CHARACTERISTICS IN DIVERSE WEAR TOLERANT GENOTYPES OF KENTUCKY BLUEGRASS

A Thesis Presented

by

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Submitted to the Graduate School of the
University of Massachusetts Amherst in partial fulfillment
of the requirements for the degree of

MASTER OF SCIENCE

September 2004

Plant and Soil Science

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DEDICATION

I would like to dedicate this to the love of my life, Kate Gause. I need to recognize my parents as well. They were integral in making this dream a reality. I would also like to thank my prestigious committee members for their constant guidance. Lastly, I would like to thank my entire turfgrass network. Without you, I would not be where I am today.

ACKNOWLEDGMENTS

I would like to acknowledge the New England Regional Turfgrass Foundation (NRTF), as well as the University of Massachusetts Amherst Department of Plant and Soil Sciences, for funding this research. I would also like to acknowledge Mr. Kevin Morris from the National Turfgrass Evaluation Program (NTEP). Mr. Morris was essential in obtaining the plant materials needed for this research.

I would like to thank my committee members, Drs. Scott Ebdon, William Dest, Robert Bernatzky, and Andrew McNitt. Dr. Scott Ebdon, the chair of my committee, has provided endless guidance during my time at the University of Massachusetts. He has helped to further my abilities as a researcher and a student. I do not know where I would be without his guidance.

I would also like to thank the multiple University of Massachusetts faculty, staff personnel, and graduate students that provided assistance in completing this research project. Those people include (in no particular order) Dr. Prasanta Bhowmik, Mr. Neal Woodard, Mr. Tom Beauchesne, Mr. Jeff Anderson, Mr. Tom Griffin, Mr. Dave Webster, Ms. Pat Killay, as well as Ms. Beth Johnson and the entire Environmental Soil Chemistry research group. I would also like to thank Montreal resident Ms. Marcy Gibson, who found my stolen data files and lab notebook and returned them to me.

ABSTRACT

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SEPTEMBER 2004

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A turfgrass' ability to withstand wear stress is an important factor in species selection. Evaluations of Kentucky bluegrass (*Poa pratensis* L.) wear tolerance have been conducted in the past, yet many inconsistencies are found in the results. Research investigating the mechanisms of wear tolerance within species is also limited. This information would be valuable in selecting wear tolerant genotypes. To that end, wear treatments were applied to the 2000 National Turfgrass Evaluation Program (NTEP) Kentucky bluegrass field plots in the fall of 2002 and 2003. Treatments were applied using a differential slip-wear apparatus and plots were visually rated for wear injury. The ten most wear tolerant and intolerant genotypes were selected from 173 NTEP entries for further evaluation. Eleven characteristics were measured in 2003 and 2004 comparing tolerant and intolerant genotypes in both field plots and as greenhouse grown space plants. Characteristics included tiller density, shoot fresh weight and dry weight, moisture content and relative turgidity, number of leaves per shoot, leaf width, leaf strength, leaf angle, leaf cell wall constituents [total cell wall content, hemicellulose, and lignocellulose]. Significant differences were found between tolerant and intolerant

groupings. Tolerant genotypes were associated with a more vertical leaf angle, greater total cell wall content, and a lower moisture content and relative turgidity.

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PREFACE

The first chapter of this document will be a review of current literature relevant to Kentucky bluegrass wear tolerance and the mechanisms involved in wear tolerance. The second chapter will discuss the selection of wear tolerant and intolerant genotypes using a wear simulator. The third chapter will discuss evaluations of the specific plant characteristics (mechanisms) involved in Kentucky bluegrass wear tolerance.

CHAPTER 1

LITERATURE REVIEW AND JUSTIFICATION

Introduction

Kentucky bluegrass (*Poa pratensis* L.) is the most widely used cool-season turfgrass in the United States (Turgeon, 1999). There is a considerable interest in developing Kentucky bluegrass genotypes with improved turfgrass performance to match specific uses. This is evidenced by the two most recent National Turfgrass Evaluation Program (NTEP) Kentucky bluegrass trials. The 1993 NTEP trial contains 125 different genotype selections, while the 2000 NTEP trial increased the number of entries to include 173 selections (USDA, 1993, 2000).

One of the reasons for this growing interest in the development of Kentucky bluegrass genotypes is their repeated use in the sports turf industry. Along with perennial ryegrass (*Lolium perenne* L.), Kentucky bluegrass is cited by Puhalla (1999) as the most commonly used turfgrass species in athletic fields grown in cool-season climates. Kentucky bluegrass has a rhizomatous growth habit that allows it to form stronger, more durable sod than other cool-season species (Beard, 1973). Also, like other species such as perennial ryegrass, when Kentucky bluegrass is grown under optimum conditions it provides a dense cover and sufficient shoot biomass to give it resiliency, which is essential in providing a “cushioning effect” needed to protect plant crown tissues as well as athletes from injury (Carrow and Wiecko, 1989).

The most frequent and damaging stress to turfgrass plants in a sports turf situation is traffic (Minner et al., 1993). Traffic can be broken down into two separate stresses, wear and soil compaction (Carrow and Petrovic, 1992). Minner et al. (1993) explained that wear stress affects the turfgrass plants, while compaction alters the physical properties of the soil. These effects need to be differentiated if the mechanisms of wear tolerance are to be understood.

Carrow and Petrovic (1992) defined wear as an injury of tissues from pressure, tearing or scuffing. Beard et al. (1974) defined wear injury as the immediate result of crushing, tearing, and shearing actions of foot and vehicular traffic. The effects of wear from both vehicular and foot traffic cause injury to the shoots and foliage of the plant. This injury may include chlorophyll degradation, and thus a subsequent reduction in photosynthesis, which will eventually give way to a weaker plant (Trenholm et al., 2000). This weakening of the turfgrass stand can reduce its function and quality (Bonos et al., 2001), which can lead to secondary problems such as weed encroachment and fungal invasion.

Wear Assessment

The effects of wear injury are immediate and must be assessed before the turfgrass begins to recuperate, as those made after are a measure of the turfgrass' recuperative potential (Canaway, 1983). This differs from soil compaction, which is characterized as a chronic soil problem with lingering effects that must be evaluated over time (Canaway, 1983).

Shearman and Beard (1975a) were the first to measure differences in interspecies wear tolerance. They evaluated differences in wear tolerance (both foot and vehicular) using genotypes from seven turfgrass species. The species evaluated included 'Manhattan' perennial ryegrass, 'Merion' Kentucky bluegrass, 'Kentucky 31' tall fescue (*Festuca arundinacea* Schreb.), Italian ryegrass (*Lolium multiflorum* Lam.), 'Pennlawn' red fescue (*Festuca rubra* L.), 'Cascade' chewings fescue (*Festuca rubra commutata* L.), and rough bluegrass (*Poa trivialis* L.). The parameters used to evaluate wear tolerance included an overall visual rating of the foliar injury from the applied wear stress, percent total cell wall content, percent verdure (shoot biomass), and chlorophyll content remaining after the wear stress had been imposed. Through this interspecies investigation Shearman and Beard (1975a) found a significant difference between the seven different species in their tolerance to wear stress for all characteristics evaluated. Furthermore, they found perennial ryegrass to be the most wear tolerant species and rough bluegrass to be the least tolerant species of those evaluated. Kentucky bluegrass ranked second to perennial ryegrass in terms of overall wear tolerance. Shearman and Beard (1975a) concluded that all characteristics were satisfactory measures in assessing wear tolerance.

Minner et al. (1993) investigated traffic tolerance among different turfgrass species. Traffic can be defined as the effects of wear stress and soil compaction in combination with one another (Beard, 1973). Thirty traffic treatments were applied weekly to the 1980 and 1985 NTEP Kentucky bluegrass trials, the 1987 NTEP tall fescue trial, and the 1986 perennial ryegrass trial using a Brinkman Traffic Simulator (Cockerham et al., 1990). The effects of traffic were assessed by visually estimating percent turfgrass cover and turfgrass quality on a scale of 1 to 10, with a score of 1 representing the lowest turfgrass quality and a score of 10 indicating the highest turfgrass quality. Turfgrass color and texture were not considered as a component of turfgrass quality in this study (Minner et al, 1993). Minner et al. (1993) found a wide range of traffic tolerance among genotypes within the same species, with the greatest difference being between genotypes of Kentucky bluegrass. The genotypes, 'Sydsport,' 'Trenton,' 'Wabash,' 'Glade,' and 'A-34' ranked "excellent" in terms of traffic tolerance in both the 1980 and 1985 NTEP trials. Minner et al. (1993) suggested that some genotypes of Kentucky bluegrass may possess mechanisms (characteristics) that make them more tolerant to traffic stress.

Bonos et al. (2001) conducted an interspecies analysis of wear tolerance using three different turfgrass species. Bonos et al. (2001) investigated 54 Kentucky bluegrass genotypes, 96 perennial ryegrass genotypes, and 32 fine fescue genotypes. Kentucky bluegrass genotypes received daily wear treatments for an eight-day period in 1998 and a ten-day period in 1999. A wear treatment consisted of making two passes with a wear simulator derived from a M24C5A Sweepster (Meyer et al., 1997). Wear tolerance was assessed by visually rating turfgrass quality on a 1 to 9 scale, with a score of 9 representing the highest level of wear tolerance (highest turf quality) and a score of 1 indicating the lowest level of wear tolerance (poorest turf quality). They found significant differences between genotypes of all species. Among Kentucky bluegrass genotypes, 'Princeton-104,' 'Princeton -105,' 'Unique,' and 'Eclipse' were reported to have good to excellent wear tolerance (turfgrass quality greater than or equal to 6.0, post wear).

Considerable differences exist between studies in wear and traffic tolerance among the same Kentucky bluegrass selections. For example, Minner et al. (1993) ranked 'Sydsport,' 'Trenton,' 'Wabash,' 'Glade,' and 'A-34' as excellent traffic tolerant genotypes, while Bonos et al. (2001) found 'Trenton' and 'Wabash' to be very poor in terms of wear tolerance. Minner et al. (1993) found the 'Amazon' genotype to be poor in terms of traffic tolerance, while Bonos et al. (2001) found it to have very good wear tolerance. This contradiction may in part be due to the differences that were present across the two sites. For example, the level of thatch accumulation, as well as soil moisture content, may affect the performance of certain genotypes under wear stress. Variations of that nature have resulted in differing levels of turfgrass wear tolerance (Shearman, 1988). Furthermore, the visual assessments of Bonos et al. (2001) were made after a short duration of exposure to wear stress, while those made by Minner et al. (1993) were made following long term exposure to traffic stress (wear and soil compaction). Thus, turfgrass recuperative potential may have been expressed and may have caused variation in genotype performance. Differing intensities of wear (traffic) stress, as well as differences among wear simulators, may have also served as significant sources of variation in genotype performance.

Wear Mechanisms

Various anatomical and morphological plant characteristics have been suggested to correspond with turfgrass wear tolerance. Genotypes with superior wear tolerance have been associated with plant characteristics including total cell wall content, schlerenchyma fiber quantity, leaf width, leaf angle, shoot density, and root density (Shearman and Beard, 1975b). Research (Shearman and Beard, 1975b, 1975c; Trenholm et al., 2000) has verified the associations these characteristics have with turfgrass wear tolerance.

Cell walls are an amorphous matrix consisting of cellulose, hemicellulose, and lignin (Taiz et al., 1972). Cellulose is a tightly packed group of linear polysaccharide chains that give plant tissues a high tensile strength (Taiz et al., 1972). This suggests plants having higher percentages of cellulose will be more tolerant to wear stress. Hemicelluloses are a heterogeneous group of polysaccharides that bind to cellulose to further strengthen cell walls (Taiz et al., 1972). Lignin is a highly branched polymer of phenylpropanoid groups that possesses high mechanical rigidity and therefore serves to strengthen both stems and vascular tissues (Taiz et al., 1972). Due to its physical toughness, it deters feeding by animals (Van Soest, 1994), and therefore may play a role in wear tolerance.

Shearman and Beard (1975b) focused on the constituents of cell walls as a means of explaining turfgrass wear tolerance. Shearman and Beard (1975b) evaluated the anatomical characteristics that were unique to the cell walls of wear tolerant species. Evaluation parameters included total cell wall content, lignocellulose content, hemicellulose content, and lignin content on a mg/dm^2 basis. Total cell wall content can be described as the relationship between cellulose, hemicellulose, lignin, and lignocellulose (lignin bound to cellulose). Shearman and Beard (1975b) selected the same seven species listed in (Shearman and Beard, 1975a) for analysis in both the field and the growth chamber. Shearman and Beard (1975b) found that among wear tolerant species, no single cell wall constituent served as a significant indicator of wear tolerance. They did report that the most significant indicator was total cell wall content. They found that over 96% of the variation in wear tolerance among species evaluated was due to the combined effects of these cell wall constituents, what can be termed total cell wall content (Shearman and Beard, 1975b).

Esau (1965) discussed the importance of schlerenchyma fibers as a means of mechanical protection for plants. Schlerenchyma fibers main function in plants is to provide mechanical support, particularly to regions of the plant that have ceased elongating (Taiz et al., 1972). Taiz et al., (1972) stated that schlerenchyma fibers enable plants to withstand pressure from outside sources (weight, bending, crushing) without damaging thinner walled plant cells. This provides additional evidence that certain cell wall constituents may be associated with wear tolerant species.

Shearman and Beard (1975c) conducted a third inter-species analysis, examining the anatomical and morphological characteristics of turfgrasses subjected to wear stress. Shearman and Beard (1975b) selected the same seven species listed in (Shearman and Beard, 1975a) for this evaluation. After measuring plant characteristics including verdure (shoot biomass), load bearing capacity, leaf blade tensile strength (rigidity), and relative turgidity, differences were found. Species varied among the different characteristics, yet only the combined effects of leaf tensile strength and leaf width, accounted for a significant amount of the variation (97%) in interspecies wear tolerance.

Shearman and Beard (1975c) examined the association between the relative amounts of schlerenchyma cells present and wear tolerance. Kentucky 31 tall fescue and rough bluegrass were the two species that were selected for anatomical analysis. Kentucky 31 tall fescue represented a wear tolerant species and rough bluegrass represented a wear intolerant species. Leaf blade cross sections of each species were taken and their constituents were analyzed. It was found that Kentucky 31 tall fescue contained greater amounts of schlerenchyma cells than the rough bluegrass (18.6 % and 8.9 %, respectively).

Trenholm et al. (2000) conducted an intraspecies analysis of wear tolerance among seashore paspalum (*Paspalum vaginatum* Swartz.) genotypes as well as hybrid bermudagrass genotypes (*Cynodon dactylon* L. X C. *transvaalensis* Burtt-Davy). Wear stress was applied (90 passes) in a strip within replicates, using a differential slip wear device. This study assessed cell wall constituents as indicators of wear tolerance, while also evaluating other plant characteristics including, leaf strength, plant moisture content, shoot density, and verdure. Trenholm et al. (2000) found total cell wall content of the leaf to be the most important mechanism in determining wear tolerance within seashore paspalum genotypes. Unlike Shearman and Beard (1975b), wear tolerance decreased as leaf total cell wall content increased. Trenholm et al. (2000) explain that the contradiction was due to the fact that increased total cell wall content in the leaves gave rise to increased leaf strength. This subsequently resulted in a decrease in leaf elasticity. This hypothesized that this lack of elasticity lead to a reduction in wear tolerance (Trenholm et al., 2000). Trenholm et al. (2000) further observed that a higher plant moisture content was associated with increased wear tolerance within seashore paspalum genotypes. This is also in sharp contrast to (Shearman and Beard, 1975c) who found no significant correlation between plant moisture content and wear tolerance.

Similar to Beard (1973), Trenholm et al. (2000) reported that greater shoot densities were associated with increased wear tolerance within seashore paspalum genotypes. Trenholm et al. (2000) hypothesized two reasons why this occurred. First, increased shoot density provided more tissue available to absorb the impact of the injury caused by wear, and the second was that increased shoot densities lead to the presence of more meristematic growth points. This increase would then allow for increased growth potential, thus allowing the plant to deal with the stress more efficiently (Trenholm et. al 2000).

Among bermudagrass genotypes Trenholm et al. (2000) reported that higher plant moisture content and higher shoot densities were associated with superior wear tolerance. This, the same as within the seashore paspalum genotypes, is in contradiction to the findings of Shearman and Beard (1975c). However, Trenholm et al. (2000) did report that reduced cellulose content and increased lignin content were associated with increased wear tolerance. These findings agree with Shearman and Beard (1975c) but differ from those reported by Trenholm et al. (2000) for seashore paspalum genotypes. Increased cellulose and lignin content are plant characteristics that may serve to increase tissue rigidity (Beard, 1973). Within the seashore paspalum genotypes of this same experiment, Trenholm et al. (2000) found decreased tissue rigidity to be associated with increased wear tolerance.

Confounding Issues

Beard (1973) first attempted to identify the anatomical and morphological characteristics of wear tolerant species, but the data are limited to interspecific wear tolerance. Anatomical and morphological characteristics correlating with wear tolerance across different species may not correlate to wear tolerance within a particular species.

Minner et al. (1993) objectives were to identify traffic tolerant genotypes and thus Minner et. al (1993) did not attempt to separate out the effects from wear from the effects of soil compaction. Wear (traffic) treatments were imposed over long periods of time, which may have lead to the selection of plants resistant to soil compaction, or a combination of wear and soil compaction. There is a need to determine anatomical and morphological indicators of wear tolerance without confounding the experiment with soil compaction.

Research (Minner et al, 1993; Bonos et al., 2001) has shown inconsistencies in characterizing genotypes as wear tolerant or intolerant. The data reported by Bonos et al. (2001) showed that results varied in wear tolerance data from different regions. Theoretically, evaluations conducted in Iowa (Minner et al., 1993) and New Jersey (Bonos et al., 2001) should have classified genotypes as similar, yet this was not the case (Bonos et al., 2001).

Discrepancies are also present in research examining the mechanisms involved in wear tolerance. As previously discussed, Trenholm et al. (2000) found lower leaf total cell wall content to be associated with increased wear tolerance within seashore paspalum genotypes. This contradicts earlier work conducted by Shearman and Beard (1975b), which reported that increased leaf total cell wall content was associated with improved wear tolerance. Trenholm et al. (2000) also reported low leaf tensile strength in seashore paspalum genotypes to be associated with increased wear tolerance. This too contradicts Shearman and Beard's (1975b) earlier work, which found superior wear tolerance to be associated with an increase in leaf tensile strength. The findings of Trenholm et al. (2000) do correlate with those of Sun and Liddle (1993) who also found stem flexibility to be more important in imparting resistance to trampling than high leaf tensile strength.

