0
Midnight II CM	62.0	67.3	74.0	74.7	70.3
Lakeshore SH	75.3	67.0	70.7	79.0	68.5
Cabernet MA	74.9	78.0	69.0	83.3	61.5
Bedazzled CA	41.5	54.0	58.6	50.7	50.4
Moonlight CT	36.7	61.3	61.8	43.8	61.0
Liberator CM	52.0	65.6	63.3	61.7	66.7
Eagleton MA	49.5	59.3	55.6	63.3	64.1
Langara CA	31.9	45.3	59.0	51.0	62.9
Touchdown HD	36.9	62.1	59.0	58.3	59.2
LSD (0.05)	16.8	12.8	12.9	10.0	9.7
CV, %	16.8	11.8	12.1	8.6	9.1

†Relative recovery = $(C_W/C_{NW}) \times 100$; where C_W represents fullness of canopy after wear and C_{NW} represents represents fullness of canopy on nonworn plots.

‡Days after wear treatment was terminated.

§CL CELA Type CT Compact Type; CA Compact-America Type; CM Compact-Midnight Type; HD High Density Type; JL Julia Type; MA Mid-Atlantic Ecotype; OT Other Type; SH Shamrock Type.

CONCLUSIONS

Kentucky bluegrass had the greatest tolerance to wear during spring in contrast to summer and, surprisingly, fall. Additionally, cultivars differences in response to wear tended to more evident during spring than summer or fall. Screening for wear tolerance might be more effective if performed during spring. Kentucky bluegrass recovered (~67% of full canopy) from wear during spring within 70 d compared to more than 220 d after summer and fall wear. The better tolerance to spring wear as well as recovery of Kentucky bluegrass are probably attributable to more vigorous shoot growth, which occurs during spring through early summer.

Julia exhibited the most consistent seasonal and greatest wear tolerance as well as recovery of the Kentucky bluegrass cultivars studied. However, it should be noted that other stresses, particularly susceptibility to diseases caused by fungal pathogens, can compromise performance of Julia (NTEP, 2009), which limits the utility of

Table 9. Encroachment of annual bluegrass into Kentucky bluegrass cultivars after wear in spring, summer, and fall 2005 as affected by season of wear and cultivar.

Season of wear	20 Apr. 2006
	1–9 scale†
None	8.3
Spring	8.0
Summer	3.7
Fall	8.7
LSD (0.05)	0.3
	ANOVA
Source of variation	
Season	***
Cultivar	***
Season × cultivar	***
CV, %	11.3

** Significant at $p \leq 0.01$.

*** Significant at $p \leq 0.001$.

†Visual rating, where 9 represented <5% of the plot area infested with annual bluegrass encroachment and 1 represented >75% annual bluegrass encroachment into the plots.

Table 10. Encroachment of annual bluegrass into Kentucky bluegrass cultivars as affected by season of wear and cultivar on 20 Apr. 2006 after wear during spring, summer, and fall of 2004 and 2005.

Cultivar	Season of wear			
	None	Spring	Summer	Fall
	1–9 scale†			
Julia JL‡	9.0	8.0	4.0	8.7
Brilliant CA	7.7	7.0	4.7	9.0
Coventry OT	8.0	8.3	3.0	8.7
Brunswick HD	8.0	9.0	4.3	9.0
Jefferson CL	8.3	8.0	5.7	8.3
Limousine HD	8.0	8.0	1.7	8.0
Moon Shadow CT	8.0	7.7	3.7	8.7
P-707 CT	8.3	8.3	5.0	9.0
Princeton 105 CT	8.0	8.3	5.3	9.0
Champlain SH	9.0	8.0	5.3	9.0
Brooklawn SH	8.3	8.0	3.3	8.7
Avalanche JL	8.7	8.3	2.7	9.0
Midnight CM	7.3	8.3	3.7	8.7
Midnight II CM	9.0	8.0	4.0	9.0
Lakeshore SH	8.3	8.0	5.0	9.0
Cabernet MA	8.3	7.7	5.0	8.3
Bedazzled CA	8.3	7.0	1.7	9.0
Moonlight CT	8.7	8.0	3.7	8.0
Liberator CM	8.3	8.7	3.0	8.3
Eagleton MA	8.7	8.0	4.0	8.3
Langara CA	7.7	8.3	2.3	8.3
Touchdown HD	8.3	8.0	1.3	8.3
LSD (0.05)			1.7	

†Visual rating, where 9 represented <5% of the plot area infested with annual bluegrass encroachment and 1 represented >75% annual bluegrass encroachment into the plots.

