

Heritability of Simulated Wear and Traffic Tolerance in Three Fine Fescue Species

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Abstract. In recent years, turfgrass breeders have given increased attention to the development of lower maintenance turfgrass cultivars. Fine fescues (*Festuca* spp.) have been identified as potential candidate species for low-maintenance lawns because of their reduced need for water, mowing, and fertilizer. Unfortunately, these species have some weaknesses that must be improved to facilitate their use; perhaps, the most important of these is tolerance to wear and traffic. For this trait to be improved in new cultivars, there must be sufficient heritable variation available for plant breeders to exploit; however, little is known about the heritability of this complex trait in fine fescue species. Therefore, the objective of this study was to determine the heritability of wear and traffic tolerance in three fine fescue species. Replicated field studies were established in North Brunswick, NJ, and St. Paul, MN, and each included 157 Chewing's fescue (*Festuca rubra* L. subsp. *fallax*), 155 hard fescue (*Festuca brevipilia*), and 149 strong creeping red fescue (*F. rubra* L. subsp. *rubra*) genotypes. Wear tolerance was evaluated in North Brunswick and traffic tolerance was evaluated in St. Paul during 2015 and 2016 using different simulators to determine both plant performance and broad-sense heritability estimates for wear and traffic tolerance. Broad-sense heritability estimates for the three species when calculated on a clonal basis was between 0.69 and 0.82 for wear tolerance in the North Brunswick location and between 0.49 and 0.60 for traffic tolerance in the St. Paul location. On a single-plant basis, broad-sense heritability estimates for the three species were between 0.31 and 0.45 for wear tolerance in the North Brunswick location and 0.09 and 0.12 for traffic tolerance in St. Paul. However, this research does indicate that improvement of wear and traffic tolerance in fine fescues is possible through recurrent breeding methods based on selection of replicated clonally propagated genotypes rather than selection of single individual plants of a population. This was the first study to determine the genetic effects of wear and traffic tolerance in any turfgrass species.

Historically, there has been a high consumer expectation for turfgrass quality and performance in home lawns and landscapes leading to greater fertilizer use and water consumption over the years (Osmond and Hardy, 2004). Interest in conserving natural resources has grown within both the public sector and various political groups (Hamrick, 2016). As restrictions on pesticide and water use on turfgrass landscapes become more

prevalent, there will be increased demand for sustainable solutions. Yue et al. (2017) showed that many consumers are environmentally conscious and would be willing to pay more for low-maintenance grasses, which suggests that turfgrass breeders should devote more resources to the development of low-input turfgrass species.

Fine fescues (*Festuca* spp.) are considered to be among the best low-maintenance cool-season turfgrasses (Bonos and Huff, 2013; Dernoeden et al., 1994) and provide a number of benefits for low-input turf uses. Fine fescues are generally adapted to dry, shady, low pH conditions, and perform best in well drained soils that are not saturated (Bertin et al., 2009; Rummele et al., 2003). Fine fescues can develop dense, fine turf cover requiring low amounts of water, fertilizer, and pesticides.

Three of the fine fescue species most widely used for turfgrass areas are strong

creeping red fescue (*F. rubra* L. subsp. *rubra*), Chewing's fescue [*F. rubra* L. subsp. *fallax* (Thuill.) Nyman], and hard fescue (*F. brevipilia* Tracey). Strong creeping red fescue has a rhizomatous growth habit which aids in recovery when leaf tissue is severely damaged; however, it does not have high levels of drought tolerance when compared with other fescue species such as hard fescue (Smith et al., 2010) and does not produce turf as dense as Chewing's and hard fescues. Strong creeping red fescue is also more susceptible to dollar spot (caused by *Sclerotinia homoeocarpa* F.T. Benn), red thread [caused by *Laetisaria fuciformis* (McAlpine) Burds.] and leaf spot diseases (caused by *Bipolaris* spp.) than Chewing's and hard fescues (Han et al., 2003; Shortell et al., 2005). Chewing's fescue is a bunch-type grass able to withstand lower mowing heights than most other fine fescues, allowing it to be used on golf courses (Watkins et al., 2010). Hard fescue, also a bunch-type grass, has been shown to perform the best out of all the fine fescue species in low-maintenance situations and usually maintains its dark green color longer in drought conditions (Cortese et al., 2011), especially on sandy, well-drained soils. However, in heavier soils, hard fescue can be severely affected by summer patch disease (caused by *Magnaportheopsis poae* Landschoot and N. Jackson).