Trenholm et al. (2000) also identified inconsistencies within their own data. While reduced leaf strength and less rigid leaf and stem cells served to increase wear tolerance in seashore paspalum genotypes, bermudagrass genotypes exhibited contradictory results. Increased wear tolerance within bermudagrass genotypes was associated with high stem moisture content and reduced levels of stem cellulose. Also, higher tissue rigidity (leaf tensile strength) from leaf lignin as well as leaf and stem lignocellulose content improved wear tolerance in bermudagrass genotypes. The combination of these mechanisms will serve to decrease the overall "elasticity" of the plant (Beard, 1973). This differs greatly from the seashore paspalum genotypes which demonstrated a correlation between greater tissue elasticity (less rigid leaf blades) and increased wear tolerance. Trenholm et al. (2000) concluded that these differences between species imply that to accurately screen for wear tolerance mechanisms, anatomical and morphological factors must be determined at the intraspecies level.

The discrepancies in genotype responses to wear stress may also be due in part to the fact that there are many different machines that can be used to simulate this stress. Many wear simulators have been developed, one of the earliest was described by Perry (1958). A commonly used component of a number of wear simulators has been the studded roller (e.g. van der Horst 1970), Vos (1972), Shildrick (1971, 1973), and Dahlsson (1973). One advantage with the studded roller is that a large number of experimental plots can be treated with a uniform level of wear relatively quickly. (Canaway, 1982) Also, the entire plot can be treated with a studded roller, unlike wear simulators that rotate around a fixed axis (Younger, 1961; Shearman et. al, 1974). Wear simulators of that nature are impractical as they do not treat the entire plot (wear is applied in two bands), and they cannot be used to treat large numbers of plots at the same time. The principal drawback with using studded rollers is that they do not reproduce the damaging horizontal forces exerted by actual wear (Canaway, 1982). Differential slip wear simulators, such as the D.S.1 developed by P.M. Canaway (1976), impose both vertical and horizontal forces to the foliage. The number of studs contacting the ground at any one time determines the vertical force imposed by the D.S.1 (Canaway, 1976). Horizontal forces are produced due to the fact that two sets of rotors were coupled together by the belt drive and unequal sized pulleys, and when in operation they rotate at different speeds (Canaway, 1982).

Justification

Inconsistencies are present in previous wear tolerance research. Variations in genotype performance occur often. This variation in performance may arise for a number of reasons including differences in environment and experimental methodology (i.e. wear simulators, rating scale). Also, many of the Kentucky bluegrass genotypes that are currently used in the sports turf industry, such as 'Bronco' and 'Princeton 105,' were developed since the conclusion of previous research trials (Minner et al, 1993). There is a need for ongoing assessment of wear tolerance of newer Kentucky bluegrass genotypes, which have been introduced into the market place since the conclusion of the 1995 NTEP Kentucky bluegrass test (USDA, 2000). It is also important to recognize that much of the previous research cited (Bonos et al., 2001; Minner et al., 1993) did not address specific wear mechanisms, but was principally interested in visually assessing differences in wear (traffic) tolerance among genotypes.

An intraspecies analysis of differences in wear tolerance of cool-season species would be of great value to breeders in improving wear tolerance in cool-season turfgrass performance. Kentucky bluegrass is used extensively in the sports turf industry, one in which wear is a predominate stress. To that end, specific wear mechanisms need to be identified that are responsible for enhanced wear tolerance, which in turn can be used by breeders to screen for superior wear tolerance in Kentucky bluegrass genotypes.

Objectives

The objectives of this research are (i) to provide an intraspecies analysis of wear tolerance among Kentucky bluegrass genotypes, and (ii) to determine specific anatomical and morphological characteristics that may be useful in identifying genotypes tolerant to wear stress. This will aid breeders in developing more wear tolerant Kentucky bluegrass genotypes for use in intensely trafficked turfgrass stands.

CHAPTER 2

SELECTING WEAR TOLERANT AND INTOLERANT GENOTYPES

Abstract

A turfgrass' ability to withstand a wear stress is an important factor in species selection. Shear strength (traction) has also been thought to be possibly related to wear tolerance. Evaluations of Kentucky bluegrass (*Poa pratensis* L.) wear tolerance and shear strength (traction) have been conducted in the past, yet many inconsistencies are found in the results (Bonos, 2001; Minner et al., 1993). To that end, wear treatments were applied to the 2000 National Turfgrass Evaluation Program (NTEP) Kentucky bluegrass field plots in the fall of 2002 and 2003. Treatments were applied using a differential slip-wear apparatus. Field plots were visually rated for wear injury. The ten most wear tolerant and intolerant genotypes were selected from 173 NTEP entries for further evaluation. Shear strength (traction) ratings were also made to the same field plots using a studded disc apparatus. In the fall of 2002, wear tolerance ratings were highly correlated with turf shear strength (traction) measurements. ($r = 0.63$, $p \leq 0.001$). In 2003, no relationship was present between wear tolerance and shear strength (traction).

Introduction

The most widely used cool-season turfgrass in the United States is Kentucky bluegrass (*Poa pratensis* L.) (Turgeon, 1999). Considerable interest has arisen in the development Kentucky bluegrass genotypes with improved turfgrass performance to match specific uses. The sports turf industry is one area in which Kentucky bluegrass is used extensively. Along with perennial ryegrass (*Lolium perenne L*.), Kentucky bluegrass is cited by Puhalla (1999) as the most commonly used turfgrass species in athletic fields grown in cool-season climates.

Traffic due to the activity of athletes is a frequent and damaging stress to turfgrass plants in a sports turf situation (Minner et al., 1993). Traffic can be broken down into two stresses, wear and soil compaction (Carrow and Petrovic, 1992). The effects of these distinctly different stresses need to be differentiated in order to obtain selections that are specific to wear.

Multiple definitions of wear stress have been developed. Beard et al. (1974) defined wear injury as the immediate result of crushing, tearing, and shearing actions of foot and vehicular traffic. Wear has also been defined as an injury to tissues from pressure, tearing or scuffing (Carrow and Petrovic, 1992). Regardless of definition, the effects of wear stress cause injury to the shoots and foliage of the plant. Chlorophyll degradation may result from this injury, and thus photosynthesis would subsequently be reduced. This reduction in photosynthesis would eventually give way to weaker plants (Trenholm et al., 2000) and thus reduce the function and quality of the turfgrass stand (Bonos et al., 2001).

Methods for screening for differences in interspecies wear tolerance have been developed (Shearman and Beard, 1975a). Proposed parameters used in screening for wear tolerance included an overall visual rating of the foliar injury caused by the applied wear stress, percent total cell wall content, percent verdure (shoot biomass), and chlorophyll content remaining after stress imposition (Shearman and Beard, 1975a). Significant differences were found between species in their tolerance to imposed wear stress using these techniques. Perennial ryegrass was found to be the most wear tolerant species and rough bluegrass the least tolerant species (Shearman and Beard, 1975a). Kentucky bluegrass ranked second to perennial ryegrass in overall wear tolerance (Shearman and Beard, 1975a). It was determined that all the different characteristics used in the screening procedure were satisfactory in assessing wear tolerance at the interspecies level (Shearman and Beard, 1975a).

In addition to wear tolerance, other surface characteristics are important in maintaining safe, durable, and functional sports fields. One such component of surface quality is shear strength (traction), which has been described as traction measured using studded measuring devices (Canaway and Bell., 1986). Traction, or grip, is measured as the lateral force required to rotate studded plates (Canaway and Bell., 1986). Shear resistance, along with ball bounce resilience, rolling resistance, and surface hardness are important attributes in maintaining the playing quality of athletic turf (Bell et al., 1985).

Interspecies differences have been noted in shear resistance (Gramckow, 1968), however there are very few studies that have investigated variation among genotypes within species such as Kentucky bluegrass. Zebarth and Sheard (1985) and Adams et al. (1985) reported that superior shear strength (traction) was associated with increased rooting density. Sorochan et al. (2001) suggested that the quantity of rhizomes was an important morphological characteristic associated with maximizing shear strength (traction).

There is a distinct need for an intraspecies analysis of differences in wear tolerance and shear strength (traction) of cool-season species. This analysis would be of great value to breeders in improving wear tolerance and shear strength (traction) in cool-season turfgrasses. The fact that Kentucky bluegrass is used extensively in the sports turf industry, one in which wear and shear are predominate stresses, indicates a need for an intraspecies analysis of its wear tolerance and shear strength (traction).

Objective

The objective of this research was to provide an intraspecies analysis of wear tolerance and shear strength (traction) among Kentucky bluegrass genotypes. This analysis will in turn aid turfgrass managers in selecting better performing Kentucky bluegrass genotypes for use in the sports turf industry.

Materials and Methods

Genotypes for evaluation were selected from the 2000 National Turfgrass Evaluation Program (NTEP) Kentucky bluegrass trial. The plots were established in October 2000 at the Joseph Troll Turf Research Center, South Deerfield, MA. Genotypes evaluated in the NTEP trial represent a wide array of Kentucky bluegrasses, including the potential for wear tolerant and intolerant genotypes, as well as the potential for genotypes with high and low shear strength (traction) (USDA, 2000). All plots were established on a Hadley silt loam soil (coarse, silty, mixed, nonacid, mesic Typic Udifluvent) and received the same management practices (147 kg N ha^{-1} yr^{-1}, 3.75 cm mowing height) as directed by the National Turfgrass Evaluation Program..

The ten most wear tolerant genotypes and the ten most wear susceptible (intolerant) genotypes were selected after the application of wear treatments to the NTEP plots in the fall of 2002. Wear treatments were applied as a strip within replicates (split block) using a differential slip-wear device called D.S.1 The wear simulator was designed to create a scuffing action while minimizing pressure to the soil, therefore limiting soil compaction. Thus, the majority of the stress was applied to the foliage. The simulator was developed by P.M. Canaway (1976) based on components from the Wolseley Merry Tiller Titan G.T. powered cultivator (Canaway, 1976) and parts specifically designed by Soil Machine Dynamics Ltd (Fawdon, Newcastle upon Tyne, NE3 2AH).

Machine specifications were as follows. The machine used was 53 cm wide, 93 cm long (plus an additional 94 cm for the handlebars), and weighed 158 kg. Two sets of studded rotors were mounted on separate axles, each set being spaced in such a manner that gaps from the front rotors were covered by the rear rotors, thus giving a pass 53 cm wide. Three rotors were present on the front axle and four rotors on the rear axle. Rotors were used in order to reduce the overall weight of the machine. These rotors were 24.5 cm in diameter, 7.6 cm wide, and each carried 24 metal studs identical in size to screw in football cleats and placed randomly on the rotor. (Canaway, 1976)

In order to simulate wear, both vertical and horizontal forces must be imposed to the foliage. The number of studs that contacted the ground at any one time determined the vertical force imposed by the D.S.1 (Canaway, 1976). This force was proportional to the weight of the machine. Horizontal forces were produced due to the fact that two sets of rotors were coupled together by the belt drive and unequal sized pulleys. When in operation the two sets of rotors rotated in the same direction but at different speeds. This caused the front rotors to slip and the rear rotors to skid as the studs moved through the turfgrass. The horizontal forces exerted by the machine were a result of this slip and skid action. The front rotors imposed a tractive force (opposite to the traveling direction) and the rear rotors produced a braking force (acting in the direction of travel). Thus at full speed on level ground, horizontal forces were approximately equal in magnitude, but in the opposite direction (Canaway, 1976).

A cumulative total of seventy-five passes were applied using this differential slip-wear device from 25 October 2002 to 31 October 2002. The same wear treatment was applied from 8 November to 11 November in 2003.Wear tolerance was measured by visually rating the percentage of the surface covered by the turfgrass foliage (% ground cover) after wear was applied. These percent ground cover ratings were made using a 0 to 9 scale one day after wear applications were completed. A rating of 0 indicated that zero to ten percent of the surface was covered by the foliage, while a rating of 9 indicated that 90 to 100 percent of the surface was covered by the foliage. The ten genotypes with the highest percentage of surface coverage were deemed wear tolerant, while the ten genotypes with the lowest percentage of surface coverage were identified as wear intolerant.

Shear strength (traction) measurements were made using a studded plate device fitted with a torque wrench similar to the instrument described by Canaway and Bell (1986). Three weights (totaling 34 kg) rested upon a studded plate 145 mm in diameter and 14 mm deep. The plate contained six studs (1.95 cm x 0.64 cm) that simulate a soccer cleat. When in use, the weights resting on the studded plate simulated a 90.7 kg soccer player (Canaway and Bell, 1986). A bearing in the bottom weight allowed for the studded plate to move independently of the weights above it (Canaway and Bell, 1986). The apparatus was dropped onto the turfgrass from a standard height of 150mm and the torque wrench was turned until sod was displaced. The instrument measured the lateral force (Nm) required to displace sod, therefore shear resistance (traction) increased with higher instrument readings. Shear strength (traction) measurements were taken on 5 September 2002 and 27 September 2003.

Statistical Analysis

Wear tolerance ratings were made by three different evaluators, one day after the application of the wear treatments. Analysis of variance (ANOVA) was conducted to test the effects due to genotype as well those due to the interaction of genotype and evaluator. The interaction between genotype and evaluator was tested for significance to determine if the means developed by each evaluator could be pooled together to form one grand (evaluator) mean for each genotype. The effect of the interaction between group (tolerant vs. intolerant) and year was also determined.

Two shear strength (traction) readings were taken per plot, and averaged in order to derive a mean shear strength (traction) measurement for each genotype included in the NTEP Kentucky bluegrass trial. Shear strength (traction) measurements that were made in the fall of 2002 and averaged with those made previously in the fall of 2001. No statistical interaction was identified between genotype and year, thus a two-year shear strength (traction) average was calculated for each genotype. A subsequent mean was created for each genotype in 2003 and the interaction between the pooled (2001, 2002 and 2003) genotype means and year was also determined

Results

The interaction between genotype and evaluator was not significant for wear tolerance, ($p \leq 0.05$) thus allowing one grand mean percent ground cover rating to be determined for each genotype within each year (Appendix A, Table 15). A Fisher's Least Significant Difference (LSD) test was performed and the LSD was subtracted from the highest ground cover mean and added to the lowest ground cover mean. This created two distinct ranges of wear tolerant genotypes and wear intolerant genotypes.

Within each grouping, the ten genotypes with the highest and lowest rating for wear tolerance were selected. In order to be selected, genotypes were required to have a turf quality score (before wear) greater than or equal to six. These turf quality scores were taken on 24 October 2002 and 22 October 2003 respectively (Appendix A, Table 15). There was no significant interaction between 2002 and 2003 data, thus the same groups were selected as wear tolerant and intolerant in 2003. The final wear (tolerant, intolerant) selections are listed in Table 1.

Table 1- Mean squares (ms) and means for wear tolerant and intolerant genotypes in 2002 and 2003

Source of variation	df	2002 Ground Cover Rating	2003 Ground Cover Rating	2-yr Average Ground Cover Rating
		ms		
Block	2	2.01†	0.69	0.50
Genotype	19	5.82***	2.72***	7.43***
Tolerant vs. intolerant‡	1	107.11***	32.27***	128.48***
Among tolerant§	9	0.19	0.96	0.72
Among intolerant§	9	0.18	1.20	0.68
Year	1	-----	-----	2.85†
Genotype X year	19	-----	-----	1.11
Error	38(78)¶	0.74	0.80	0.81
Gentoype		Genotype means		
Wear tolerant		0 to 9		
99AN-53		7.39	7.33	7.36
B4-128A		8.06	8.22	8.14
Ba-84-140		7.61	6.33	6.97
Baronie		7.56	7.89	7.72
Goldrush		7.56	7.56	7.56
Limousine		8.06	7.56	7.81
Misty		7.83	7.11	7.47
NA-K991		7.89	7.44	7.67
PST-H8-150		7.44	7.78	7.61
Sonoma		7.44	6.67	7.06
Tolerant mean		7.68	7.39	7.54
Wear intolerant				
A96-451		5.22	5.44	5.33
A97-1409		5.17	6.22	5.69
A97-1439		5.11	6.78	5.94
A98-296		5.00	5.33	5.17
Arcadia		5.11	6.22	5.67
BH 00-6003		4.72	5.44	5.08
Langara		4.44	6.56	5.50
PST-York Harbor4		5.00	4.89	4.95
Rita		5.11	5.78	5.44
Unique		5.22	6.56	5.89
Intolerant mean		5.01	5.92	5.47
LSD(0.05) for cultivar		0.95	1.46	1.03
% Range#		44.84	40.55	39.25
CV(%)		13.54	13.45	13.82

†,*,**,*** Significant at $P \leq$ 0.10, 0.05, 0.01, 0.001 levels, respectively.

‡Single df test for the difference between the combined means for wear tolerant and intolerant genotypes.

§Test for the difference within the combined group means for wear tolerant and intolerant genotypes

¶Number in parenthesis indicates degrees of freedom for the 2 year average

#[(Max-min)/max] × 100.

The interaction between years (2001 and 2002) for shear strength (traction) ratings was not significant ($p \leq 0.05$), thus a two-year shear average was calculated for each genotype (Table 16). A correlation was performed to determine if a relationship was present between wear tolerance and shear strength (traction). Wear tolerance ratings were highly correlated with turf shear strength (traction) measurements in 2002. ($r = 0.63$, $p \leq 0.001$) In 2003, no relationship between shear strength (traction) and wear tolerance was detected.

Discussion

After comparing this wear tolerance data set to previous evaluations (Minner et al., 1993; Bonos et al., 2001), many inconsistencies arise in genotype performance. Minner et al. (1993) ranked 'Sydsport,' 'Trenton,' 'Wabash,' 'Glade,' and 'A-34' as excellent traffic tolerant genotypes, while Bonos et al. (2001) found 'Trenton' and 'Wabash' to be very poor in terms of wear tolerance. It would be logical to assume that genotypes identified as traffic tolerant would also be somewhat wear tolerant, as wear stress is a principle component of traffic, yet this was not the case. Minner et al. (1993) found the 'Amazon' genotype to be poor in terms of traffic tolerance, and conversely Bonos et al. (2001) found it to have very good wear tolerance. Bonos et al. (2001) found the genotype 'Limousine' to be low in wear tolerance, yet it was the top performing genotype in this evaluation (Table 1). Also, Bonos et al. (2001) found the genotype 'Unique' to have superior wear tolerance, yet this analysis found it have low wear tolerance (Table 1)

These inconsistencies in genotype performance may be due in part to the differences that were present between the methods of imposing wear stress (machine specifications and features) in the three studies, methods of evaluating wear tolerance (rating parameters and scale), as well as the differing levels of wear intensity involved in each. In Minner et al.'s (1993) evaluation 30 passes per week were applied with a Brinkman Traffic Simulator (Cockerham, 1990). In Bonos et al.'s (2001) study, daily wear treatments (2 passes) were applied with a simulator derived from an M24C5A sweepster (Meyer et. al, 1997). In this evaluation seventy five passes were applied with a differential slip wear apparatus (Canaway, 1976). These machines may be imposing different stresses, or the same stress using a different intensity. Minner at al. (1993) and Bonos et al. (2001) screened for wear tolerance using turfgrass quality (post wear). This analysis quantified genotype performance based on 0-9 scale of percent ground cover. These differences in methodology, as well as in environments (Iowa, New Jersey, Massachusetts) and the interaction between genotype and environment, could contribute to the differing genotype performances that were observed.