‡CL CELA Type CT Compact Type; CA Compact-America Type; CM Compact-Midnight Type; HD High Density Type; JL Julia Type; MA Mid-Atlantic Ecotype; OT Other Type; SH Shamrock Type.

this cultivar. Compact-Midnight Type cultivars (Midnight, Midnight II, and Liberator) had good wear tolerance during fall wear, however were slow to achieve 33% recovery after fall wear. Other cultivars including Cabernet, Lakeshore, Moon Shadow, Limousine, and Jefferson exhibited more rapid recovery after fall wear and may be better choices for sports fields receiving fall play. Langara, Bedazzled, and Touchdown had poor wear tolerance and recovery during all seasons; use of these cultivars on sports fields probably should be limited to low use intensities.

Wear damage during summer creates more suitable conditions for germinating annual bluegrass to invade Kentucky bluegrass turf. Thus, sports turfs are more likely to be dominated by annual bluegrass if management practices to control annual bluegrass or reestablish desirable turfgrass cover are not performed on fields receiving intense summer play.

Acknowledgments

This work was supported by the New Jersey Agricultural Experiment Station, State and Hatch funds, Rutgers Center for Turfgrass Science, and other grants and gifts.

References

Beard, J.B. 1970. An ecological study of annual bluegrass. USGA Green Sect. Rec. 8(2):13–18.

Beard, J.B. 1973. Turfgrass: Science and culture. Prentice Hall, Englewood Cliffs, NJ.

Beard, J.B., J.F. Wilkinson, and R.C. Shearman. 1974. Turfgrass wear tolerance: The anatomical and physiological basis. p. 1–2, 4–6. *In* Proc. of the 44th Annu. Michigan Turfgrass Conf., East Lansing, MI. 15–16 Jan. 1974. Michigan State Univ., East Lansing.

Bonos, S.A., W.K. Dickson, B.S. Park, E. Watkins, R.F. Bara, D.A. Smith, M.M. Wilson, T.J. Lawson, J. Clark, J.A. Murphy, C.R. Funk, and W.A. Meyer. 2004. Performance of Kentucky bluegrass cultivars and selections in New Jersey turf trials. Rutgers Turfgrass Proc. 35:45–111.

Bonos, S.A., W.A. Meyer, and J.A. Murphy. 2000. Classification of Kentucky bluegrass genotypes grown as spaced-plants. HortScience 35(5):910–913.

Bonos, S.A., J.A. Murphy, W.A. Meyer, W.K. Dickson, E. Watkins, R.F. Bara, D.A. Smith, M.M. Mohr, and C.R. Funk. 2003. Performance of Kentucky bluegrass cultivars and selections in New Jersey turf trials. Rutgers Turfgrass Proc. 34:57–112.

Bonos, S.A., E. Watkins, J.A. Honig, M. Sosa, T. Molnar, J.A. Murphy, and W.A. Meyer. 2001. Breeding cool-season turfgrasses for wear tolerance using a wear simulator. Int. Turfgrass Soc. Res. J. 9:137–145.

Bourgoin, B., and P. Mansat. 1979. Persistence of turfgrass species and cultivars. J. Sports Turf Res. Inst. 55:121–140.

Brosnan, J.T., J.S. Ebdon, and W.M. Dest. 2005. Characteristics in diverse wear tolerant genotypes of Kentucky bluegrass. Crop Sci. 45:1917–1926.

Canaway, P.M. 1976. A differential slip wear machine (D.S.1.) for the artificial simulation of turfgrass wear. J. Sports Turf Res. Inst. 52:82–99.

Canaway, P.M. 1978. Trials of turfgrass wear tolerance and associated factors–A summary of progress 1975–1977. J. Sports Turf Res. Inst. 54:7–14.

Canaway, P.M. 1981. Wear tolerance of turfgrass species. J. Sports Turf Res. Inst. 57:108–121.

Carrow, R.N. 1980. Influence of soil compaction on three turfgrass species. Agron. J. 72:1038–1042.

Carrow, R.N., R.R. Duncan, J.E. Worley, and R.C. Shearman. 2001. Turfgrass traffic (soil compaction plus wear) simulator: Response of *Paspalum vaginatum* and *Cynodon* spp. Int. Turfgrass Soc. Res. J. 9:253–258.

Carrow, R.N., and A.M. Petrovic. 1992. Effects of traffic on turfgrass. p. 285–330. *In* D.V. Waddington et al. (ed.) Turfgrass. Agron. Monogr. 32. ASA, CSSA, and SSSA, Madison, WI.