For low-input turfgrasses to be useful they also need to meet the demands required of turf landscapes, such as recreational uses in home lawns, parks, or athletic fields. This includes the ability to withstand and maintain quality under wear and traffic conditions. Turfgrass traffic tolerance is made up of two components: wear and compaction (soil surface disruption) (Beard, 1973). Wear stress includes tissue tearing, tissue bruising, and tissue removal resulting from horizontal forces, whereas surface soil disruption includes soil compaction and displacement as a result of vertical forces (Vanini et al., 2007). Therefore, it is important to distinguish between the two types of traffic when developing a turfgrass. Most traffic tolerance research in turfgrass systems has focused on higher maintenance situations such as athletic fields (Brosnan et al., 2005; Carroll and Petrovic, 1991; Samaranyake et al., 2008).

Wear or traffic tolerance is a critical need in fine fescue development, especially because fine fescues are known for their poor performance under wear or traffic conditions. They lack traffic tolerance and have very slow recuperative ability compared with other cool-season turfgrasses (Bonos and Huff, 2013). In fact, they are often not used in high traffic areas. This attribute was also found to be the most important to consumers (Yue et al., 2017), so it is important to improve wear/traffic tolerance in fine fescues that otherwise perform at acceptable levels under low maintenance. A few recent studies have shown that fine fescues have the potential to perform well under wear in low-maintenance situations (Cortese et al., 2011; Horgan et al., 2007; Watkins et al., 2010). In addition,

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considerable genetic variability in wear tolerance (Bonos et al., 2001; Cross et al., 2013) or traffic tolerance (Chen et al., 2014) has been observed within the fine leaf fescues under medium maintenance management. However, no research has been conducted to characterize the genetic contribution of wear or traffic tolerance in any turfgrass species.

Understanding the genetic and environmental effects on the phenotypic expression of a trait is useful to develop a breeding strategy to improve the trait. Heritability determines the amount of variability in the phenotype that is due to genetic and environmental factors. Heritability calculations give a measure of the genetic component controlling the phenotype, so the larger the value of heritability, the more quickly and less intensively improvement of a trait can be made (Nyquist and Baker, 1991). Breeders can only manipulate genetic factors and, therefore, a large genetic component is desired over a large environmental component which cannot be influenced by selection. Because heritability estimates are not known for traffic or wear tolerance in any turfgrass species, the objective of this study was to estimate the variance components and broad-sense heritability of wear and traffic tolerance in three of the most widely used fine fescue species.

Materials and Methods

Plant propagation and field trial establishment. Individual genotypes of Cheving's fescue (157 total), hard fescue (155), and strong creeping red fescue (149) were selected from improved breeding material from the turfgrass breeding program at Rutgers University and the New Jersey Agricultural Experiment Station and from several commercial cultivars. Breeding material consisted of individual plants selected from several hundred half-sib progeny turf plots that exhibited superior performance in mowed turf plots; seed used to establish these turf plots originated from numerous isolated polycrosses. Commercial cultivars (four of each of the three fine fescue species) were represented by 12 individual genotypes. In total, one-third of the genotypes in this study originated from commercial cultivars and the remaining were from breeding material. Single tillers were propagated from each genotype and then transplanted to 6.4-by 6.4-cm cell flats filled with BX potting media (Pro-Mix HP; K.C. Shafer, York, PA). After these plants reached the multiple tiller stage (≈ 2 months), each individual plant (clone) was split evenly into two ramets. One ramet of each clone was separated equally into six vegetative replications and maintained under greenhouse conditions for 6 months. The other ramet was sent to the University of Minnesota where it was split into six vegetative replications as mentioned previously. This provided enough plant material to establish two field trials in randomized complete block designs with six

replications at each location (described in the following paragraphs).