Conclusion

This evaluation provides the most up to date information regarding the wear tolerance of Kentucky bluegrass genotypes using the D.S.1. differential slip wear simulator. The genotypes '99AN-53,' 'B4-128A,' 'Ba-84-140,' 'Baronie,' 'Goldrush,' 'Limousine,' 'Misty,' 'NA-K991,' 'PST-H8-150,' and 'Sonoma' were found to be tolerant to wear stress (Table 1). The genotypes, 'A96-451,' 'A97-1409,' 'A97-1439,' 'A98-296,' 'Arcadia,' 'BH 00-6003,' 'Langara,' 'PST-York Harbor 4,' 'Rita,' and 'Unique' were found to not be tolerant to wear stress (Table 1). Thus, this evaluation can serve as a key tool in selecting better performing (more wear tolerant) Kentucky bluegrass genotypes for use in today's sports turf industry.

Future research is needed to standardize the methods in which sports turf performance (i.e. traffic tolerance, wear and soil compaction) is evaluated. Machines to impose such stresses vary greatly, as do the protocols in the application of such stresses. If specific (standard) procedures are followed in evaluating genotype traffic stress performance, many inconsistencies in wear (traffic) tolerance data could be minimized.

CHAPTER 3

DETERMINING ANATOMICAL AND MORPHOLOGICAL CHARACTERISTICS OF WEAR TOLERANT AND INTOLERANT GENOTYPES

Abstract

Research investigating the mechanisms of wear tolerance within species is limited. This information would be valuable in selecting wear tolerant genotypes. To that end, wear treatments were applied in the fall of 2002 and 2003 using a differential slip-wear apparatus to the 2000 National Turfgrass Evaluation Program (NTEP) Kentucky bluegrass (*Poa pratensis* L.) field plots. Field plots were visually rated for wear injury. Ten wear tolerant and intolerant genotypes were selected from 173 NTEP entries. Eleven characteristics were measured in 2003 and 2004 comparing tolerant and intolerant genotypes in both field plots and as greenhouse grown space plants. Characteristics included tiller density, shoot fresh weight and dry weight, moisture content and relative turgidity, number of leaves per shoot, leaf width, leaf strength, leaf angle, leaf cell wall constituents [total cell wall content, hemicellulose, and lignocellulose]. Significant differences were found between tolerant and intolerant groupings. Tolerant genotypes were associated with a more vertical leaf angle, greater total cell wall content, and lower moisture content and relative turgidity based upon greenhouse measurements. Not all differences observed in the greenhouse were present in field plots. Wear tolerance ratings were correlated with turf shear strength (traction) measurements in the field in 2002 ($r = 0.63$, $p \leq 0.001$) and in turn, turf shear was

correlated with LA (r= 0.51, $p \leq 0.05$) and TCW (r= 0.51, $p \leq 0.05$). This relationship between wear tolerance and shear strength (traction) was not detected in 2003

Introduction

Along with perennial ryegrass (*Lolium perenne L.*), Kentucky bluegrass (*Poa pratensis* L.) is cited by Puhalla (1999) as the most commonly used turfgrass species in athletic fields grown in cool-season climates. In a sports turf situation, the most frequent and damaging stress to turfgrass plants is traffic (Minner et al., 1993). Traffic can be divided into two separate stresses, wear and soil compaction (Carrow and Petrovic, 1992). Minner et al. (1993) explained that wear stress affects the turfgrass plants, while soil compaction affects the physical properties of the soil.

The relationship between specific plant mechanisms and superior wear tolerance has been explored (Shearman and Beard, 1975c, Trenholm et al., 2000) at both the interspecies and intraspecies levels. Superior wear tolerance has been suggested to correspond with various anatomical and morphological plant characteristics. These characteristics include, yet are not limited to, total cell wall content, quantity of schlerenchyma fibers, leaf width, shoot density, and root density. (Shearman and Beard, 1975b)

Studies (Shearman and Beard, 1975c; Trenholm et. al., 2000; Esau, 1965) have focused on the constituents of cell walls as a principle means of explaining turfgrass wear tolerance. Cell walls are characterized as an amorphous matrix consisting of cellulose, hemicellulose, and lignin (Taiz et al., 1972). Cellulose is a tightly packed group of linear polysaccharide chains that provides plant tissues with a high tensile strength (Taiz et al., 1972). This suggests that plants with higher percentages of cellulose may be more tolerant to wear stress. Hemicelluloses are a heterogeneous group of polysaccharides that bind to cellulose to further strengthen cell walls (Taiz et al., 1972). Lignin is a highly branched polymer of phenylpropanoid groups that possesses high mechanical rigidity and therefore strengthens stems and vascular tissues (Taiz et al., 1972). Due to its physical toughness, it deters feeding by animals (Van Soest, 1994), and therefore may play a role in wear tolerance.

Anatomical characteristics unique to the cell walls of wear tolerant species have been analyzed (Shearman and Beard, 1975b). At the interspecies level, no single cell wall constituent has been significantly associated with increased wear tolerance. A highly significant association between superior wear tolerance and increased total cell wall content has been observed (Shearman and Beard, 1975b). Total cell wall content is the relationship between cellulose, hemicellulose, lignin, and lignocellulose (lignin bound to cellulose) on an mg/dm^2 basis (Van Soest, 1994). Over 96% of the variation in interspecies wear tolerance has been associated with the combined effects of these cell wall constituents, what can be termed total cell wall content (Shearman and Beard, 1975b).

Morphological characteristics among turfgrasses species subjected to wear stress have also been investigated (Shearman and Beard, 1975c). Verdure (shoot biomass), load bearing capacity, leaf blade tensile strength, and relative turgidity were evaluated at the interspecies level. Among the different plant characteristics, species variations were observed, yet only the combined effect of increased leaf tensile strength and increased leaf width, accounted for a significant amount of the variation in interspecies wear tolerance (97 %) (Shearman and Beard, 1975c).

An intraspecies analysis of wear tolerance within seashore paspalum (*Paspalum vaginatum* Swartz.) genotypes, as well as hybrid bermudagrass genotypes (*Cynodon dactylon* L. X C. *transvaalensis* Burtt-Davy), was conducted by Trenholm et al. (2000). Trenholm et al. (2000) continued to investigate the relationship present between increased amounts of differing cell wall constituents and tolerance to wear stress, while also examining other plant characteristics to see if relationships to increased wear tolerance were apparent. The plant characteristics evaluated included leaf strength, plant moisture content, shoot density, and verdure.

Within both seashore paspalum and bermudagrass genotypes, increased plant moisture content and increased shoot densities were associated with superior wear tolerance. At the interspecies level, no relationship between moisture content and wear tolerance was observed, yet increased shoot density was found to be associated with superior wear tolerance (Shearman and Beard, 1975c).

Associations between cell wall constituents and superior wear tolerance were observed within both seashore paspalum and bermudagrass genotypes (Trenholm et al., 2000). Within seashore paspalum genotypes, wear tolerance decreased as leaf total cell wall content increased. Within bermudagrass genotypes, reduced cellulose content and increased lignin content were associated with improved wear tolerance. Increased leaf total cell wall content, as well as increased lignin content, was associated with superior wear tolerance at the interspecies level (Shearman and Beard, 1975b). Greater quantities of the leaf total cell wall content will lead to a decrease in leaf elasticity (Beard, 1973). Within seashore paspalum genotypes, the concept of increased leaf blade elasticity was associated with superior wear tolerance (Trenholm et al., 2000). As was true at the interspecies level (Shearman and Beard, 1975b), within bermudagrass genotypes decreased elasticity (higher rigidity) was significantly associated with superior wear tolerance.

Plant characteristics associated with superior wear tolerance vary greatly, both at the interspecies and intraspecies level. Relationships between plant characteristics and wear tolerance observed at the interspecies level (Shearman and Beard, 1975b,c) are often not consistent within a particular species. The same is true at the intraspecies level. Anatomical and morphological characteristics associated with superior wear tolerance within a particular species may not be the same within another species (Trenholm et al., 2000).

Objective

The objective of this research was to evaluate Kentucky bluegrass genotypes, differing in wear tolerance, based on anatomical and morphological characteristics that have been shown to be associated with wear tolerance at the inter- and intraspecific levels. These characteristics may then serve as selection criteria (mechanisms) for breeding wear tolerance within this species.

Materials and Methods

Twenty genotypes, ten wear tolerant and ten intolerant, were selected for evaluation in this experiment (Table 1). Genotypes were selected based on their response to imposed wear treatments in the fall of 2002 and 2003 (Chapter 2). Seeds for each genotype were obtained from the National Turfgrass Evaluation Program. Twenty-five seeds per genotype germinated for four weeks beginning 1 February 2003, and again on 2 December 2003. After coleoptile emergence, genotypes were seeded in Pro-Mix BX growing medium and placed in the greenhouse at the University of Massachusetts, Amherst, MA on 24 February 2003, and 17 December 2003. The seedlings were maintained under mist heads and received daily irrigation. The day/night temperature in the greenhouse was maintained at 25°C.

On 1 April 2003, and 22 January 2004, the seedlings were transplanted into clear polyethylene slant tubes and maintained in the greenhouse as unmowed space plants for eight weeks. Plant breeders typically evaluate plant characteristics from space planted nurseries (Bourgoin and Mansat, 1977), and therefore space plants have some relevance to evaluations used by turfgrass breeders.

Clear polyethylene tubing (3 ml wall thickness, 3.2- cm outside diameter) was cut to a length of 70-cm and heat sealed at one end. Small holes were made in the heat-sealed end of each tube to allow for adequate drainage. 879 grams (+/- 10 grams) of medium grade sand (67.3 % 0.5-0.25mm diameter), 0.55 grams of 28-2.2-9.9 fertilizer, and 0.28 grams of dolomite were evenly mixed, poured into the tube and vibrated to form a sand column 70 cm. long. Polyvinyl chloride (PVC) pipe, 4.3 cm inside diameter, was cut to 70 cm lengths. A wire grid was positioned in one end for support of the sand column. The sand-filled tube was inserted into the PVC pipe, which formed a sleeve around the sand filled tube, holding it at a 30-degree angle from horizontal.

Genotypes were replicated four times in a randomized complete block design, and were fertigated daily to saturation with combinations of Sungrow 17-2.2-19.9 and 15-0-12.4 at 200 ppm nitrogen. This prevented any moisture stress as well as provided continuous nutrition. A gas thermocouple (Model 422314; Extech Instruments, Cole

Palmer, Vernon Hills, Ill.) recorded the daily maximum, minimum and average temperatures. In 2003, the overall average temperature was 23.2°C (+/- 3.8°C), with a mean maximum temperature of 31.0°C (+/- 6.7°C) and a mean minimum temperature of 15.5°C (+/- 3.5°C) (Appendix A, Table 14) . In 2004, temperatures were slightly cooler. The overall average temperature was 22.2°C (+/- 2.4°C), with a mean maximum temperature of 28.0°C (+/- 4.8°C) and a mean minimum temperature of 16.2°C (+/- 0.4°C) (Appendix B, Table 32).

A total of eleven plant attributes were evaluated in the unmowed space plants. Leaf extension rate measurements were made three, five, and seven weeks after placement into the sand column. Measurements were made on the eighty space plants (20 genotypes by 4 replications) by sampling genotypes within a replicate over several days. Time was used as a blocking variable. Leaf character measurements included leaf extension rate, leaf number per shoot, leaf width, leaf angle, leaf strength, relative turgidity, and leaf fiber analysis for cell wall constituents. Whole plant characteristics included plant moisture content, tiller density, and verdure. Other characteristics included rooting density and the number of rhizomes.

Leaf extension rate was measured on the youngest leaf (budleaf) over a 24 hour period by means of one leaf sample per replicate. All remaining leaf characteristics mere measured on three shoot samples per replicate. Leaf width and leaf strength were measured at the midpoint of the second subtending leaf from the budleaf, which has been reported to vary most between genotypes while minimizing variation within a genotype (Sheffer et al., 1978; Brede and Duich, 1982). Leaf strength was defined as a measure of the tension (in grams) required to reach the breaking point and tear a leaf blade in half. Leaf strength was measured using Shimpo Digital Force Gauge (Model FGS-50H; Nidec-Shimpo America Corporation, Itasca, Ill.) Leaf number per shoot was defined as the number of green leaves per tiller or shoot. Leaf angle was rated on a scale of 1 to 4 with the budleaf as the vertical axis, with a score of 1 indicating a horizontal orientation (0-22.5º), a score of 2 indicating a semi-horizontal orientation (22.5-45º), a score of 3 indicating a semi-vertical (45-67.5º), and a score of 4 indicating a vertical orientation (67.5-90º) from horizontal.

Leaf turgidity was determined using the formula [(fresh weight-dry weight)/((turgid weight-dry weight)]X 100. Turgid weight was measured after soaking leaves in distilled water for twelve hours. Leaf fiber analysis assessed the amount of total cell wall content (entire fibrous portion), lignocellulose, and hemicellulose according to the methods of Goering and Van Soest (1970). Polyester bag technology (PBT) (Contreras Lara, 1999; Komarek et. al, 1994) was used for this analysis as well. This procedure required acid and neutral detergent testing with different reagents to measure quantities of cell wall constituents. The neutral detergent fiber (NDF) procedure was used to determine the percent total cell wall content (TCW) on a dry weight basis. Lignocellulose content was determined on a dry weight basis using the acid detergent fiber method (ADF). The difference between the quantity of NDF and ADF served to estimate the percent hemicellulose (NDF-ADF).

Filter bags (ANKOM Technology, Macedon, NY) were used in both fiber procedures. These polyester bags had a uniform pore size of 30 µm. Bags were weighed and filled with approximately 0.1g of dried sample. Bags were then placed in an 11 ball flask, and depending on the analysis, moistened with 70 ml of the appropriate detergent solution (neutral detergent solution or acid detergent solution). All solutions were prepared according to the methods of Goering and Van Soest (1970). The flask was heated keeping temperature between 95 and 100ºC, and continuously agitated. After sixty minutes for neutral detergent fiber analysis and seventy minutes for acid detergent fiber analysis, the bags were removed from the flask and washed with boiling water to remove any detergent solution. They were then soaked in acetone for three minutes and oven dried for sixty hours at 70ºC. Oven dry weights were then recorded and converted to percentages [{(initial weight-final weight)/initial weight)}X 100] with the percentage of neutral detergent fiber representing the total cell wall content, the percentage of acid detergent fiber representing the lignocellulose content, and the difference between the two (NDF-ADF) representing the hemicellulose content.

Whole plant characteristics measured included plant moisture content, tiller density, and verdure (fresh weight). Plant moisture content was determined at harvest using the formula, moisture content = [(fresh weight- oven dry weight)/fresh weight] X 100. Tiller density was defined as the total number of primary lateral shoots per plant and verdure was the total shoot biomass at harvest. Rooting density (mg/cm^3) was determined at five different intervals. Those depth intervals were 0-10-cm, 10-20-cm, 20-30-cm, 30-50-cm, and 50-70-cm. Roots were washed free of soil and oven dried at 70°C for 24 hours. Weights in milligrams were then recorded. Rhizomes were identified and counted.

All plant measurements (with the exception of the number of rhizomes) made on the twenty Kentucky bluegrass space plants were also obtained from the mowed field plots from which the genotypes had been previously selected (Chapter 2). Three 2.25-

cm plugs were taken from each field plot and measured in the same manner as greenhouse samples, with two exceptions. Rooting density was only calculated at the 0-10cm interval, and leaf extension rate was estimated using oven dry (24 hours at 70ºC) clipping yield (mg/cm^2). Greenhouse measurements were made 2 June through 20 June in 2003, and 25 March through 3 April in 2004. Field measurements were made from 6 May through 23 May in 2003, and 1 May through 11 May in 2004.

Statistical Analysis

Sub-samples that were taken on the various plant characteristics were averaged and analysis of variance (ANOVA) was performed on those averages. Genotype sum of squares were partitioned into single degree of freedom (df), orthogonal, contrasts to test for the difference between the combined means of wear tolerant and wear intolerant genotypes. Contrasts were also performed to test for differences within wear tolerant and intolerant groupings. Correlations were calculated to investigate how each plant characteristic related to wear tolerance and shear strength (traction), as well as how different plant characteristics related to one another in both the greenhouse and field settings. Interactions between genotype and year, as well as group (tolerant vs. intolerant) and year were tested. No interaction between genotype and year was detected so pooled (averaged across year) means will be discussed in detail, while means for plant attributes within individual years are located in the appendices.

Results and Discussion

The twenty Kentucky bluegrass genotypes were classified as wear tolerant or intolerant based on each genotype's individual wear tolerance rating (Table 1). The grouping of genotypes in this manner was based on two premises: (i) genotypes that are dissimilar in wear tolerance are likely to be dissimilar in important anatomical and morphological characteristics, and (ii) these differences should separate clearly into wear tolerant and intolerant groups for plant attributes important in comparative tolerance to wear. Wear tolerance ratings were correlated with turf shear strength (traction) (traction) measurements in the field ($r = 0.63$, $p \leq 0.001$) in 2002, thus indicating that attributes important to wear tolerance may also be important in shear strength (traction).

Greenhouse Plants

Genotype differences were present in all attributes measured on greenhouse space plants except the number of leaves per shoot (Table 2). Large genotype differences were present in most plant attributes measured. Genotype differences were quantified as % range (% range = {[maximum value-minimum value] ÷ maximum value} X 100). Shoot fresh weight, dry weight, and leaf angle varied by 67%, 65%, and 53% respectively (Table 3, Table 2). Minimal variation was observed between genotypes when examining moisture content (7.21%, Table 4). Coefficients of variation were calculated for all attributes measured. The coefficient of variation (CV) was also the smallest for moisture content (2.41%, Table 4) and the largest for rooting density at the 50-70cm depth (95%, Table 5).