Cockerham, S.T., and D.J. Brinkman. 1989. A simulator for cleated-shoe sports traffic on turfgrass research plots. California Turfgrass Culture 39(3–4):9–10.

Fushtey, S.G., D.K. Taylor, and D. Fairey. 1982. The effect of wear stress on survival of turfgrass in pure stands and in mixtures. Can. J. Plant Sci. 63:317–322.

Henderson, J.J., J.L. Lanovaz, J.N. Rogers, III, J.C. Sorochan, and J.T. Vanini. 2005. A new apparatus to simulate athletic field traffic: The Cady Traffic Simulator. Agron. J. 97:1153–1157.

Kaminski, J.E., and P.H. Dernoeden. 2005. Seasonal annual bluegrass seedling emergence patterns. Proc. NE Weed Sci. Soc. 59:110.

Minner, D.D., J.H. Dunn, S.S. Burghrara, and B.S. Fresenburg.

1993. Traffic tolerance among cultivars of Kentucky bluegrass, tall fescue, and perennial ryegrass. Int. Turfgrass Soc. Res. J. 7:687–694.

Murphy, J.A., S. Bonos, and P. Perdomo. 1997. Classification of *Poa pratensis* genotypes. Int. Turfgrass Soc. Res. J. 8:1176–1183.

National Turfgrass Evaluation Program. 2009. National Kentucky bluegrass test-2000. Available at www.ntep.org/reports/kb00/kb00_06-11f/kb00_06-11f.htm (verified 25 Mar. 2010).

Park, B.S., J.A. Murphy, W.A. Meyer, S.A. Bonos, J. den Haan, D.A. Smith, and T.J. Lawson. 2004. Traffic tolerance of cool-season turfgrasses. Rutgers Turfgrass Proc. 35:199–219.

Park, B.S., J.A. Murphy, W.A. Meyer, S.A. Bonos, J. den Haan, D.A. Smith, and T.J. Lawson. 2005. Performance of Kentucky bluegrass within phenotypic classifications as affected by traffic. Int. Turfgrass Soc. Res. J. 10:618–626.

Puhalla, J., J. Krans, and M. Goatley. 1999. Sports fields: A manual for design construction and maintenance. Wiley & Sons, Hoboken, NJ.

Schery, R.W. 1965. This remarkable Kentucky bluegrass. Ann. Mo. Bot. Gard. 52(3):444–451.

Shearman, R.C. 1988. Improving sports turf wear tolerance. Proc. of the 58th Annu. Michigan Turfgrass Conf. 17: 153–155.

Shearman, R.C., J.B. Beard, C.M. Hansen, and R. Apaclla. 1974. Turfgrass wear simulator for small plot investigations. Agron. J. 66:332–334.

Shearman, R.C., R.N. Carrow, L.A. Wit, R.R. Duncan, L.E. Trenholm, and J.E. Worley. Turfgrass traffic simulators: A description of two self-propelled devices simulating wear and compaction stress injury. 2001. Int. Turfgrass Soc. Res. J. 9:347–352.

Shortell, R.R., W.K. Dickson, B.S. Park, R.F. Bara, D.A. Smith, M.M. Wilson, T.J. Lawson, J. Clark, S.A. Bonos, J.A. Murphy, C.R. Funk, and W.A. Meyer. 2005. Performance of Kentucky bluegrass cultivars and selections in New Jersey turf trials. Rutgers Turfgrass Proc. 36:49–118.

Shortell, R.R., W.A. Meyer, and S.A. Bonos. 2009. Classification and inheritance of morphological and agronomic traits in Kentucky bluegrass. HortScience 44(2):274–279.

Taivalmaa, S.L., H. Talvitie, L. Jauhiainen, and O. Niemelainen. 1998. Influence of wear-stress on turfgrass species and cultivars in Finland. J. Turfgrass Sci. 74:52–62.

Trenholm, L.E., R.N. Carrow, and R.R. Duncan. 2000. Mechanisms of wear tolerance in seashore paspalum and bermudagrass. Crop Sci. 40:1350–1357.

Turgeon, A.J. 1999. Turfgrass management. Prentice Hall, Upper Saddle River, NJ.

Wood, G.M., and A.G. Lwa. 1972. Evaluating Kentucky bluegrass cultivars for wear resistance. p. 65. *In* 1972 Agronomy abstracts. ASA, Madison, WI.

Youngner, V.B. 1961. Accelerated wear tests on turfgrasses. Agron. J. 53:217–218.