Wear tolerance trial. The wear tolerance trial was conducted on a Nixon loam (fine-loamy, mixed, and mesic Typic Hapludults) at the Rutgers Turfgrass Research Facility at Horticultural Farm #2 in North Brunswick, NJ. The trial was seeded to Stellar GLR perennial ryegrass (*Lolium perenne*) maintained with 16–0–8 granular N–P–K fertilizer (2.44 g N/m²) in the fall of 2013. The plants were transplanted into the field within the established ryegrass stand in June 2014 on 38 cm spacing with a tubular turf plugger (Turf-Tec Intl., Tallahassee, FL). Supplemental watering was applied as needed to ensure establishment and avoid severe drought stress. Fungicides (cyazofamid and boscalid) were applied monthly from May to August to preventatively control diseases so that wear responses were not confounded by disease presence. The trial was maintained at 7.62-cm mowing height. Before wear applications, the ryegrass stand and fine fescues were treated with fluazifop herbicide (1000 g a.i./ha) every 6 weeks during the growing season to selectively retard the growth of the perennial ryegrass while at the same time not injuring the fine fescue clones. This allowed the fine fescue clones to grow to their full potential without competition from the perennial ryegrass groundcover because fine fescues are resistant to fluazifop herbicide effects. It also allowed full exposure of the fine fescues to wear/traffic forces. Wear was applied using the Rutgers Wear Simulator (Park et al., 2016), a 0.8-m-wide wear simulator constructed from a modified walk-behind power broom (Sweepster; LLC, Dexter, MI) as described by Bonos et al. (2001) (Fig. 1A). This machine applies wear without causing soil compaction. Treatments consisted of two passes of the wear simulator applied once a week for 6 weeks (12 passes in total) from mid-September through Oct. 2015 and 2016.

Traffic tolerance trial. The traffic tolerance trial was conducted on a Waukegan silt loam (fine-silty over sandy, mixed, and mesic Typic Hapludoll) at the Turfgrass Research, Outreach, and Education Center at the University of Minnesota in St. Paul, MN. The trial was planted into established "Champ GQ" perennial ryegrass, maintained with Sustane 15–3–9 granular N–P–K fertilizer (2.44 g N/m²), irrigated at establishment,

and sprayed with clopyralid herbicide for control of broadleaf weeds. This trial was maintained at 7.62-cm mowing height and treated with fluazifop to retard the ryegrass before traffic treatment, similar to those methods described previously for the wear tolerance trial. Fine fescue clones were trafficked with a custom-built golf cart traffic simulator towed behind a turf utility vehicle which had been used successfully in previous studies to simulate traffic (Horgan et al., 2007; Watkins et al., 2010). The traffic simulator consisted of two 454-kg traffic units on an axle containing five golf cart tires. This simulator imparts both wear and soil compaction to the turf, thus simulating golf cart traffic of two golfers and equipment on pneumatic tires (Alderman, 2016) (Fig. 1B). Traffic was applied 3 d each week beginning mid-September through Oct. 2015 and 2016. Plots received two passes of traffic on each day for a total of six passes of traffic each week (36 passes total).

Wear/traffic assessment. Assessment of wear/traffic quality was made during October/November of 2015 and 2016. Turf quality was based on a 1–10 scale with 10 = no effect and 1 = clone death. The turf quality rating contained elements of density, and bruising or discoloration of plant tissues. A visual guide of the quality rating was developed to allow raters at both locations to have a uniform rating scale. At the North Brunswick location, diameters (centimeters) of clones were taken before and after wear application to evaluate reduction in size of plants due to wear. Diameters were determined by measuring across the clone from edge to edge of the base of the plant using a ruler.