Table 2- Pooled mean squares (ms) and means averaged over year (2003 and 2004) for leaf characteristics measured on 20 genotypes of Kentucky bluegrass representing diverse wear tolerance grown in the greenhouse as space plants and as field plots during 2003 and 2004

Source of variation	df	Leaves/shoot GH	Leaves/shoot FD	Leaf width GH	Leaf width FD	Leaf strength GH	Leaf strength FD	Leaf angle[‡] GH	Leaf angle[‡] FD
		ms							
Block	3(2)[§]	0.97***	0.05	0.48	0.05	783.7	4929.2*	0.24	0.09
Genotype	19	0.19	0.10	1.10***	1.13***	1823.6**	2959.1**	1.58***	1.21***
Tolerant vs. intolerant[¶]	1	0.08	0.03	0.02	0.03	270.5	1468.7	27.23***	10.21***
Among tolerant[#]	9	0.33*	0.13†	1.16***	1.22***	2897.6**	4848.3***	0.24	1.27***
Among intolerant[#]	9	0.05	0.07	0.72**	1.16***	922.2	1235.6	0.07	0.16
Year	1	8.57***	0.30*	3.35***	3.50***	130800.4	10897.4**	5.63***	0.04
Genotype X year	19	0.14	0.07	0.21	0.15	1082.0	881.3	0.39***	0.39***
Tolerant vs. intolerant X year	1	0.31	0.00	0.00	0.08	2661.5†	1196.4	5.37***	5.20***
Among tolerant X year	9	0.15	0.09	0.23	0.06	403.0	136.9***	0.11	0.16
Among intolerant X year	9	0.11	0.06	0.20	0.24	1585.2	1590.7	0.08	0.10
Error	117(78)[§]	0.14	0.07	0.26	0.11	865.5	1173.9	0.15	0.12
Gentoype		Genotype means							
Wear tolerant		no.		mm		g		1 to 4	
99AN-53		3.25	2.94	3.52	2.61	153.6	148.0	2.25	1.94
B4-128A		3.54	3.11	2.31	1.97	125.4	82.1	2.00	2.67
Ba-84-140		3.33	3.17	3.27	2.81	173.7	125.5	1.96	1.78
Baronie		3.83	3.33	3.48	3.25	169.0	166.8	2.08	2.39
Goldrush		3.33	3.17	3.71	2.83	197.6	137.2	1.92	1.89
Limousine		3.58	3.05	3.25	2.17	172.2	108.1	2.04	2.83
Misty		3.75	3.33	3.85	3.19	173.4	141.2	2.33	1.67
NA-K991		3.25	3.00	3.40	2.97	149.8	145.4	2.17	1.39
PST-H6-150		3.38	2.89	2.79	2.17	158.8	101.6	1.79	2.06
Sonoma		3.50	3.11	3.25	2.36	157.5	86.2	1.83	1.72
Tolerant mean		3.48	3.11	3.28	2.63	163.1	124.2	2.04	2.03
Wear intolerant									
A96-451		3.29	3.11	3.33	2.97	180.4	137.0	1.21	1.39
A97-1409		3.50	3.22	3.31	3.11	166.8	144.8	1.33	1.28
A97-1439		3.46	3.17	3.35	2.75	150.4	131.2	1.17	1.33
A98-296		3.42	3.05	2.96	2.50	158.5	133.1	1.08	1.44
Arcadia		3.46	3.33	2.81	2.33	142.2	135.9	1.33	1.78
BH 00-6003		3.42	3.28	3.50	3.33	169.9	149.3	1.33	1.56
Langara		3.58	3.00	3.02	1.83	160.7	104.3	1.13	1.33
PST-York Harbor 4		3.38	3.06	3.81	2.75	164.5	139.1	1.21	1.39
Rita		3.42	3.17	3.46	2.77	153.2	128.1	1.13	1.33
Unique		3.38	3.06	3.04	2.27	158.4	109.2	1.21	1.67
Intolerant mean		3.43	3.14	3.26	2.66	160.5	131.2	1.21	1.45
LSD(0.05) for cultivar		0.37	0.29	0.51	0.38	29.1	39.4	0.38	0.40
% Range[††]		15.14	13.33	40.00	45.00	36.5	50.7	53.45	54.90
CV(%)		10.87	8.23	15.65	12.57	18.2	26.8	23.64	19.75

[‡]Rating: 1= horizontal, 2 = semi horizontal, 3 = semi-vertical, 4 = vertical.
[§]Number in parenthesis indicates degrees of freedom for field study.
†,*,**,*** Significant at $P \leq 0.10, 0.05, 0.01, 0.001$ levels, respectively.
[¶]Single df test for the difference between the combined means for wear tolerant and intolerant genotypes.
Test for the differences within wear tolerant or intolerant genotypes.
[††][(Max-min)/max] × 100.

Table 3-Pooled means squares (ms) and means averaged over year (2003 and 2004) for whole plant characteristics measured on 20 genotypes of Kentucky bluegrass representing diverse wear tolerance grown in the greenhouse as space plants and as field plots during 2003 and 2004

		Shoots per cm^2		Shoot fresh weight		Shoot dry weight	
Source of variation	df	GH	FD	GH	FD	GH	FD
		---------------------------ms---------------------------------					
Block	3(2)[‡]	5.43^{**}	$1.20^{\dagger}$	0.061	0.0029^{***}	0.0021	0.00022^{***}
Genotype	19	5.14^{***}	4.19^{***}	0.184^{***}	0.0008^{***}	0.0063^{***}	0.00002^{***}
Tolerant vs. intolerant[§]	1	8.82^{**}	0.25	0.230^{*}	0.0019^{**}	0.0018	0.00001
Among tolerant[¶]	9	4.00^{**}	6.19^{***}	0.148^{***}	0.0011^{***}	0.0057^{***}	0.00003^{***}
Among intolerant[¶]	9	5.88^{***}	2.63^{***}	0.214^{***}	0.0004	0.0072^{***}	$0.00001^{\dagger}$
Year	1	19.52^{***}	1.01	11.986^{***}	0.0089^{***}	0.4619^{***}	0.00034^{***}
Genotype X year	19	1.48	0.38	0.091^{**}	0.0004^{*}	0.0030^{**}	0.00002^{*}
Tolerant vs. Intolerant X year	1	0.26	0.57	0.055	0.0003	0.0002	0.00001
Among tolerant X year	9	1.41	0.35	0.049	0.0005	0.0021	0.00002
Among intolerant X year	9	1.70	0.39	0.136	0.0004	0.0042	0.00001
Error	117(78)[‡]	1.19	0.46	0.037	0.0003	0.0013	0.00001
Gentoype		--------------------------Genotype means-------------------					
Wear tolerant		----no./cm^2---		-------------------g/cm^2--------------------			
99AN-53		3.55	2.05	0.578	0.0422	0.1118	0.00907
B4-128A		4.34	5.27	0.304	0.0933	0.0570	0.01851
Ba-84-140		2.69	2.58	0.420	0.0670	0.0837	0.01199
Baronie		4.48	2.77	0.724	0.0754	0.1399	0.01323
Goldrush		3.39	2.98	0.684	0.0611	0.1342	0.01239
Limousine		4.17	4.34	0.722	0.0671	0.1363	0.01282
Misty		3.18	2.28	0.604	0.0635	0.1130	0.01236
NA-K991		2.83	2.64	0.545	0.0664	0.1247	0.01306
PST-H8-150		4.34	3.94	0.468	0.0671	0.0869	0.01276
Sonoma		4.55	2.95	0.608	0.0804	0.1056	0.01455
Tolerant mean		3.75	3.18	0.565	0.0683	0.1093	0.01307
Wear intolerant							
A96-451		4.79	3.17	0.727	0.7984	0.1225	0.01348
A97-1409		4.23	3.09	0.731	0.0844	0.1172	0.01562
A97-1439		3.34	2.99	0.461	0.0714	0.0834	0.01323
A98-296		5.24	3.08	0.928	0.0822	0.1661	0.01401
Arcadia		3.50	3.55	0.449	0.0808	0.0779	0.01562
BH 00-6003		2.85	2.29	0.401	0.0639	0.0740	0.01136
Langara		5.20	4.18	0.679	0.0874	0.1328	0.01606
PST-York Harbor 4		3.61	2.75	0.733	0.0733	0.1417	0.01346
Rita		4.37	3.06	0.600	0.0746	0.1102	0.01243
Unique		5.10	4.54	0.706	0.0661	0.1353	0.01288
Intolerant mean		4.22	3.27	0.641	0.0764	0.1161	0.01376
LSD(0.05) for cultivar		1.08	0.77	0.192	0.0187	0.0363	0.00310
% Range[#]		48.67	61.00	67.289	54.7797	65.6613	50.98060
CV(%)		27.35	20.94	32.082	22.4895	31.7038	20.36439

‡Number in parenthesis indicates degrees of freedom for field study.

†,*,**,*** Significant at $P \leq 0.10, 0.05, 0.01, 0.001$ levels, respectively

§Single df test for the difference between the combined means for wear tolerant and intolerant genotypes.

¶ Test for the differences within wear tolerant or intolerant genotypes.

#[(Max-min)/max] × 100.

Table 4-Pooled mean squares (ms) and means averaged over year (2003 and 2004) for water related plant characteristics measured on 20 genotypes of Kentucky bluegrass representing diverse wear tolerance grown in the greenhouse as space plants and as field plots during 2003 and 2004

		Moisture‡		Relative turgidity§	
Source of variation	df	Greenhouse	Field	Greenhouse	Field
		ms			
Block	3(2)¶	1.44	56.83***	176.59*	1242.48***
Genotype	19	14.28***	9.68*	116.34*	113.72
Tolerant vs. intolerant#	1	69.45***	41.32**	412.21**	1.93
Among tolerant††	9	17.20***	9.70†	85.61	177.72
Among intolerant††	9	5.23	6.15	114.18†	62.14
Year	1	62.25***	5.21	1056.58***	699.39*
Genotype X year	19	4.20	5.32	85.09	100.63
Tolerant vs. intolerant X year	1	8.93	0.64	1.41	92.60
Among tolerant X year	9	2.71	8.05	94.12	123.22
Among intolerant X year	9	5.10	3.10	85.35	78.93
Error	117(78)‡	3.84	5.10	59.29	112.34
Gentoype		Genotype means			
Wear tolerant		%			
99AN-53		81.10	78.83	71.44	61.22
B4-128A		80.11	79.41	71.78	77.72
Ba-84-140		80.06	82.00	76.04	82.07
Baronie		80.88	82.52	71.19	77.69
Goldrush		81.17	79.32	75.77	77.13
Limousine		81.29	80.88	74.06	75.90
Misty		81.01	80.74	77.89	73.33
NA-K991		77.19	80.23	71.57	77.05
PST-H8-150		81.72	81.13	77.58	75.26
Sonoma		82.79	82.13	80.47	75.86
Tolerant mean		80.73	80.72	74.78	75.32
Wear intolerant					
A96-451		83.19	83.09	79.97	77.37
A97-1409		83.11	82.08	87.34	75.66
A97-1439		82.37	81.53	77.60	74.35
A98-296		82.55	82.77	73.41	76.82
Arcadia		82.28	80.36	77.04	76.85
BH 00-6003		81.35	82.09	78.79	74.45
Langara		81.22	81.65	75.72	74.30
PST-York Harbor 4		81.28	81.27	78.18	74.52
Rita		80.93	83.45	76.58	82.11
Unique		82.21	80.63	75.29	69.36
Intolerant mean		82.05	81.89	77.99	75.58
LSD(0.05) for cultivar		1.94	2.60	7.63	12.18
% Range‡‡		7.21	5.54	18.48	25.44
CV(%)		2.41	2.78	10.08	14.05

‡Moisture (%) = [(fresh weight - oven dry weight)/fresh weight] × 100.

§Turgidity (%) = [(fresh weight – oven dry weight)/(turgid weight-oven dry weight)] × 100, turgid weight = weight (g) after 12 hours in distilled H_20.

¶ Number in parenthesis indicates degrees of freedom for field study.

†,*,**,*** Significant at $P \leq 0.10, 0.05, 0.01, 0.001$ levels, respectively.

#Single df test for the difference between the combined means for wear tolerant and intolerant genotypes.

†† Test for the differences within wear tolerant or intolerant genotypes.

‡‡ [(Max-min)/max] × 100.

Table 5- Pooled means squares (ms) and means averaged over year (2003 and 2004) of rooting densities at different depths (cm) measured on 20 genotypes of Kentucky bluegrass representing diverse wear tolerance grown in the greenhouse as space plants and as field plots during 2003 and 2004

		Rooting Density					
		Field plots	Greenhouse plants				
Source of variation	df	0-10cm	0-10cm	10-20cm	20-30cm	30-50cm	50-70cm
		ms					
Block	3(2)‡	0.834**	0.209	0.010	0.025	0.008	0.003
Genotype	19	0.216*	1.098***	0.324***	0.105**	0.154***	0.020*
Tolerant vs. intolerant§	1	0.825*	0.010	0.246	0.113†	0.012	0.003
Among tolerant¶	9	0.267*	1.057***	0.472***	0.181***	0.289***	0.031**
Among intolerant¶	9	0.097	1.259***	0.184†	0.027	0.035	0.011
Year	1	0.504*	32.398***	4.931***	1.378***	2.865***	0.721***
Genotype X year	19	0.123	0.315	0.104	0.061	0.066	0.018†
Tolerant vs. intolerant X year	1	0.039	0.053	0.230	0.076	0.178†	0.012
Among tolerant X year	9	0.141	0.289	0.110	0.049	0.033	0.021
Among intolerant X year	9	0.113	0.369	0.085	0.071	0.087	0.014
Error	117(78)‡	0.120	0.265	0.100	0.043	0.057	0.012
Gentoype		Genotype means					
Wear tolerant		mg/cm^3					
99AN-53		1.106	1.928	1.012	0.598	0.515	0.095
B4-128A		1.129	0.816	0.420	0.265	0.253	0.048
Ba-84-140		1.256	1.485	0.912	0.638	0.764	0.112
Baronie		1.557	1.945	1.165	0.717	0.759	0.218
Goldrush		1.042	1.834	0.822	0.443	0.555	0.185
Limousine		0.903	1.691	0.983	0.577	0.503	0.137
Misty		0.933	1.643	0.853	0.466	0.391	0.118
NA-K991		1.029	1.669	0.636	0.332	0.260	0.032
PST-H8-150		0.893	1.082	0.462	0.308	0.255	0.031
Sonoma		1.328	1.471	0.666	0.478	0.451	0.128
Tolerant mean		1.118	1.556	0.793	0.482	0.471	0.110
Wear intolerant							
A96-451		1.329	1.425	0.674	0.503	0.496	0.155
A97-1409		1.215	1.538	0.802	0.481	0.507	0.139
A97-1439		1.257	1.171	0.529	0.358	0.384	0.107
A98-296		1.352	2.010	0.863	0.413	0.456	0.096
Arcadia		1.418	1.149	0.615	0.387	0.374	0.053
BH 00-6003		1.013	1.206	0.589	0.393	0.429	0.091
Langara		1.209	1.591	0.809	0.482	0.471	0.170
PST-York Harbor 4		1.355	2.158	0.865	0.443	0.538	0.139
Rita		1.231	2.021	0.906	0.489	0.528	0.146
Unique		1.453	1.133	0.496	0.342	0.353	0.087
Intolerant mean		1.283	1.540	0.715	0.429	0.454	0.118
LSD(0.05) for cultivar		0.399	0.509	0.313	0.206	0.236	0.108
% Range#		42.649	62.175	63.961	63.061	66.923	85.845
CV(%)		28.909	32.234	41.985	45.697	51.546	95.196

‡ Number in parenthesis indicates degrees of freedom for field study.

†,*,**,*** Significant at $P \leq 0.10, 0.05, 0.01, 0.001$ levels, respectively

§Single df test for the difference between the combined means for wear tolerant and intolerant genotypes.

¶ Test for the differences within wear tolerant or intolerant genotypes.

#[(Max-min)/max] × 100

Wear tolerant and intolerant groups differed in multiple plant characteristics evaluated. Significant differences were found between tolerant and intolerant genotypes for the parameters of fresh weight verdure (Table 3), shoot density (Table 3), moisture content (Table 4), relative turgidity (Table 4), leaf angle (Table 2), total cell wall content (Table 6), and lignocellulose content (Table 6). Groups also differed in vertical leaf extension rate at the 3 and 5 week timing, but that did not hold true for measurements made at 7 weeks after transplanting (Table 7).

Table 6- Pooled means squares (ms) and means averaged over year (2003 and 2004) for percentages of cell wall components measured on 20 genotypes of Kentucky bluegrass representing diverse wear tolerance grown in the greenhouse as space plants and as field plots during 2003 and 2004

Source of variation	df	Total cell wall content GH	Total cell wall content FD	Lignocellulose GH	Lignocellulose FD	Hemicellulose GH	Hemicellulose FD
		ms					
Block	3(2)‡	418.9***	91.8***	19.5	1.8	477.9***	83.4**
Genotype	19	86.3***	23.5**	29.2***	11.1**	57.7*	20.7†
Tolerant vs. intolerant§	1	118.1**	44.5*	66.9*	22.0*	7.2	3.9
Among tolerant¶	9	67.1***	33.2**	37.9***	10.3*	49.4†	25.0†
Among intolerant¶	9	101.9***	11.3	16.3	10.6*	71.7*	18.3
Year	1	1382.0***	165.9	814.8***	95.4***	74.5†	512.9***
Genotype X year	19	25.5	3.7	14.8	14.2***	14.4	15.9
Tolerant vs. intolerant X year	1	19.7	4.8	14.0	3.8	0.5	0.1
Among tolerant X year	9	32.5	3.4*	16.5	17.1	21.3	13.7
Among intolerant X year	9	19.2	3.9	13.2	12.3	9.2*	19.9
Error	117(78)‡	19.3	10.1	10.9	4.9	28.6	12.9
Gentoype		Genotype means					
Wear tolerant		%					
99AN-53		71.2	73.3	32.9	33.6	38.3	39.6
B4-128A		75.6	74.3	33.0	33.2	42.6	41.0
Ba-84-140		71.7	68.7	34.6	30.6	37.1	38.0
Baronie		74.3	71.4	36.7	32.0	37.6	39.5
Goldrush		66.6	71.8	33.3	31.3	33.4	40.4
Limousine		76.2	74.1	38.6	31.9	37.6	42.1
Misty		70.6	67.8	32.7	31.1	37.9	36.6
NA-K991		70.3	70.0	32.4	33.9	38.0	36.0
PST-H8-150		73.5	70.2	31.9	33.3	41.5	36.8
Sonoma		74.3	68.6	35.9	30.3	38.4	38.2
Tolerant mean		72.4	71.0	34.2	32.1	38.2	38.9
Wear intolerant							
A96-451		70.7	68.4	33.6	31.4	37.1	36.9
A97-1409		69.7	69.6	32.2	27.8	37.5	41.8
A97-1439		72.0	70.5	33.4	31.8	38.7	38.7
A98-296		70.3	70.2	33.8	31.9	36.5	38.2
Arcadia		76.7	72.1	36.0	31.2	40.7	40.9
BH 00-6003		70.9	70.9	32.5	32.5	38.4	38.4
Langara		72.0	67.2	33.3	31.0	38.6	36.1
PST-York Harbor 4		63.7	69.4	31.9	30.9	31.7	38.4
Rita		67.0	69.3	31.3	32.5	35.8	36.8
Unique		74.1	70.3	31.1	31.7	43.0	38.6
Intolerant mean		70.7	69.8	32.9	31.3	37.8	38.5
LSD(0.05) for cultivar		4.3	3.7	3.3	2.6	5.3	4.1
% Range#		16.9	9.6	19.4	17.9	26.2	14.5
CV(%)		6.1	4.5	9.8	7.0	14.1	9.3

‡Number in parenthesis indicates degrees of freedom for field study.

†,*,**,*** Significant at $P \leq 0.10$, 0.05, 0.01, 0.001 levels, respectively

§Single df test for the difference between the combined means for wear tolerant and intolerant genotypes.

¶ Test for the differences within wear tolerant or intolerant genotypes

#[(Max-min)/max] × 100

Table 7- Pooled means squares (ms) and means averaged over year (2003 and 2004) of vertical budleaf extension rates (mm d^{-1}) measured on 20 genotypes of Kentucky bluegrass representing diverse wear tolerance grown in the greenhouse as space plants and as field plot clipping yield in 2003 and 2004

		Field plots	Greenhouse plants		
Source of variation	df	clipping yield	3 wks	5 wks	7 wks
		----------------------------ms-------------------------			
Block	3(2)‡	0.136	38.77***	10.16	27.61**
Genotype	19	0.097	24.37***	18.71***	9.13†
Tolerant vs. intolerant§	1	0.017	21.03*	24.41*	0.33
Among tolerant¶	9	0.122	31.15***	23.64***	12.16*
Among intolerant¶	9	0.083	17.96**	13.15*	7.08
Year	1	2.467***	549.45***	688.90***	1511.36
Genotype X year	19	0.063	7.94	7.61	6.79
Tolerant vs. intolerant X year	1	0.007	13.22	3.31	2.31
Among tolerant X year	9	0.057	11.30	5.16	5.43
Among intolerant X year	9	0.076	3.97	10.53	8.66
Error	117(78)‡	0.080	5.76	6.75	5.64
Gentoype		--------------------Genotype means---------------			
Wear tolerant		mg/cm^2	-------------mm d^{-1}----------		
99AN-53		0.680	5.38	7.68	8.78
B4-128A		0.923	2.97	5.06	6.22
Ba-84-140		0.774	5.97	7.44	7.41
Baronie		0.770	8.63	10.34	9.59
Goldrush		0.695	6.41	9.63	8.63
Limousine		0.835	5.88	7.06	6.53
Misty		1.122	6.88	7.56	7.75
NA-K991		0.704	10.28	10.94	9.22
PST-H8-150		0.984	5.19	7.97	6.47
Sonoma		0.877	6.16	8.00	6.91
Tolerant mean		0.836	6.37	8.17	7.75
Wear intolerant					
A96-451		0.793	2.97	6.38	8.63
A97-1409		1.012	6.00	8.34	8.63
A97-1439		0.794	6.09	7.44	6.91
A98-296		0.849	6.41	8.34	8.13
Arcadia		0.753	4.59	6.63	6.25
BH 00-6003		1.128	3.88	4.63	6.72
Langara		0.849	7.09	8.09	8.53
PST-York Harbor4		0.813	6.59	9.03	7.84
Rita		0.797	7.78	8.00	8.38
Unique		0.808	5.06	7.00	6.59
Intolerant mean		0.861	5.65	7.39	7.66
LSD(0.05) for cultivar		0.326	2.38	2.57	2.35
% Range#		39.727	71.12	57.71	35.17
CV(%)		33.425	39.92	33.41	30.85

‡Number in parenthesis indicates degrees of freedom for field study.
†,*,**,*** Significant at $P \leq 0.10, 0.05, 0.01, 0.001$ levels, respectively.
§Single df test for the difference between the combined means for wear tolerant and intolerant genotypes.
¶ Test for the differences within wear tolerant or intolerant genotypes.
#[(Max-min)/max] × 100.

Wear tolerant genotypes had a lower shoot density compared to intolerant genotypes, 3.75 shoots/cm^2 compared to 4.22 shoots/cm^2, respectively (Table 3). No significant group (tolerant vs. intolerant) by year interaction was present. The relationship between groups remained consistent in both 2003 and 2004. In 2003, the tolerant group exhibited a lower shoot density than the intolerant group, 4.06 shoots/cm^2 and 4.61 shoots/cm^2, respectively (Appendix A, Table 17). The same relationship was evident in 2004. The tolerant group exhibited a shoot density of 3.46 shoots/cm^2, while the shoot density for the intolerant group was 3.83 shoots/cm^2 (Appendix B, Table 23).

Wear tolerant genotypes had lower fresh weights compared to intolerant genotypes, 0.565 g/cm^2 compared to 0.641 g/cm^2 , respectively (Table 3). Although a significant group (tolerant vs. intolerant) by year interaction was present, the relationship between groups remained consistent in both 2003 and 2004. In 2003, the tolerant group exhibited a lower fresh weight than the intolerant group, 0.821 g/cm^2 and 0.934 g/cm^2, respectively (Appendix A, Table 17). The same was true in 2004, where the tolerant group exhibited a fresh weight of 0.310 g/cm^2, while the fresh weight for the intolerant group was 0.349 g/cm^2 (Appendix B, Table 23).

This difference in fresh weight between groups may have been related to moisture content. The tolerant group had a lower moisture content, and in turn a lower relative turgidity than the intolerant group, 80.73% to 82.05% and 74.78% to 77.99% respectively (Table 4). This relationship was present in the 2003 and 2004 data as well. In 2003, the observed moisture content relationship was 79.87% for the tolerant group and 81.66% for the intolerant group (Appendix A, Table 21). In terms of relative turgidity, the tolerant group had a group mean of 72.3% as compared to 75.3% for the intolerant group (Appendix A, Table 21). In 2004, the tolerant group again exhibited a lower moisture content and relative turgidity than the intolerant group, 81.59% compared to 82.44% and 77.26% compared to 80.65% respectively (Appendix B, Table 27).

Leaf angle was the attribute yielding the largest difference between wear tolerant and intolerant groups. Wear tolerant genotypes had a steeper leaf angle than intolerant genotypes, 2.04 to 1.21, respectively (Table 2). A significant group (tolerant vs. intolerant) by year interaction was present, yet the relationship between the tolerant and intolerant groups remained constant in both growing seasons. In 2003, tolerant genotypes possessed a steeper leaf angle than did intolerant genotypes, 1.67 and 1.21, respectively (Appendix A, Table 20). This difference was accentuated to a further degree in 2004, with the tolerant group exhibiting a leaf angle of 2.41 as compared to 1.22 for the intolerant group (Appendix B, Table 26).

Tolerant and intolerant groups also exhibited differences in cell wall constituents. Groups differed in total cell wall content (TCW) and lignocellulose content (Table 6). Wear tolerant genotypes had greater total cell wall content and lignocellulose content than intolerant genotypes, 72.4% to 70.7% and 34.2% to 32.9%, respectively (Table 6). These relationships between tolerant and intolerant groups were also observed in both the 2003 and 2004 data. In 2003, the tolerant group contained 75.7% total cell wall content and 36.8% lignocellulose content, as compared to 73.3% and 34.9% for the intolerant group, respectively (Appendix A, Table 18). In 2004, total cell wall content was 69.2% for the tolerant group, as compared to 68.1% for the intolerant group (Appendix B, Table 24). Lignocellulose percentages were 31.6% for the tolerant group, as compared to 30.9% for the intolerant group (Appendix B, Table 24).

Only three attributes were significantly correlated to wear tolerance among greenhouse space plants, leaf angle (r = 0.95, $P \leq 0.001$, Table 8), relative moisture content (r = -0.51, $P \leq 0.05$, Table 8), and relative turgidity (r = -0.43, $P \leq 0.10$, Table 8) . Leaf angle was also significantly correlated to shear strength (traction), (r = 0.51, $P \leq 0.05$, Table 8) as was relative moisture content (r = - 0.45, $P \leq 0.10$, Table 8) and relative turgidity (r = -0.40, $P \leq 0.10$, Table 8)

Table 8- Correlations of the pooled means of plant characteristics compared to 2-year averages of sports turf stresses

	Wear tolerance		Shear strength (traction)	
	Greenhouse	Field	Greenhouse	Field
Leaf characteristics				
Leaf width	0.01	-0.02	-0.09	-0.19
Leaf angle	0.95^{***}	0.69^{***}	0.86^{***}	0.69^{***}
Leaf strength	0.05	-0.17	0.10	-0.28
Total cell wall content	0.29	0.37	0.35	0.30
Lignocellulose	0.35	0.32	0.33	0.35
Hemicellulose	0.10	0.16	0.19	0.06
Whole plant characteristics				
Number of leaves per shoot	0.16	-0.01	0.14	-0.25
Shoot density	-0.30	0.00	-0.15	0.11
Fresh weight (g/cm^2)	-0.26	-0.33	-0.21	-0.34
Dry weight (g/cm^2)	-0.13	-0.14	-0.09	-0.18
Moisture (%)	-0.51^{*}	-0.48^{*}	$-0.45^{\dagger}$	$-0.41^{\dagger}$
Relative turgidity (%)	$-0.43^{\dagger}$	0.13	$-0.40^{\dagger}$	0.00
Sub-surface characteristics				
Root density at 10cm	-0.01	-0.45^{*}	-0.04	-0.53^{*}
Number of rhizomes	0.06	N/A	0.11	N/A

†,*,**,*** Significant at $P \leq$ 0.10, 0.05, 0.01, 0.001 levels, respectively

Field Plots

Genotype differences were present in all attributes measured with the exception of the number of leaves per shoot (Table 2), shoot density (Table 3), and relative turgidity (Table 4). Large genotype differences were present in most plant attributes. Genotype differences were quantified as % range (% range = {[maximum value-minimum value] ÷ maximum value} X 100). Shoot density, fresh weight and leaf angle exhibited the most variation between genotypes. In terms of shoot density, genotypes varied by as much as 61% (Table 3). With fresh weight and leaf angle, genotypes varied by 54.7% (Table 3) and 50.9% (Table 2), respectively. Coefficients of variation were calculated for all attributes measured. The coefficient of variation (CV) was also the smallest for total cell wall content (4.5%, Table 6) and the largest, 33.4%, for 3-day clipping yield (Table 7).

As with the greenhouse space plants, tolerant and intolerant groups differed for the parameters of fresh weight verdure (Table 3), leaf angle (Table 2), total cell wall content, and lignocellulose content (Table 6), and moisture content (Table 4). Although evident within the greenhouse space plants, no difference was present between tolerant and intolerant groups for relative turgidity (Table 4). A significant difference was found between groups for rooting density (mg/cm^3) at the 0 to 10-cm depth interval (Table 5). However, this was not seen in the greenhouse environment.

Wear tolerant genotypes had lower fresh weights compared to intolerant genotypes, 0.068 g/cm^2 compared to 0.076 g/cm^2 , respectively (Table 3). Although a significant group (tolerant vs. intolerant) by year interaction was present, the relationship between tolerant and intolerant groups remained constant in both 2003 and

2004. In 2003, the tolerant group had a lower fresh weight mean than the intolerant group, 0.075 g/cm^2 and 0.087 g/cm^2, respectively (Appendix A, Table 17). The same was true in 2004, where the tolerant group exhibited a fresh weight of 0.061 g/cm^2, while the fresh weight for the intolerant group was 0.066 g/cm^2 (Appendix B, Table 23).

As with the greenhouse space plants, the difference in fresh weight present between groups may have been related to moisture content. The tolerant group had lower moisture content, and in turn lower relative turgidity than the intolerant group, 80.72% to 81.89% and 75.32% to 75.58% respectively (Table 4). This relationship between superior wear tolerance and moisture content was observed in the 2003 and 2004 data as well. In 2003, the tolerant group had a moisture content of 80.58% as compared to 81.61% for the intolerant group (Appendix A, Table 21). In 2004, tolerant and intolerant groups exhibited moisture content values of 80.86% and 82.17% respectively (Appendix B, Table 27). In 2003, the relationship between tolerant and intolerant groups in terms of relative turgidity was not present (Appendix A, Table 21), yet in 2004 it was highly pronounced. In 2004, the tolerant group possessed a relative turgidity of 76.86%, as compared to 78.87% for the intolerant group. (Appendix B, Table 27)

Another relationship present in the field plots that closely resembled the greenhouse space plants occurred in the evaluation of leaf angle. As with the greenhouse environment, the attribute for which the largest difference between wear tolerant and intolerant groups in the field was observed in evaluating leaf angle. Wear tolerant genotypes had a steeper leaf angle from horizontal than intolerant genotypes, 2.0 to 1.5, respectively (Table 2). A significant group (tolerant vs. intolerant) by year interaction was present, however the relationship between the tolerant and intolerant groups remained constant in both growing seasons. In 2003, the tolerant group possessed a steeper leaf angle than the intolerant group, 1.8 and 1.7, respectively (Appendix A, Table 20). This difference was greater in 2004, with the tolerant group exhibiting a mean leaf angle of 2.2 as compared to 1.2 for the intolerant group. (Appendix B, Table 26).

Tolerant and intolerant groups also exhibited differences in cell wall constituents. Groups differed in total cell wall content and lignocellulose content (Table 6). Wear tolerant genotypes had greater total cell wall content and lignocellulose content than intolerant genotypes, 71.0% to 69.8% and 32.1% to 31.3%, respectively (Table 6). This relationship was also present in both the 2003 and 2004 observations as well. In 2003, the tolerant group contained 70.0% total cell wall content and 33.2% lignocellulose content, as compared to 68.4% and 32.0% for the intolerant group, respectively (Appendix A, Table 18). In 2004, total cell wall content was 72.0% for the tolerant group, as compared to 71.2% for the intolerant genotype group (Appendix B, Table 24). Lignocellulose percentages were 31.1% for the tolerant group, as compared to 30.6% for the intolerant group (Appendix B, Table 24)

A relationship present in the field plots that was not observed in the greenhouse space plants occurred in the evaluation of rooting density at the 0-10-cm depth interval. Wear tolerant genotypes possessed fewer roots at this depth than intolerant genotypes, 1.12 to 1.28 mg/cm^3, respectively (Table 5). No significant group (tolerant vs. intolerant) by year interaction was detected, although the relationship between the tolerant and intolerant groups did not remain constant in both growing seasons. In 2003, tolerant genotypes had a larger root mass at the 0-10-cm depth than did intolerant genotypes, 1.16 and 1.37 mg/cm^3, respectively (Appendix A, Table 19). In 2004 tolerant genotypes possessed a smaller root mass at the 0-10-cm depth, 1.07 mg/cm^3, as compared to 1.20 mg/cm^3 for intolerant genotypes (Appendix B, Table 25).

Those attributes, leaf angle and relative moisture content, that were significantly correlated to wear tolerance among greenhouse space plants were also significantly correlated to wear tolerance in the field plots. Leaf angle was highly correlated to wear tolerance (r = 0.69, $P \leq 0.001$, Table 8), as was moisture content was to a lesser extent (r = -0.48, $P \leq 0.001$, Table 8). Rooting density at the 0 to 10-cm depth was also correlated to wear tolerance among field plots (r = 0.45, $P \leq 0.05$, Table 8). Leaf angle, (r = 0.69, $P \leq 0.05$, Table 8), moisture content (r = -0.41, $P \leq 0.10$, Table 8) and rooting density at the 0 to 10cm depth (r = -0.53, $P \leq 0.05$, Table 8) were all correlated to shear strength (traction) in addition to wear tolerance.

Recovery rates were also measured on field plots in the spring of 2003 to investigate whether tolerance to wear stress was related to recovery rate. Relative green-up ratings, measuring the rate of green-up from the worn portion of the plot in comparison to the unworn “check” portion, showed wear tolerant genotypes to have faster rate of green-up than intolerant genotypes (Table 9). Relative turfgrass quality ratings were taken throughout the spring until the worn portion of the plot was equivalent in quality to the unworn check. Worn portions of wear tolerant plots reached quality ratings equal to their corresponding unworn check portions sooner than intolerant plots (Table 9). Recovery rate measurements were not made in the spring of 2004.

Table 9- Means squares (ms) and means for relative turfgrass quality ratings of worn field plots in relation to their unworn check plots in the spring of 2003

Source of variation	df	Relative green-up[‡] 4/3/03-4/13/03	Relative turfgrass quality[§] 4/19/03	5/18/03
		ms		
Block	2	0.064*	0.019	0.196
Genotype	19	0.038*	0.051*	0.047***
Tolerant vs. intolerant[¶]	1	0.359***	0.518***	0.362***
Error	38	0.018	0.023	0.014
Gentoype		Genotype means		
Wear tolerant		relative quality		
99AN-53		0.59	0.75	1.00
B4-128A		0.81	0.74	0.95
Ba-84-140		0.59	0.71	1.00
Baronie		0.65	0.66	1.00
Goldrush		0.60	0.66	0.79
Limousine		0.82	0.74	1.00
Misty		0.57	0.85	1.00
NA-K991		0.72	0.80	1.15
PST-H8-150		0.67	0.68	0.94
Sonoma		0.53	0.56	0.84
Tolerant mean		0.65	0.72	0.97
Wear intolerant				
A96-451		0.52	0.42	0.89
A97-1409		0.46	0.52	0.85
A97-1439		0.51	0.51	0.85
A98-296		0.53	0.51	0.78
Arcadia		0.48	0.53	0.75
BH 00-6003		0.42	0.52	0.73
Langara		0.48	0.46	0.63
PST-York Harbor4		0.60	0.60	0.82
Rita		0.58	0.78	1.01
Unique		0.43	0.44	0.79
Intolerant mean		0.50	0.53	0.81
LSD(0.05) for cultivar		0.22	0.25	0.19
% Range[‡‡]		48.89	47.50	45.21
CV(%)		23.00	24.22	13.11

‡Relative green-up = 1 –{[(Green-up, non-wear)-(Green-up, wear)]/(Green-up, non-wear)}, 0 to 1 scale. with 1= green-up on the wear plot equal to unworn check.

§ Relative turfgrass quality rated on a 0 to 1 scale, with 1= total quality in wear plot equal to non-wear check plot.

†,*,**,*** Significant at $P \leq$ 0.10, 0.05, 0.01, 0.001 levels, respectively.

¶Single df test for the difference between the combined means for wear tolerant and intolerant genotypes.

Test for the differences within wear tolerant or intolerant genotypes.

‡‡[(Max-min)/max] × 100.

Conclusion

These results provide evidence that certain plant characteristics are associated with superior tolerance to wear stress in Kentucky bluegrass genotypes. The combination of a low moisture content and low relative turgidity allow for increased elasticity in the leaf blade (Beard, 1973). This concept of increased leaf blade elasticity was associated with superior wear tolerance in this study. This relationship between superior wear tolerance and the concept of an "elastic leaf blade" was also observed by Trenholm et al. (2000) within seashore paspalum genotypes. Sun and Liddle (1993) also concluded that leaf flexibility (i.e. elasticity) was of greater importance than leaf strength in imparting wear tolerance. In this study, leaf strength was not important in Kentucky bluegrass wear tolerance.

A reduction in plant moisture content and relative turgidity was found to be associated with superior wear tolerance in this evaluation. These relationships are similar to those observed by Trenholm et al. (2001), yet they are contrary to those observed by Shearman and Beard (1975c). Shearman and Beard (1975c) found moisture content, relative turgidity, and the combined effects of those two factors to have no significant association with improved interspecies wear tolerance. The variation accounted for in that work is much larger than the variation found in this experiment, as all units in this experiment are of the same species. Differences found between species will be more variable than those evaluated on an intraspecies level. Thus, the relationship observed between superior wear tolerance and moisture content, as well as relative turgidity, in Shearman and Beard's (1975c) results at the interspecies level are not necessarily relevant to studies conducted at the intraspecific level.