Statistical analysis. Because of differences in the type of wear (New Jersey) or traffic (Minnesota) that was applied, data were analyzed and presented separately for wear and traffic. Data were subjected to analysis of variance (ANOVA). Wear and traffic quality mean separation was achieved by a paired *t* test ($\alpha = 0.05$) with Bonferroni method for correction of multiple comparison. Broad-sense heritability for wear or traffic tolerance was determined by means of variance components calculated from expected means squares from the ANOVA. Data from each year were analyzed separately using the *lme4* version 1.1–12 in *R* with all sources of variation considered as random effects. Wear (and traffic) performance was

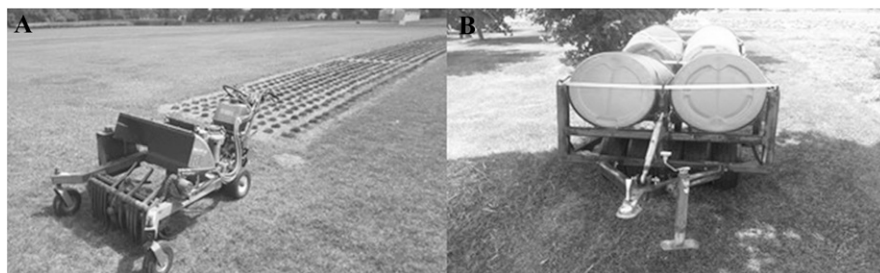


Fig. 1. Comparisons of wear [New Jersey (A)] and traffic [Minnesota (B)] simulators used to evaluate fine fescue species for wear and traffic tolerance.

analyzed as a randomized complete block for 1 year or split plot in time for 2 years. Variance components were obtained by a model summary function in *lme4* package. Estimates of heritability were determined and their SE were determined using a simulation method by refitting the model 1000 times using parametric bootstrap samples by applying the *simulate* and *refit* functions of the *lme4* package to estimate the distribution of heritability (Yousef et al., 2015).

Broad-sense heritability was calculated on a clonal mean basis (H_c) and on a single-plant basis (H_{sp}) using the following formula for traits evaluated on

$$\text{one date : } H_c = \frac{\sigma_g^2}{\sigma_p^2} = \frac{\sigma_g^2}{\sigma_g^2 + \frac{\sigma_e^2}{R}}$$

and on multiple dates :

$$H_c = \frac{\sigma_g^2}{\sigma_p^2} = \frac{\sigma_g^2}{\sigma_g^2 + \frac{\sigma_{dg}^2}{D} + \frac{\sigma_{gr}^2}{R} + \frac{\sigma_e^2}{RD}}$$

$$H_{sp} = \frac{\sigma_g^2}{\sigma_g^2 + \sigma_{dg}^2 + \sigma_{gr}^2 + \sigma_e^2}$$

where σ_g^2 equals the variance of genotypes, σ_p^2 equals the phenotypic variance, σ_{dg}^2 equals the variance of dates \times genotypes, σ_{gr}^2 equals the variance of genotypes \times replications, σ_e^2 equals the error variance, D equals the number of dates, and R equals the number of replications (Yousef et al., 2015).

Results and Discussion

Species response to wear. At North Brunswick, hard fescue received the highest average wear quality rating of (4.1 and 4.9, for 2015 and 2016, respectively), followed by Chewing's fescue (4.0 and 4.6), and strong creeping red fescue (4.0 and 4.3) (Table 1). These results were similar to those found in other studies when full turf plots were worn (Cross et al., 2013; Smith et al., 2010), but contrasted with Bonos et al. (2001) who reported that strong creeping red fescues performed better than hard fescue under simulated wear. Cross et al. (2013) suggested that change in the ranking of species was due to increased breeding and selection work performed with hard and Chewing's fescue during the early 2000s. In our trial, posttreatment quality ratings were higher in 2016 than 2015 and had a more uniform distribution (data not shown). In addition, there were no significant differences between species in 2015 but in 2016, hard fescue was greater than Chewing's fescue which was greater than strong creeping red fescue. This would indicate that plants that were more mature and larger in size (Table 2) generated a greater resolution in wear quality within the species and suggesting that evaluation of fine fescues on mature plants is preferable. Indeed, studies have shown that different morphological states (Dowgielwicz, 2009) and physiological

Table 1. Wear and traffic quality means of fine fescues in New Brunswick, NJ, and St. Paul, MN, in 2015 and 2016 post wear and application.