Similarities to Shearman and Beard's work were also present in this analysis. Cell wall constituents were also found to be significantly associated with superior wear tolerance. Similar to Shearman and Beard (1975b), increased total cell wall content, as well as greater lignocellulose content was associated with wear tolerance. Shearman and Beard (1975b) found hemicellulose to be associated with interspecies wear tolerance. No association between hemicellulose content and superior wear tolerance was observed in this evaluation. Increases in the quantities of cell wall constituents, be they cellulose, hemicellulose, lignin, or a combination of all three, will increase the durability of plant tissues (Van Soest, 1994). This increase in durability will allow for improved genotype performance under wear stress (wear tolerance).

The greatest difference between wear tolerant and intolerant genotypes was observed in the measurement of leaf angle. Genotypes possessing a steeper leaf angle from horizontal were associated with having superior wear tolerance. The association between leaf angle and wear tolerance can be viewed in the canopy structure. Genotypes with a more horizontal leaf orientation provide more leaf tissue per unit area to be subjected to stress. Horizontally oriented leaf tissues lie on a plane more parallel to the soil surface. Genotypes with a more vertical leaf orientation will have less tissue on this parallel plane, thus less tissue available to be exposed to the horizontal forces present in wear stress. Also, increases in leaf blade elasticity (lower moisture content and relative turgidity) will prevent crushing of tissues from the vertical forces involved in wear stress. This reduction of the effects associated with both the horizontal and vertical forces involved in wear stress can lead to superior wear tolerance in Kentucky bluegrass genotypes. Measurements such as leaf angle can be determined directly or indirectly (visual rating) and are routinely assessed by turfgrass breeders.

In conclusion, it is important to recognize that the plant characteristics associated with wear tolerance and shear strength (traction) in this study may only be relevant to Kentucky bluegrass genotypes. Turfgrass species and genotypes vary considerably in their anatomical and morphological characteristics associated with wear tolerance, which can be altered by cultural practices and management strategies. This research, as well as previous research, has shown that factors that are associated with wear tolerance in one species may have no relationship to other species. Thus, further research is needed to determine the factors (mechanisms) that lead to superior wear tolerance in all species. By understanding wear mechanisms, selection criteria can be developed to aid breeders in developing improved turfgrasses for use in the sports turf industry and help practioners to develop better management strategies.

APPENDICES

APPENDIX A

2003 TABLES

Table 10- Mean squares (ms) and means of root lengths (mm) and number of rhizomes measured on 20 genotypes of Kentucky bluegrass representing diverse wear tolerance grown in the greenhouse as space in
2003

Source of variation	df	Rhizome number	Root Length 3 wks	5 wks	7 wks
		ms			
Block	3	4.90	1964.6	9166.0	5337.0
Genotype	19	39.98***	2741.9***	9941.0***	8035.0*
Tolerant vs. intolerant§	1	14.45	0.0	174.0	174.1
Among tolerant¶	9	63.58***	3514.2***	12159.0***	12159.0***
Among intolerant¶	9	19.22	2274.3*	8807.5**	8807.5**
Error	57	12.03	899.5	3022.0	4286.0
Gentoype		Genotype means			
Wear tolerant		no.	mm		
99AN-53		12.8	227.8	402.3	574.5
B4-128A		6.0	148.5	279.5	485.5
Ba-84-140		5.5	178.3	354.5	542.5
Baronie		11.5	190.0	405.0	602.5
Goldrush		10.0	219.8	430.0	619.5
Limousine		14.0	235.0	476.0	642.5
Misty		14.3	196.3	387.5	604.3
NA-K991		3.3	171.3	354.5	537.8
PST-H8-150		5.3	160.8	333.5	505.8
Sonoma		10.3	215.5	412.0	588.5
Tolerant mean		9.3	194.3	383.5	570.3
Wear intolerant					
A96-451		8.5	235.3	497.8	651.0
A97-1409		7.0	186.3	367.0	563.5
A97-1439		6.5	179.3	357.5	554.5
A98-296		9.8	224.0	409.8	615.0
Arcadia		9.0	160.5	342.8	533.3
BH 00-6003		13.3	196.8	375.5	579.0
Langara		7.8	168.3	340.0	547.5
PST-York Harbor4		5.5	208.8	351.3	516.8
Rita		7.3	181.5	365.3	582.8
Unique		9.8	202.5	398.5	603.5
Intolerant mean		8.4	194.3	380.5	574.7
LSD(0.05) for cultivar		4.9	42.4	77.7	92.6
% Range#		77.2	36.9	41.3	24.4
CV(%)		39.2	15.4	14.4	11.4

†,*,**,*** Significant at $P \leq$ 0.10, 0.05, 0.01, 0.001 levels, respectively

§Single df test for the difference between the combined means for wear tolerant and intolerant genotypes.

¶ Test for the differences within wear tolerant or intolerant genotypes.

#[(Max-min)/max] × 100

Table 11- Correlations between the means of various plant characteristics measured in field plots in 2003

	Leaf strength	Leaf width	Leaves /shoot	Shoots /cm^2	Fresh weight	Dry weight	Leaf angle	Moisture	Turgidity	Root density	Total cell wall	Ligno cell.	Hemi-Cell
Leaf strength													
Leaf width	0.759												
Leaves/shoot	0.087	0.167											
Shoots/cm^2	-0.598	-0.703	0.014										
Fresh weight	-0.555	-0.484	0.356	0.606									
Dry weight	-0.559	-0.530	0.289	0.657	0.945								
Leaf angle	-0.232	-0.374	0.204	0.656	0.276	0.322							
Moisture	-0.107	0.070	0.331	-0.027	0.331	0.012	-0.093						
Turgidity	-0.311	-0.152	0.241	0.244	0.352	0.141	0.222	0.703					
Root Density	0.059	-0.113	0.149	0.229	0.298	0.186	0.215	0.350	0.142				
Total cell wall	-0.038	-0.169	-0.184	0.267	-0.092	0.044	0.712***	-0.489*	-0.114	0.000			
Lignocellulose	-0.101	-0.120	-0.339	-0.034	-0.352	-0.273	-0.045	-0.306	-0.063	-0.142	0.244		
Hemicellulose	0.062	-0.016	0.168	0.223	0.246	0.274	0.566**	-0.082	-0.026	0.126	0.507*	-0.712***	

†,*,**,*** Significant at $P \leq$ 0.10, 0.05, 0.01, 0.001 levels, respectively

Table 11- Correlations between the means of various plant characteristics measured in greenhouse space plants in 2003

	Leaf strength	Leaf width	Leaves /shoot	Shoots /cm^2	Fresh weight	Dry weight	Leaf angle	Moisture	Turgidity	Root density	Rhizomes	T. cell wall	Ligno. cell.	Hemi. cell.
Leaf strength														
Leaf width	0.659^{***}													
Leaves/shoot	0.030	-0.206												
Shoots/cm^2	0.025	-0.319	0.138											
Fresh weight	0.368	0.359	-0.042	0.615										
Dry weight	0.393	0.441^{*}	-0.052	0.484	0.945									
Leaf angle	0.243	0.120	0.364	-0.454	-0.209	-0.140								
Moisture	-0.108	-0.125	-0.015	0.426	0.267	-0.039	$-0.412^{\dagger}$							
Turgidity	0.093	0.079	-0.372	-0.071	-0.060	-0.242	-0.155	0.490^{*}						
Root Density	$0.394^{\dagger}$	0.683^{***}	-0.217	0.125	0.736^{***}	0.837^{***}	-0.041	-0.141	-0.161					
Rhizomes	$0.403^{\dagger}$	0.315	0.483^{*}	0.040	0.222	0.195	0.350	0.115	-0.228	0.210				
Total cell wall	-0.055	-0.476^{*}	0.615^{***}	0.183	-0.229	-0.301	0.199	0.118	-0.308	-0.558^{**}	0.313			
Lignocellulose	-0.096	0.010	0.572^{**}	-0.076	-0.041	0.015	0.300	0.040	-0.218	-0.024	$0.392^{\dagger}$	0.674^{***}		
Hemicellulose	-0.164	-0.654^{***}	0.304	0.318	-0.347	$-0.42^{\ddagger}$	-0.008	0.123	-0.216	-0.733^{***}	0.061	0.730^{***}	-0.012	

†,*,**,*** Significant at $P \leq 0.10$, 0.05, 0.01, 0.001 levels, respectively

Table 12- Correlations between the means of various plant characteristics measured in field plots and greenhouse space plants in 2003

	Greenhouse space plants												
Field Plots	Leaf strength	Leaf width	Leaves /shoot	Shoots /cm^2	Fresh weight	Dry weight	Leaf angle	Moisture	Turgidity	Root density	Total cell wall	Ligno- cell	Hemi- cell
Leaf strength	0.371†												
Leaf width		0.623***											
Leaves/shoot			0.484*										
Shoots/cm^2				0.571**									
Fresh weight					0.042								
Dry weight						-0.173							
Leaf angle							0.146						
Moisture								0.113					
Turgidity									-0.134				
Root Density(10cm)										0.022			
Total cell wall											0.254		
Lignocellulose												-0.298	
Hemicellulose													0.035

†,*,**,*** Significant at P≤ 0.10, 0.05, 0.01, 0.001 levels, respectively

Table 13-2003 Greenhouse Temperature Data (°C)

Date	Average Temp.	Max. Temp.	Min Temp
17-Apr	20.8	26.0	15.6
20-Apr	23.4	29.8	17.0
21-Apr	23.5	30.7	16.4
22-Apr	23.4	29.9	17.0
23-Apr	23.1	29.7	16.6
24-Apr	22.8	29.2	16.4
27-Apr	22.6	30.0	15.3
28-Apr	26.1	35.4	16.8
29-Apr	25.6	36.8	14.5
30-Apr	22.8	30.7	14.9
1-May	19.7	22.3	17.2
2-May	25.4	34.9	16.0
4-May	22.8	30.4	15.2
5-May	23.2	29.5	16.9
6-May	21.6	26.3	17.4
7-May	26.9	36.7	17.1
8-May	OL	OL	17.1
9-May	25.7	34.6	16.9
10-May	24.8	33.7	15.9
11-May	12.8	31.0	-5.3
12-May	19.1	23.5	14.2
13-May	20.4	24.7	16.2
14-May	24.9	33.8	16.1
15-May	24.1	33.8	14.4
16-May	-----	-----	14.7
18-May	25.8	37.8	13.8
21-May	31.0	45.8	16.2
22-May	18.8	23.0	14.7
23-May	17.9	21.7	14.2
24-May	21.8	27.0	16.6
25-May	18.7	21.0	16.5
26-May	N/A	32.2	N/A
27-May	22.3	29.4	15.2
28-May	26.4	35.3	17.5
29-May	34.7	53.1	16.4
30-May	21.3	25.1	17.6
31-May	19.2	23.2	15.3
1-Jun	24.0	32.4	15.6
2-Jun	28.3	39.6	17.1
3-Jun	19.0	21.0	17.0
4-Jun	27.2	38.8	15.6
Mean	23.2	31.0	15.5
Standard Dev	3.8	6.7	3.5

Table 14- Turf quality scores (0 to 9 scale, before wear) and ground cover ratings (0 to 9 scale, 0 = 0 to 10% ground cover and 9 = 90 to 100% ground cover, after wear) for field plots in 2002 and 2003

Cultivar	Turf Quality 10/24/02	Ground Cover Rating Fall 2002	Turf Quality 10/22/03	Ground Cover Rating Fall 2003
	--------------------------0 to 9	------------------------		
Midnight	7.0	7.0	6.3	7.7
Baron	6.3	5.8	5.7	7.0
Lily	5.3	5.9	4.7	4.9
Limerick	5.6	6.5	6.0	6.6
Bodacious	6.0	7.1	4.7	6.4
Bedazzled	7.6	7.0	7.0	7.8
Boomerang	5.3	6.8	5.3	6.8
Eagleton	7.0	6.3	6.0	7.2
HV 140	4.6	5.1	5.3	5.2
Pp H 6370	6.6	6.7	6.0	7.0
Pp H 6366	7.6	7.3	7.0	7.3
Pp H 7929	6.6	6.9	5.3	7.1
Pp H 7832	6.0	7.3	6.3	7.1
Pp H 7907	6.0	6.7	4.0	6.6
Monte Carlo (A96-402)	6.6	5.9	5.7	6.2
Royale (A97-1336)	7.0	6.6	5.0	6.6
Shamrock	6.3	5.5	5.0	5.3
Wellington	4.6	5.5	3.7	5.3
Wildwood	6.6	6.3	6.3	7.1
Hallmark	6.6	7.0	4.0	7.7
Lakeshore (A93-200)	7.0	7.1	5.7	7.6
Glenmont (H94-293)	7.6	6.7	6.3	7.2
Coventry	6.6	6.3	4.3	6.2
AVALANCHE (PST-1701)	6.3	7.1	6.3	7.7
PST-B5-125	6.6	6.8	6.0	6.8
PST-604	6.6	6.2	5.3	5.6
PST-108-79	7.0	5.5	6.3	6.1
Voyager II (PST-1QG-27)	8.0	6.6	6.7	8.0
PST-161	6.0	6.1	6.0	6.4
Bluemax (PST-B5-89)	7.3	6.7	6.3	6.6
Brilliant	8.0	6.9	7.0	7.7
PST-222	7.3	6.4	6.0	6.1
Midnight II (A98-739)	6.6	6.9	6.3	6.8
PST-York Harbor 4	6.3	5.0	6.0	4.9
Blacksburg II (PST-1BMY)	7.0	5.8	6.0	5.4
Mallard (A97-1439)	6.6	5.1	6.0	6.8
Blue Ridge (A97-1449)	7.3	5.8	6.3	5.7

(continued on next page)

Table 15-continued

Cultivar	Turf Quality 10/24/02	Ground Cover Rating Fall 2002	Turf Quality 10/22/03	Ground Cover Rating Fall 2003
	---------------------------0 to 9------------------------			
Apollo	7.3	6.8	6.7	7.3
A97-1432	7.6	7.3	6.0	7.9
HV 238	6.6	6.3	6.0	7.3
Mercury (Pick-232)	7.0	5.2	6.0	5.2
Arrow (A97-1567)	6.6	6.7	7.0	6.7
PST-1804	7.0	6.9	5.7	6.6
B3-185	7.6	6.6	6.0	6.4
B5-43	4.3	6.2	4.3	6.7
B5-45	4.3	5.3	4.3	6.4
1B7-308	7.0	7.3	6.0	7.0
H92-203	7.3	6.2	6.3	7.3
B3-171	7.6	6.2	6.3	7.3
B5-144	3.6	6.1	4.7	6.3
PST-B4-246	7.0	6.6	5.7	6.6
PST-H6-150	7.0	7.4	6.3	7.8
Alpine	6.0	6.7	5.7	7.4
Pick 453	6.3	5.8	6.0	6.4
Pick 417	6.0	6.9	6.7	6.4
Limousine	7.3	8.1	7.3	7.6
Quantum Leap	6.6	6.8	7.0	7.8
Envicta	6.3	6.5	5.7	6.4
Goldrush	6.6	7.5	5.0	7.6
Misty	6.3	7.8	5.7	7.1
Ascot	7.3	6.9	4.0	7.0
BH 00-6002	6.3	6.3	6.0	6.8
Fairfax	5.6	5.5	4.3	6.0
Abbey	6.3	7.0	5.7	7.2
BH 00-6003	6.0	4.7	5.0	5.4
Baronette (Ba 81-058)	6.3	5.2	5.0	5.4
Raven	6.0	6.6	5.7	6.8
Ba 83-113	6.6	6.4	5.7	6.7
Marquis	6.6	6.5	5.7	7.0
Ba 84-140	7.6	7.6	6.0	6.3
Ba 82-288	6.3	6.4	5.3	7.1
Chateau	5.6	6.8	4.3	6.4
Ba 00-6001	7.3	6.5	5.7	6.4
CVB-20631	6.3	6.6	6.3	7.2
Chelsea	7.0	6.4	5.0	6.2
A97-1409	6.6	5.2	5.3	6.2
A96-451	7.6	5.2	6.3	5.4

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Table 15-continued

Cultivar	Turf Quality 10/24/02	Ground Cover Rating Fall 2002	Turf Quality 10/22/03	Ground Cover Rating Fall 2003
	---------------------------0 to 9	------------------------		
Julius	7.3	6.9	6.0	5.8
Allure	2.6	4.2	4.0	5.4
A97-1330	7.6	6.9	6.3	7.2
H92-558	6.3	6.6	6.3	7.6
Julia	6.6	6.8	6.3	7.7
Brooklawn	6.6	7.2	5.3	6.9
Boutique	7.3	6.3	6.3	7.8
Markham (NA-K991)	6.0	7.9	5.0	7.4
NA-K992	5.3	5.9	4.3	5.2
Showcase	7.6	6.0	6.7	7.2
Arcadia	6.6	5.1	6.7	6.2
SRX 2394	7.3	5.8	7.3	6.0
SRX 26351	6.6	6.8	6.0	7.0
SRX 27921	4.3	5.9	4.0	6.4
Sonoma	7.6	7.4	6.3	6.7
Bordeaux	7.3	6.3	6.7	7.1
Cabernet	6.3	5.5	5.7	5.8
Champagne	7.0	7.3	6.3	7.4
A96-427	7.0	5.9	5.0	5.9
A97-1715	7.0	7.1	6.0	7.3
Jewel	7.0	5.3	5.3	6.1
Unknown	7.0	5.8	6.7	5.6
Blue Knight	6.0	6.7	4.7	6.8
DLF 76-9032	6.6	6.5	7.0	5.9
DLF 76-9034	5.3	5.1	6.0	5.7
DLF 76-9036	7.0	6.9	6.0	6.9
DLF 76-9037	7.0	6.3	7.0	6.8
SI A96-386	7.3	6.3	6.3	6.6
SRX 2114	7.0	6.0	5.7	7.1
SR 2284 (SRX 2284)	7.3	6.1	7.0	6.0
Pro Seeds - 453	7.3	6.4	6.3	6.6
SRX QG245	6.3	6.1	4.3	6.4
99AN-53	7.0	7.4	5.7	7.3
A98-881	6.3	6.9	5.3	6.4
Jefferson	6.6	6.4	6.0	6.9
A98-407	8.0	6.6	6.7	7.2
A98-1028	6.6	7.0	6.0	7.2
A98-183	6.6	6.1	5.3	6.6
Champlain (A98-1275)	7.0	6.6	6.3	6.8
Goldstar (A98-296)	7.0	5.0	6.3	5.3

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Table 15-continued

Cultivar	Turf Quality 10/24/02	Ground Cover Rating Fall 2002	Turf Quality 10/22/03	Ground Cover Rating Fall 2003
	--------------------------0 to 9-----------------------			
Royce (A98-304)	7.6	6.6	7.0	6.9
A98-139	5.6	5.9	5.0	6.1
A98-365	7.6	6.6	5.7	6.3
Kenblue	4.3	4.8	3.3	6.6
Princeton 105	6.6	7.2	6.7	8.8
Impact	6.6	6.4	6.3	7.1
Total Eclipse	7.0	6.7	7.0	6.4
Odyssey	6.6	6.1	6.7	6.3
Chicago II	6.6	5.8	7.0	5.9
NuGlade	6.6	5.9	6.7	6.6
Perfection (J-1515)	6.6	6.6	7.0	7.2
Tsunami (J-2487)	6.3	6.1	6.3	6.2
Ginney (J-1368)	6.0	6.6	7.3	6.2
J-1838	6.3	6.5	7.0	7.1
J-2561	6.6	5.8	7.0	6.2
J-2885	6.6	6.3	6.7	6.7
J-1513	7.0	5.9	6.7	6.3
Everest	7.0	6.5	6.7	6.3
Awesome (J-1420	6.3	6.7	7.0	7.0
Excursion (J-1648)	6.6	6.8	7.0	6.9
J-2890	6.6	7.2	7.0	7.0
EverGlade	7.0	6.2	6.7	6.4
NU Destiny (J-2695)	7.0	5.6	6.7	6.3
Barrister (J-1655)	6.3	6.4	6.7	6.8
Beyond (J-1880)	7.0	6.3	7.0	6.3
Rugby II	6.6	5.9	6.3	7.7
Award	6.6	6.4	6.7	7.1
Rambo	6.3	6.5	6.7	7.7
Freedom II	6.6	6.6	6.3	6.4
Liberator	6.6	6.2	6.7	6.2
GO-9LM9	4.3	3.3	2.3	3.8
Moon Shadow (Pick 113-3)	6.6	6.2	6.7	6.6
Langara	7.0	4.4	7.0	6.6
A96-739	7.0	6.3	6.3	6.8
PST-H5-35	7.3	6.5	5.7	6.2
PST-B3-170	7.0	5.8	6.3	7.2
B4-128A	7.6	8.1	6.7	8.2
Bluestone (PST-731)	6.3	6.2	7.0	6.6
Washington	7.0	6.5	6.0	7.3
A96-742	7.0	6.3	6.0	6.2

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Table 15-continued

Cultivar	Turf Quality 10/24/02	Ground Cover Rating Fall 2002	Turf Quality 10/22/03	Ground Cover Rating Fall 2003
	---------------------------0 to 9	-----------------------		
A97-857	5.0	7.2	4.3	7.7
BAR Pp 0468	7.6	7.2	6.7	8.2
BAR Pp 0471	7.3	6.0	6.3	6.4
BAR Pp 0566	7.0	7.1	6.0	6.7
BAR Pp 0573	7.0	6.4	7.3	7.7
Bartitia	6.3	6.8	5.3	6.9
Baritone	6.3	7.3	5.3	7.8
Bariris	6.6	6.7	6.7	7.1
Barzan	6.6	6.2	6.0	6.9
Baronie	7.0	7.6	7.0	7.9
Unique	8.0	5.2	7.0	6.6
Serene	7.0	6.1	6.7	6.6
Moonlight	7.3	6.7	5.3	6.4
Blackstone	6.6	6.3	6.3	8.3
Rita	6.0	5.1	5.3	5.8
North Star	6.6	6.9	6.0	7.0
LSD (0.05) for Cultivar	**0.9**	**0.9**	**0.9**	**1.4**

Table 15- Shear strength measurements (Nm) on field plots in the fall of 2001, 2002, and 2003

Cultivar	Shear Strength Fall 2001	Shear Strength Fall 2002	Pooled Shear Strength 2001-2002	Shear Strength Fall 2003
	-------------------------	---Nm---	-------------------------	
Midnight	41.3	46.3	43.8	51.5
Baron	41.0	53.0	47.0	56.7
Lily	42.0	47.5	44.8	54.5
Limerick	39.5	49.0	44.3	58.7
Bodacious	37.8	48.7	43.3	60.0
Bedazzled	40.7	50.0	45.3	58.8
Boomerang	40.3	48.8	44.6	55.3
Eagleton	40.3	49.3	44.8	58.3
HV 140	43.3	47.2	45.3	59.7
Pp H 6370	42.7	49.0	45.8	55.0
Pp H 6366	42.2	48.8	45.5	51.0
Pp H 7929	39.8	49.0	44.4	54.3
Pp H 7832	39.2	48.8	44.0	55.0
Pp H 7907	39.7	45.2	42.4	55.3
Monte Carlo (A96-402)	43.0	50.2	46.6	59.5
Royale (A97-1336)	42.3	48.2	45.3	60.5
Shamrock	42.5	47.7	45.1	57.5
Wellington	41.3	48.8	45.1	55.5
Wildwood	38.3	47.5	42.9	54.5
Hallmark	38.8	48.2	43.5	54.7
Lakeshore (A93-200)	39.5	49.3	44.4	54.7
Glenmont (H94-293)	42.3	49.8	46.1	55.2
Coventry	38.2	49.8	44.0	54.0
AVALANCHE (PST-1701)	40.7	53.3	47.0	58.8
PST-B5-125	38.3	50.3	44.3	55.3
PST-604	40.8	48.7	44.8	57.0
PST-108-79	40.8	50.3	45.6	55.3
Voyager II (PST-1QG-27)	42.7	47.3	45.0	54.8
PST-161	41.0	48.8	44.9	59.0
Bluemax (PST-B5-89)	42.8	50.8	46.8	57.3
Brilliant	43.0	48.5	45.8	57.5
PST-222	39.7	44.2	41.9	50.7
Midnight II (A98-739)	42.5	48.5	45.5	57.7
PST-York Harbor 4	37.7	44.7	41.2	52.0
Blacksburg II (PST-1BMY)	37.7	50.0	43.8	56.7
Mallard (A97-1439)	40.2	49.5	44.8	55.0
Blue Ridge (A97-1449)	39.0	47.7	43.3	53.5

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Table 16-continued

Cultivar	Shear Strength Fall 2001	Shear Strength Fall 2002	Pooled Shear Strength 2001-2002	Shear Strength Fall 2003
	---------------------------	---Nm---	---------------------------	
Apollo	42.2	48.7	45.4	58.5
A97-1432	41.2	49.0	45.1	56.2
HV 238	40.5	52.0	46.3	59.3
Mercury (Pick-232)	44.2	54.0	49.1	59.3
Arrow (A97-1567)	41.5	48.5	45.0	58.5
PST-1804	40.8	49.7	45.3	57.5
B3-185	42.8	49.3	46.1	58.5
B5-43	41.0	49.7	45.3	55.5
B5-45	42.7	46.2	44.4	56.5
1B7-308	41.7	47.7	44.7	57.8
H92-203	41.7	47.2	44.4	56.2
B3-171	42.5	51.3	46.9	59.5
B5-144	40.7	46.3	43.5	57.7
PST-B4-246	39.8	49.8	44.8	55.0
PST-H6-150	40.5	49.8	45.2	54.7
Alpine	38.8	45.8	42.3	54.0
Pick 453	41.5	47.5	44.5	59.5
Pick 417	42.8	49.2	46.0	58.5
Limousine	41.8	51.5	46.7	55.0
Quantum Leap	41.7	48.5	45.1	55.8
Envicta	40.2	48.0	44.1	58.3
Goldrush	39.7	51.2	45.4	55.2
Misty	38.7	49.3	44.0	51.0
Ascot	38.8	47.5	43.2	55.5
BH 00-6002	39.7	51.2	45.4	57.7
Fairfax	41.5	45.2	43.3	57.7
Abbey	39.2	46.3	42.8	54.7
BH 00-6003	40.8	48.7	44.8	59.8
Baronette (Ba 81-058)	39.3	46.7	43.0	55.7
Raven	42.0	50.8	46.4	57.3
Ba 83-113	39.5	50.7	45.1	56.3
Marquis	41.3	51.8	46.6	56.5
Ba 84-140	41.3	48.2	44.8	56.7
Ba 82-288	39.3	48.8	44.1	57.0
Chateau	39.7	46.7	43.2	58.3
Ba 00-6001	44.2	52.7	48.4	60.2
CVB-20631	39.2	47.8	43.5	56.7
Chelsea	39.7	47.3	43.5	55.7
A97-1409	40.3	46.3	43.3	53.8
A96-451	41.3	47.0	44.2	55.3

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Table 16-continued

Cultivar	Shear Strength Fall 2001	Shear Strength Fall 2002	Pooled Shear Strength 2001-2002	Shear Strength Fall 2003
	--------------------------Nm----------------------			
Julius	39.5	46.8	43.2	54.5
Allure	39.5	46.2	42.8	56.5
A97-1330	41.3	49.8	45.6	56.3
H92-558	39.5	51.0	45.3	58.7
Julia	40.3	49.5	44.9	55.8
Brooklawn	42.7	49.7	46.2	59.8
Boutique	41.2	48.0	44.6	55.2
Markham (NA-K991)	40.0	50.7	45.3	59.3
NA-K992	42.0	54.3	48.2	58.7
Showcase	42.5	51.0	46.8	56.8
Arcadia	41.7	49.3	45.5	59.8
SRX 2394	42.5	49.0	45.8	54.5
SRX 26351	42.0	50.7	46.3	57.0
SRX 27921	37.0	50.0	43.5	56.7
Sonoma	41.0	49.7	45.3	55.2
Bordeaux	40.8	49.2	45.0	55.8
Cabernet	41.5	51.3	46.4	59.8
Champagne	41.8	51.5	46.7	55.8
A96-427	42.8	50.7	46.8	59.3
A97-1715	43.2	51.8	47.5	58.2
Jewel	41.2	48.7	44.9	57.7
Unknown	41.0	48.0	44.5	58.7
Blue Knight	42.7	51.2	46.9	54.3
DLF 76-9032	44.0	48.8	46.4	55.2
DLF 76-9034	38.0	52.3	45.2	59.3
DLF 76-9036	40.3	53.2	46.8	56.2
DLF 76-9037	41.3	52.8	47.1	57.8
SI A96-386	41.2	46.8	44.0	53.3
SRX 2114	37.3	46.8	42.1	53.0
SR 2284 (SRX 2284)	39.3	47.5	43.4	56.7
Pro Seeds - 453	42.5	51.0	46.8	55.7
SRX QG245	38.3	52.2	45.3	56.8
99AN-53	43.0	51.3	47.2	58.0
A98-881	41.7	48.7	45.2	60.2
Jefferson	41.0	49.2	45.1	53.3
A98-407	40.5	49.7	45.1	54.0
A98-1028	41.3	46.8	44.1	53.0
A98-183	40.2	46.3	43.3	53.8
Champlain (A98-1275)	42.7	53.5	48.1	60.5
Goldstar (A98-296)	41.7	45.8	43.8	53.7

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Table 16-continued

Cultivar	Shear Strength Fall 2001	Shear Strength Fall 2002	Pooled Shear Strength 2001-2002	Shear Strength Fall 2003
	-----------------------------	Nm	-----------------------------	
Royce (A98-304)	39.8	49.3	44.6	61.2
A98-139	39.7	49.3	44.5	57.8
A98-365	40.2	46.7	43.4	55.3
Kenblue	40.5	45.7	43.1	57.7
Princeton 105	41.8	52.3	47.1	57.8
Impact	41.3	47.0	44.2	54.3
Total Eclipse	43.5	47.8	45.7	57.7
Odyssey	44.7	48.2	46.4	53.7
Chicago II	39.5	45.3	42.4	54.3
NuGlade	40.5	50.3	45.4	55.7
Perfection (J-1515)	40.8	49.3	45.1	52.2
Tsunami (J-2487)	40.3	51.2	45.8	58.3
Ginney (J-1368)	43.3	47.3	45.3	56.3
J-1838	41.7	47.3	44.5	57.0
J-2561	39.2	46.0	42.6	56.0
J-2885	42.0	51.7	46.8	59.2
J-1513	41.5	45.7	43.6	54.2
Everest	40.3	50.3	45.3	58.5
Awesome (J-1420	39.0	49.7	44.3	55.8
Excursion (J-1648)	43.8	50.0	46.9	54.8
J-2890	39.3	47.3	43.3	53.2
EverGlade	40.3	47.0	43.7	52.7
NU Destiny (J-2695)	42.0	49.7	45.8	58.2
Barrister (J-1655)	41.5	46.8	44.2	54.3
Beyond (J-1880)	41.8	48.3	45.1	50.0
Rugby II	41.0	48.3	44.7	50.8
Award	40.8	47.3	44.1	58.0
Rambo	39.8	50.0	44.9	56.5
Freedom II	43.5	49.2	46.3	58.7
Liberator	43.3	50.8	47.1	55.5
GO-9LM9	40.5	48.2	44.3	56.5
Moon Shadow (Pick 113-3)	43.8	52.3	48.1	58.2
Langara	38.2	43.3	40.8	56.0
A96-739	41.3	49.0	45.2	53.8
PST-H5-35	39.7	50.8	45.3	56.5
PST-B3-170	38.3	46.8	42.6	49.2
B4-128A	41.0	49.8	45.4	57.5
Bluestone (PST-731)	42.7	51.7	47.2	51.3
Washington	40.3	50.3	45.3	55.3
A96-742	41.5	49.5	45.5	54.5

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Table 16-continued

Cultivar	Shear Strength Fall 2001	Shear Strength Fall 2002	Pooled Shear Strength 2001-2002	Shear Strength Fall 2003
	--------------------------Nm	-----------------------		
A97-857	44.2	48.5	46.3	58.2
BAR Pp 0468	41.3	49.7	45.5	54.5
BAR Pp 0471	43.0	49.2	46.1	56.2
BAR Pp 0566	41.7	49.2	45.4	59.2
BAR Pp 0573	40.3	47.8	44.1	56.8
Bartitia	38.5	52.5	45.5	58.7
Baritone	38.2	49.7	43.9	60.0
Bariris	38.5	49.8	44.2	57.5
Barzan	41.0	49.2	45.1	55.5
Baronie	42.0	50.2	46.1	54.2
Unique	41.7	48.0	44.8	57.3
Serene	42.8	52.0	47.4	57.5
Moonlight	41.5	49.8	45.7	57.2
Blackstone	41.0	50.5	45.8	58.5
Rita	39.8	48.3	44.1	54.2
North Star	39.8	48.5	44.2	54.2
LSD (0.05) for Cultivar	**3.3**	**4.3**	**2.8**	**5.3**

Table 16 - Means squares (ms) and means for whole plant characteristics measured on 20 genotypes of Kentucky bluegrass representing diverse wear tolerance grown in the greenhouse as space plants and as field plots during 2003

		Shoots per cm^2		Shoot fresh weight		Shoot dry weight	
Source of variation	df	GH	FD	GH	FD	GH	FD
		ms					
Block	3(2)‡	0.55	0.06	0.056	0.0025**	0.002	0.00014*
Genotype	19	4.75***	2.94***	0.239***	0.0009**	0.008***	0.00003*
Tolerant vs. intolerant§	1	6.07*	0.78	0.255*	0.0019*	0.002	0.00003
Among tolerant¶	9	3.48**	4.01***	0.168*	0.0013**	0.007**	0.00004*
Among intolerant¶	9	5.88***	2.11***	0.309***	0.0005	0.009***	0.00002†
Error	57(38)‡	1.19	0.53	0.063	0.0004	0.002	0.00001
Gentoype		Genotype means					
Wear tolerant		no./cm^2		g/cm^2			
99AN-53		3.54	1.82	0.847	0.0448	0.168	0.01026
B4-128A		4.43	5.51	0.427	0.1202	0.080	0.02267
Ba-84-140		2.55	2.34	0.543	0.0679	0.111	0.01079
Baronie		4.26	3.02	0.965	0.0713	0.192	0.01292
Goldrush		3.68	3.08	1.013	0.0677	0.207	0.01292
Limousine		4.77	4.73	1.086	0.0725	0.210	0.01392
Misty		3.68	2.01	0.857	0.0728	0.165	0.01426
NA-K991		3.04	2.77	0.812	0.0658	0.185	0.01331
PST-H8-150		5.51	3.66	0.739	0.0693	0.139	0.01420
Sonoma		5.14	3.04	0.916	0.1014	0.160	0.01912
Tolerant mean		4.06	3.20	0.821	0.0754	0.162	0.01444
Wear intolerant							
A96-451		5.99	3.61	1.204	0.0952	0.204	0.01599
A97-1409		4.82	2.91	1.081	0.0874	0.166	0.01655
A97-1439		2.99	2.97	0.602	0.0711	0.112	0.01370
A98-296		5.79	3.08	1.444	0.0937	0.264	0.01613
Arcadia		4.10	4.17	0.678	0.1065	0.116	0.02024
BH 00-6003		2.77	2.32	0.528	0.0688	0.100	0.01300
Langara		5.55	4.45	0.949	0.1049	0.197	0.01946
PST-York Harbor4		3.54	2.71	0.967	0.0860	0.192	0.01521
Rita		4.74	3.19	0.932	0.0782	0.181	0.01236
Unique		5.85	4.95	0.950	0.0743	0.178	0.01512
Intolerant mean		4.61	3.43	0.934	0.0866	0.171	0.01577
LSD(0.05) for cultivar		1.49	1.19	0.347	0.0308	0.065	0.00530
% Range#		57.47	67.00	70.431	62.7121	69.487	54.74751
CV(%)		25.19	21.95	28.707	24.3123	27.803	21.78861

‡Number in parenthesis indicates degrees of freedom for field study.

†,*,**,*** Significant at $P \leq$ 0.10, 0.05, 0.01, 0.001 levels, respectively

§Single df test for the difference between the combined means for wear tolerant and intolerant genotypes.