Species	Wear quality 2015 ^z		Wear quality 2016 ^z	
	New Jersey			
Hard	4.1	a	4.9	a
Chewing's	4.0	a	4.6	b
Strong creeping red	4.0	a	4.3	c
Species	Traffic quality 2015 ^z		Traffic quality 2016 ^z	
	Minnesota			
Hard	4.5	a	4.7	b
Chewing's	4.2	c	4.8	a
Strong creeping red	4.3	b	4.6	b

^zAny two means within a column not followed by the same letter are significantly different at $P \leq 0.05$.

Table 2. Diameters of fine fescues in New Brunswick, NJ, in 2015 and 2016 prior and post wear application with net change.

Species	Pre-wear diameter (cm)		Post-wear diameter (cm)		Change (\pm cm)
	2015				
Hard	12.7		11.7		-1.0
Chewing's	15.0		15.0		-1.3
Strong creeping red	15.3		14.3		-1.0
2016					
Hard	23.1		17.6		-5.5
Chewing's	24.8		20.8		-4.0
Strong creeping red	26.4		20.9		-5.4

changes due to season of wear (Chen et al., 2016; Murphy and Ebdon, 2013; Park et al., 2010) can cause changes in wear tolerance of grasses. This study was conducted in the fall; the fall season was chosen for this study because Chen et al. (2016) showed that fine fescues subjected to traffic in the fall showed increased leaf bruising or discoloration of leaf tissue. The response of fine fescues to wear in different seasons could change evaluation parameters, species differences, and the effectiveness of selection.

Species response to traffic. In St. Paul, the average traffic quality ratings for 2015 and 2016 were as follows: hard fescue received the highest average rating (4.5, 4.7), followed by strong creeping red fescue (4.3, 4.6), and Chewing's fescue (4.2, 4.8) (Table 1). Although, there was significance between the species for traffic tolerance in Minnesota, it was not consistent between years and in fact, Chewing's fescue was significantly better than hard fescue in 2016, whereas strong creeping red fescue had the lowest traffic tolerance. Not surprisingly, we found very poor correlation for entry performance between the two sites (r -values = 0.24421; $P = 0.001$), indicating it may be difficult to identify clones with both wear and traffic tolerance. It is realized that growing environment may also play a role in the species and clone performance at the different locations.

Other researchers have found that cultivars performed differently for traffic tolerance based on location (Murphy and Ebdon, 2013; NTEP, 2009a, 2009b). The two machines used in our study applied traffic/wear to the turf in different ways. Brosnan et al. (2005) proposed that wear differences for an entry could be due to methods used to apply wear (i.e., simulator), duration of wear, and the intensity of wear. Greater traffic intensity has been shown to be required to change the

ranking between species more so than between cultivars of the same species (Bourgoin and Mansat, 1981). This makes selection for traffic and wear tolerance more difficult as it is affected by a combination of methods used to impose wear, the evaluation procedure, and the wear intensity (Murphy and Ebdon, 2013). In the case of this study, as with all heritability studies, the heritability estimates can only be truly applied to the population and study the estimates were derived from. However, the estimates can give researchers an idea as how to implement the knowledge gained and methods that might be useful to improve selection for wear and traffic tolerance.

Broad-sense heritability. Moderate to high broad-sense heritability estimates (0.69–0.82) for wear tolerance in fine fescues were calculated from the North Brunswick location (Table 3). Heritability estimates of wear tolerance on a clonal basis were 0.69 ± 0.04 for hard fescue, 0.73 ± 0.05 for Chewing's fescue, and 0.82 ± 0.03 for strong creeping red fescue (Table 3). On a single-plant basis, the estimates were 0.35 for hard fescue, 0.31 for Chewing's fescue, and 0.45 for strong creeping red fescue. The broad-sense heritability estimates for traffic tolerance in St. Paul were considerably lower (0.49–0.60) (Table 4). Heritability estimates for traffic tolerance on a clonal basis were 0.49 ± 0.09 for hard fescue, 0.57 ± 0.07 for Chewing's fescue, and 0.60 ± 0.06 for strong creeping red fescue. On a single-plant basis, the estimates were 0.09 for hard fescue, 0.12 for Chewing's fescue, and 0.11 for strong creeping red fescue.

Heritability estimates for wear tolerance were higher and less variable than the heritability estimates for traffic tolerance (Table 5). Data for wear tolerance from the North Brunswick location followed a more standard

Table 3. Analysis of variance (ANOVA) and broad-sense heritability estimates (H) of wear quality of fine fescue entries evaluated in North Brunswick, NJ, in 2015 and 2016.

Source	df	MS	F value	P > F	Variance
Hard					
Clone	157	13.11	16.3557	<0.0001	0.76
Rep	5	10.31	12.8579	<0.0001	0.03
Year	1	841.80	1049.9255	<0.0001	0.90
Clone × rep	768	1.02	1.2696	<0.0001	0.53
Clone × year	155	3.94	4.9099	<0.0001	0.53
Residuals	1207	0.80			0.80
$H_c = 0.69 H_{sp} = 0.35$					
Chewing's					
Clone	159	8.13	8.8323	<0.0001	0.50
Rep	5	23.60	14.7873	<0.0001	0.04
Year	1	214.50	233.1647	<0.0001	0.23
Clone × year	157	2.21	2.3998	<0.0001	0.22
Residuals	1559	0.92			0.92
$H_c = 0.73 H_{sp} = 0.31$					
Strong creeping red					
Clone	162	9.43	17.0675	<0.0001	0.69
Rep	5	2.30	4.1689	<0.0001	0.01
Year	1	39.62	71.6965	<0.0001	0.04
Clone × rep	728	0.74	1.3363	0.0119	0.09
Clone × year	149	1.56	2.8281	<0.0001	0.18
Residuals	733	0.55			0.55
$H_c = 0.82 H_{sp} = 0.45$					

H_c = broad-sense heritability on clonal basis; H_{sp} = broad-sense heritability on single-plant basis.

Table 4. Analysis of variance (ANOVA) and broad-sense heritability estimates (H) of traffic quality of fine fescue entries evaluated in St. Paul, MN, in 2015 and 2016.

Source	df	MS	F value	P > F	Variance
Hard					
Clone	158	1.39	2.4529	<0.0001	0.05
Rep	5	7.44	13.1764	<0.0001	0.02
Year	1	18.56	32.8715	<0.0001	0.02
Clone × year	158	0.74	1.3053	0.008	0.03
Residuals	1522	0.56			0.57
$H_c = 0.49 H_{sp} = 0.09$					
Chewing's					
Clone	156	1.61	3.0826	<0.0001	0.08
Rep	5	9.24	17.7249	<0.0001	0.03
Year	1	142.13	272.6123	<0.0001	0.15
Clone × year	156	0.69	1.3313	0.006	0.03
Residuals	1512	0.52			0.52
$H_c = 0.57 H_{sp} = 0.12$					
Strong creeping red					
Clone	150	1.30	2.4712	<0.0001	0.07
Rep	5	11.05	20.9483	<0.0001	0.04
Year	1	36.32	68.8390	<0.0001	0.04
Residuals	1578	0.53			0.52
$H_c = 0.60 H_{sp} = 0.11$					

H_c = broad-sense heritability on clonal basis; H_{sp} = broad-sense heritability on single-plant basis.

Table 5. Broad-sense heritability estimates (H) of wear (NJ) and traffic (MN) quality of all species and locations.

Species	Location	Clone	Single plant
Chewing's	New Jersey	0.73 ± 0.05	0.31
Hard	New Jersey	0.69 ± 0.04	0.35
Strong creeping red	New Jersey	0.82 ± 0.03	0.45
Chewing's	Minnesota	0.57 ± 0.07	0.12
Hard	Minnesota	0.49 ± 0.09	0.09
Strong creeping red	Minnesota	0.60 ± 0.06	0.11

bell curve than data from the traffic tolerance trial at St. Paul which was less evenly distributed. This could have been due to variability in the different machines used to impose wear and traffic as well as the soil differences throughout the field that may have affected the amount of soil compaction and related stresses that the traffic simulator may have caused.

Genetic improvement through breeding has made an impact on fine fescue performance, but it seems to have less of an impact than in other turf species. This may be due to less breeding effort given to the fine fescues but more likely by the complexity of the genomes present in fine fescues: hard and Chewing's fescue are hexaploids ($2n = 6x = 42$), whereas the strong creeping red fescues are typically

octoploids ($2n = 8x = 56$) (Huff and Palazzo, 1998).

This is the first report of heritability estimates for wear or traffic tolerance in any turfgrass species. The heritability estimates reported here suggest that selection for wear tolerance in fine fescues is possible as the variation observed was mainly due to genetic effects (Tables 3 and 4). This research supports the findings of Cross et al. (2013) who showed that wear tolerance had increased in a fine fescue breeding program after years of general quality selection. The low single-plant heritability we found suggests that selection for wear tolerance should be performed on replicated vegetative clones to account for the environmental variation associated with wear tolerance. For species such as fine fescues that can be vegetatively propagated, clonal replications are more simply obtained compared with species for which replicated progeny must be used, but breeders will still be limited by field space and time constraints to evaluate replications. This is even more important for selection for traffic tolerance. Heritability estimates were relatively low for traffic tolerance (0.49–0.60), indicating that the environment has a strong effect on the observed variation. There are more factors involved in traffic than in wear, so the added components (i.e., associated soil compaction) could be the cause of the lower heritability estimates observed. Some progress may occur, but the improvements may take longer and environmental effects should be controlled as much as possible to increase traffic tolerance among fine fescues. Interestingly, although regardless of whether wear or traffic was applied, the strong creeping red fescues exhibited the highest heritability estimates, indicating that selection would be most effective in this species. This is important because strong creeping red fescues were shown in both locations (Table 1) to have the lowest tolerance to both wear and traffic; in essence, selection would be most effective where progress is needed most.

For a trait as complex as wear or traffic, the heritability estimates are in a range similar to estimates found for disease resistance in other turfgrasses, although lower than estimates for dollar spot in creeping bentgrass (*Agrostis stolonifera*) ($H = 0.90$) (Bonos et al., 2003) and gray leaf spot (*Magnaporthe grisea*) in perennial ryegrass ($H = 0.92$) (Bonos et al., 2004) which are under strong genetic control. Nevertheless, given the complexity of wear and traffic tolerance, this research is promising to breeders in that improvements should be possible for wear and traffic tolerance in the fine fescues.

Conclusions

Although fine fescues presently make up a small percentage of the overall turfgrass seed industry (USDA, 2012), as environmental stewardship increases, and natural resources become scarcer, these low-input

species will see an increasing role in sustainable turfgrass management. Through increased breeding efforts and the continued increase in knowledge of the inheritance of important traits in these grasses, the usefulness of these species in the industry will improve. Interestingly, our findings as shown by the variances obtained for “clone” (Tables 3 and 4) illustrate the presence of a significant amount of genetic variation among different fine fescue genotypes for wear tolerance (Table 3) and somewhat less for traffic tolerance (Table 4). Moderate to high wear heritability estimates indicate that a phenotypic recurrent selection program using replicated genotypes should be an effective tool in breeding for wear tolerance in fine fescue. Traffic tolerance showed lower heritability estimates and will have less response to breeding efforts. Traffic type and machinery used may influence selection, and environmental conditions will need to be closely examined to determine the proper techniques to develop cultivars that have more wear and traffic tolerance and can be used in a wider range of applications and environments. From the results presented in this study, the use of a wear simulator reduces variation involved with selection and may increase the improvement of the fine fescues as compared with a simulator which imparts both aspects of traffic.

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