¶ Test for the differences within wear tolerant or intolerant genotypes

#[(Max-min)/max] × 100

Table 17- Means squares (ms) and means for percentages of cell wall components measured on 20 genotypes of Kentucky bluegrass representing diverse wear tolerance grown in the greenhouse as space plants and as field plots during 2003

		Total cell wall content		Lignocellulose		Hemicellulose	
Source of variation	df	GH	FD	GH	FD	GH	FD
		ms					
Block	3(2)‡	119.2***	34.0**	26.9†	27.8*	50.9†	2.2
Genotype	19	76.2***	13.9*	35.6***	21.0***	41.6*	26.6*
Tolerant vs. intolerant§	1	117.2**	39.3*	71.0*	22.1†	5.7	2.5
Among tolerant¶	9	59.8***	18.1**	46.0***	20.2**	23.6	31.0*
Among intolerant¶	9	88.0***	9.8	21.2†	21.4**	63.6**	25.1†
Error	57(38)‡	14.3	6.2	12.1	6.3	23.2	13.4
Gentoype		Genotype means					
Wear tolerant		%					
99AN-53		73.1	73.3	34.8	34.1	38.3	39.2
B4-128A		77.4	73.5	34.8	33.4	42.7	40.1
Ba-84-140		77.7	68.2	38.5	30.6	39.2	37.7
Baronie		79.2	69.8	40.5	32.2	38.7	37.6
Goldrush		70.6	69.6	33.7	32.4	36.9	37.2
Limousine		81.3	72.4	42.4	30.9	38.9	41.5
Misty		73.6	66.4	35.8	32.2	37.8	34.2
NA-K991		69.4	69.5	33.4	38.2	35.9	32.2
PST-H8-150		77.0	70.2	33.3	37.2	43.7	33.1
Sonoma		78.1	67.4	40.5	31.2	37.7	36.3
Tolerant mean		75.7	70.0	36.8	33.2	39.0	36.8
Wear intolerant							
A96-451		73.8	67.3	35.5	30.8	38.3	36.5
A97-1409		71.7	67.5	33.8	25.8	37.8	41.8
A97-1439		77.3	68.3	37.6	33.8	39.8	34.6
A98-296		74.1	69.1	37.0	33.0	37.1	36.1
Arcadia		79.6	71.7	37.7	31.8	42.0	39.9
BH 00-6003		73.8	68.9	35.1	34.2	38.7	34.6
Langara		75.3	65.8	35.6	30.9	39.7	34.9
PST-York Harbor4		63.3	69.6	32.8	31.0	30.5	38.6
Rita		68.2	67.2	33.2	35.1	35.0	32.0
Unique		76.1	68.7	30.6	33.6	45.5	35.1
Intolerant mean		73.3	68.4	34.9	32.0	38.4	36.4
LSD(0.05) for cultivar		5.3	4.1	4.9	4.1	6.8	6.0
% Range$^{\#}$		22.1	10.5	27.9	32.6	33.0	25.2
CV(%)		5.1	3.6	9.7	7.7	12.5	10.0

‡Number in parenthesis indicates degrees of freedom for field study.

†,*,**,*** Significant at $P \leq 0.10, 0.05, 0.01, 0.001$ levels, respectively

§Single df test for the difference between the combined means for wear tolerant and intolerant genotypes

¶ Test for the differences within wear tolerant or intolerant genotypes

$^{\#}$[(Max-min)/max] × 100

Table 18- Means squares (ms) and means of rooting densities at different depths (cm) measured on 20 genotypes of Kentucky bluegrass representing diverse wear tolerance grown in the greenhouse as space plants and as field plots during 2003.

		Rooting Density					
		Field plots	Greenhouse plants				
Source of variation	df	0-10cm	0-10cm	10-20cm	20-30cm	30-50cm	50-70cm
		ms					
Block	3(2)‡	0.096	0.071	0.122	0.137†	0.021	0.001
Genotype	19	0.239	1.026**	0.307*	0.115*	0.121	0.032
Tolerant vs. intolerant§	1	0.613†	0.008	0.475†	0.187†	0.140	0.002
Among tolerant¶	9	0.332†	0.974*	0.479**	0.167**	0.197*	0.050*
Among intolerant¶	9	0.944	1.192**	0.117	0.055	0.043	0.017
Error	57(38)‡	0.164	0.414	0.147	0.058	0.079	0.021
Gentoype		Genotype means					
Wear tolerant		mg/cm^3					
99AN-53		1.141	2.609	1.364	0.830	0.760	0.163
B4-128A		1.342	0.985	0.464	0.293	0.358	0.074
Ba-84-140		1.208	1.658	1.055	0.649	0.836	0.143
Baronie		1.921	2.253	1.503	0.926	1.029	0.380
Goldrush		1.057	2.569	1.131	0.551	0.776	0.309
Limousine		0.939	2.205	1.339	0.762	0.695	0.259
Misty		0.713	2.050	1.055	0.522	0.551	0.219
NA-K991		1.032	2.044	0.712	0.394	0.400	0.058
PST-H8-150		0.914	1.510	0.597	0.398	0.370	0.040
Sonoma		1.376	1.994	0.846	0.643	0.601	0.219
Tolerant mean		1.164	1.988	1.006	0.597	0.638	0.186
Wear intolerant							
A96-451		1.400	2.205	1.003	0.758	0.788	0.296
A97-1409		1.309	1.845	0.899	0.541	0.514	0.181
A97-1439		1.216	1.341	0.597	0.368	0.406	0.119
A98-296		1.552	2.651	1.051	0.458	0.563	0.155
Arcadia		1.493	1.399	0.766	0.528	0.601	0.102
BH 00-6003		1.141	1.486	0.667	0.440	0.508	0.157
Langara		1.132	2.239	1.067	0.623	0.613	0.285
PST-York Harbor4		1.225	2.862	0.848	0.396	0.575	0.191
Rita		1.552	2.432	0.597	0.436	0.480	0.141
Unique		1.644	1.620	0.846	0.452	0.492	0.141
Intolerant mean		1.366	2.000	0.852	0.500	0.554	0.177
LSD(0.05) for cultivar		0.644	0.919	0.534	0.335	0.397	0.206
% Range#		62.880	65.576	69.138	68.388	65.183	89.531
CV(%)		32.012	32.198	41.364	43.961	47.386	79.662

‡ Number in parenthesis indicates degrees of freedom for field study.
†,*,**,*** Significant at $P \leq 0.10$, 0.05, 0.01, 0.001 levels, respectively
§Single df test for the difference between the combined means for wear tolerant and intolerant genotypes
¶ Test for the differences within wear tolerant or intolerant genotypes
#[(Max-min)/max] × 100

Table 19- Mean squares (ms) and means for leaf characteristics measured on 20 genotypes of Kentucky bluegrass representing diverse wear tolerance grown in the greenhouse as space plants and as field plots during 2003

		Leaves/shoot		Leaf width		Leaf strength		Leaf angle‡	
Source of variation	df	GH	FD	GH	FD	GH	FD	GH	FD
		ms							
Block	3(2)§	1.28***	0.03	0.38	0.02	4479.2**	722.2	0.13	0.04
Genotype	19	0.23	0.11†	0.63*	0.65***	2028.4*	2359.9**	0.37*	0.56***
Tolerant vs. intolerant¶	1	0.36	0.03	0.02	0.00	2311.0	150.0	4.22***	0.42
Among tolerant#	9	0.36†	0.15*	0.78*	0.48***	1762.2†	2624.3**	0.22	0.97***
Among intolerant#	9	0.08	0.08	0.55†	0.88***	2263.0*	2341.1*	0.10	0.15
Error	57(38)§	0.21	0.06	0.30	0.08	934.1	814.9	0.17	0.17
Gentoype		Genotype means							
Wear tolerant		no.		mm		g		1 to 4	
99AN-53		3.4	2.8	3.9	2.4	200.0	182.2	1.7	1.7
B4-128A		3.9	3.1	2.4	1.8	152.6	101.4	1.7	2.8
Ba-84-140		3.5	3.1	3.4	2.7	203.7	143.4	1.7	1.4
Baronie		4.1	3.2	3.6	2.9	192.1	183.7	1.7	2.2
Goldrush		3.6	3.0	3.8	2.7	230.6	151.1	1.8	1.9
Limousine		4.2	3.1	3.7	2.2	215.4	139.8	1.7	2.8
Misty		4.1	3.4	3.7	3.0	205.2	167.2	2.2	1.3
NA-K991		3.3	2.8	3.5	2.9	181.4	163.6	1.7	1.2
PST-H6-150		3.7	2.8	3.0	2.1	186.5	114.9	1.3	1.7
Sonoma		3.8	3.2	3.3	2.2	190.4	109.1	1.4	1.4
Tolerant mean		3.7	3.1	3.4	2.5	195.8	145.7	1.7	1.8
Wear intolerant									
A96-451		3.5	3.1	3.8	2.7	229.3	172.9	1.2	1.4
A97-1409		3.6	3.0	3.3	3.1	195.8	186.7	1.5	1.4
A97-1439		3.8	3.0	3.6	2.6	173.8	159.4	1.3	1.6
A98-296		3.6	3.0	3.2	2.2	177.8	153.1	1.2	1.8
Arcadia		3.8	3.4	2.7	2.1	141.0	140.7	1.4	2.2
BH 00-6003		3.6	3.3	3.6	3.2	203.0	185.3	1.2	1.7
Langara		3.8	3.0	3.1	1.4	195.9	101.9	1.1	1.6
PST-York Harbor4		3.6	3.0	4.0	2.9	180.7	119.4	1.1	1.6
Rita		3.3	3.1	3.5	2.2	164.2	133.1	1.1	1.7
Unique		3.7	3.0	3.3	2.1	189.4	135.6	1.1	1.8
Intolerant mean		3.6	3.1	3.4	2.5	185.0	148.8	1.2	1.7
LSD(0.05) for cultivar		0.6	0.4	0.8	0.5	43.2	47.1	0.6	0.7
% Range††		19.9	19.2	33.2	56.5	38.8	45.7	50.0	52.2
CV(%)		12.4	8.1	15.9	11.5	16.1	19.3	29.0	23.5

‡Rating: 1= horizontal, 2 = semi horizontal, 3 = semi-vertical, 4 = vertical.
§Number in parenthesis indicates degrees of freedom for field study.
†,*,**,*** Significant at $P \leq 0.10$, 0.05, 0.01, 0.001 levels, respectively.
¶Single df test for the difference between the combined means for wear tolerant and intolerant genotypes
Test for the differences within wear tolerant or intolerant genotypes
††[(Max-min)/max] × 100.

Table 20- Mean squares (ms) and means for water related plant characteristics measured on 20 genotypes of Kentucky bluegrass representing diverse wear tolerance grown in the greenhouse as space plants and as field plots during 2003.

		Moisture[‡]		Relative turgidity[§]	
Source of variation	df	Greenhouse	Field	Greenhouse	Field
		ms			
Block	3(2)[¶]	4.93	20.81*	623.7***	593.8
Genotype	19	10.72*	7.50	130.6*	178.7
Tolerant vs. intolerant[#]	1	64.09***	15.85	182.7[†]	33.9
Among tolerant[††]	9	7.90	8.06	73.4	250.2
Among intolerant[††]	9	7.60	6.02	182.1**	123.2
Error	57(38)[¶]	5.48	6.33	61.2	197.4
Gentoype		Genotype means			
Wear tolerant		%			
99AN-53		80.09	77.58	71.1	54.4
B4-128A		80.17	80.78	69.7	81.4
Ba-84-140		79.01	83.90	73.2	88.8
Baronie		79.95	81.82	66.5	73.4
Goldrush		79.48	80.16	70.1	80.0
Limousine		80.35	80.80	68.3	75.3
Misty		79.29	80.61	71.8	67.5
NA-K991		76.98	79.52	76.3	73.4
PST-H8-150		80.95	79.59	74.8	71.2
Sonoma		82.45	81.07	81.2	72.5
Tolerant mean		79.87	80.58	72.3	73.8
Wear intolerant					
A96-451		83.08	83.19	77.7	76.4
A97-1409		84.05	81.00	90.7	69.2
A97-1439		81.77	80.79	72.9	71.4
A98-296		81.72	82.53	67.3	73.0
Arcadia		82.90	80.44	72.7	77.5
BH 00-6003		81.00	81.00	81.3	67.4
Langara		79.28	81.42	70.7	72.1
PST-York Harbor4		80.86	81.89	76.6	67.3
Rita		80.69	84.34	73.1	85.7
Unique		81.29	79.52	70.3	62.9
Intolerant mean		81.66	81.61	75.3	72.3
LSD(0.05) for cultivar		3.31	4.16	11.1	23.8
% Range[‡‡]		8.41	8.02	26.7	29.2
CV(%)		2.90	3.10	10.6	19.2

[‡]Moisture (%) = [(fresh weight - oven dry weight)/fresh weight] × 100.
[§]Turgidity (%) = [(fresh weight – oven dry weight)/(turgid weight-oven dry weight)] × 100, turgid weight = weight (g) after 12 hours in distilled H_20.
[†],*,**,*** Significant at $P \leq 0.10, 0.05, 0.01, 0.001$ levels, respectively.
[¶]Number in parenthesis indicates degrees of freedom for field study.
[#]Single df test for the difference between the combined means for wear tolerant and intolerant genotypes
[††]Single df test for the differences within wear tolerant or intolerant genotypes
[‡‡] [(Max-min)/max] × 100.

Table 21- Means squares (ms) and means of vertical budleaf extension rates (mm d^{-1}) measured on 20 genotypes of Kentucky bluegrass representing diverse wear tolerance grown in the greenhouse as space plants and as field plot clipping yield in 2003.

Source of variation	df	Field plots clipping yield	Greenhouse plants 3 wks	5 wks	7 wks
		ms			
Block	3(2)‡	0.51*	59.42***	13.13	43.40**
Genotype	19	0.11	28.94***	20.52**	13.26
Tolerant vs. intolerant	1§	0.00	33.80*	22.84	2.19
Among tolerant	9¶	0.12	39.76***	22.36*	15.24
Among intolerant	9¶	0.12	17.58*	18.41*	12.53
Error	57(38)‡	0.14	8.59	9.08	9.07
Gentoype		Genotype means			
Wear tolerant		mg/cm^2	mm d^{-1}		
99AN-53		0.8	7.1	9.0	12.3
B4-128A		1.1	3.1	5.7	8.8
Ba-84-140		1.0	7.8	9.3	10.4
Baronie		0.9	12.2	13.6	13.2
Goldrush		0.9	8.9	12.8	11.9
Limousine		1.0	7.9	9.5	9.6
Misty		1.5	9.1	9.9	11.3
NA-K991		0.8	14.7	13.2	14.2
PST-H8-150		1.0	6.4	10.3	8.6
Sonoma		1.0	8.1	10.8	9.2
Tolerant mean		1.0	8.5	10.4	10.9
Wear intolerant					
A96-451		0.8	3.4	9.1	12.5
A97-1409		1.3	8.4	11.7	12.8
A97-1439		1.0	7.3	9.4	8.4
A98-296		1.0	8.9	11.5	11.7
Arcadia		0.9	5.8	7.8	8.0
BH 00-6003		1.3	4.6	4.1	9.8
Langara		1.0	9.3	9.9	12.8
PST-York Harbor4		0.7	8.1	10.4	9.6
Rita		0.9	9.8	9.4	10.7
Unique		0.9	6.6	9.8	9.8
Intolerant mean		1.0	7.2	9.3	10.6
LSD(0.05) for cultivar		0.5	4.2	4.3	4.3
% Range#		49.2	79.2	69.6	43.6
CV(%)		32.7	37.3	30.6	27.9

‡Number in parenthesis indicates degrees of freedom for field study.
†,*,**,*** Significant at $P \leq$ 0.10, 0.05, 0.01, 0.001 levels, respectively.
§Single df test for the difference between the combined means for wear tolerant and intolerant genotypes
¶Single df test for the differences within wear tolerant or intolerant genotypes
#[(Max-min)/max] × 100.

APPENDIX B

2004 TABLES

Table 22 - Means squares (ms) and means for whole plant characteristics measured on 20 genotypes of Kentucky bluegrass representing diverse wear tolerance grown in the greenhouse as space plants and as field plots during 2004

		Shoots per cm^2		Shoot fresh weight		Shoot dry weight	
Source of variation	df	GH	FD	GH	FD	GH	FD
		ms					
Block	3(2)‡	7.89***	2.75***	0.019	0.0006*	0.0007	0.00008***
Genotype	19	1.88*	1.64***	0.035**	0.0003*	0.0012**	0.00001†
Tolerant vs. intolerant§	1	3.01†	0.03	0.030	0.0004	0.0004	0.00000
Among tolerant¶	9	1.93†	2.54***	0.029*	0.0003*	0.0009*	0.00001*
Among intolerant¶	9	1.70	0.92*	0.041**	0.0002	0.0015**	0.00000
Error	57(38)‡	1.09	0.32	0.013	0.0001	0.0004	0.00000
Gentoype		Genotype means					
Wear tolerant		no./cm^2		g/cm^2			
99AN-53		3.56	2.29	0.311	0.0395	0.0552	0.00788
B4-128A		4.26	5.03	0.180	0.0664	0.0336	0.01434
Ba-84-140		2.83	2.82	0.296	0.0661	0.0562	0.01319
Baronie		4.70	2.52	0.482	0.0795	0.0881	0.01353
Goldrush		3.11	2.88	0.354	0.0547	0.0611	0.01185
Limousine		3.56	3.97	0.357	0.0616	0.0626	0.01172
Misty		2.69	2.49	0.349	0.0542	0.0604	0.01046
NA-K991		2.63	2.52	0.278	0.0669	0.0641	0.01281
PST-H8-150		3.16	4.22	0.197	0.0648	0.0343	0.01132
Sonoma		3.96	2.85	0.301	0.0593	0.0510	0.00998
Tolerant mean		3.46	3.16	0.310	0.0613	0.0566	0.01171
Wear intolerant							
A96-451		3.58	2.74	0.249	0.0644	0.0413	0.01096
A97-1409		3.64	3.27	0.381	0.0813	0.0681	0.01373
A97-1439		3.70	3.02	0.320	0.0718	0.0545	0.01275
A98-296		4.68	3.10	0.412	0.0707	0.0685	0.01188
Arcadia		2.91	2.94	0.219	0.0551	0.0402	0.01098
BH 00-6003		2.95	2.26	0.274	0.0591	0.0477	0.00973
Langara		4.86	3.91	0.408	0.0699	0.0686	0.01266
PST-York Harbor4		3.68	2.79	0.499	0.0607	0.0916	0.01172
Rita		4.00	2.93	0.480	0.0709	0.0901	0.01250
Unique		4.34	4.14	0.250	0.0578	0.0424	0.01062
Intolerant mean		3.83	3.11	0.349	0.0662	0.0613	0.01175
LSD(0.05) for cultivar		1.48	0.94	0.160	0.0195	0.0290	0.00340
% Range#		45.90	54.99	63.860	51.3747	63.3267	45.03242
CV(%)		28.68	18.09	34.240	18.5355	34.7742	17.38858

‡Number in parenthesis indicates degrees of freedom for field study.
†,*,**,*** Significant at $P \leq 0.10, 0.05, 0.01, 0.001$ levels, respectively
§Single df test for the difference between the combined means for wear tolerant and intolerant genotypes.
¶ Test for the differences within wear tolerant or intolerant genotypes
#[(Max-min)/max] × 100.

Table 23- Means squares (ms) and means for percentages of cell wall components measured on 20 genotypes of Kentucky bluegrass representing diverse wear tolerance grown in the greenhouse as space plants and as field plots during 2004

Source of variation	df	Total cell wall content GH	Total cell wall content FD	Lignocellulose GH	Lignocellulose FD	Hemicellulose GH	Hemicellulose FD
		ms					
Block	3(2)‡	334.6***	173.8***	71.7***	11.5**	607.1***	199.1***
Genotype	19	35.6†	13.2	8.4	4.2*	30.6	10.0
Tolerant vs. intolerant§	1	20.6	10.0	9.8	3.8	1.9	1.5
Among tolerant¶	9	39.7	19.4*	8.4	6.9**	47.1†	7.9
Among intolerant¶	9	33.1	7.4	8.3	1.5	17.3	13.2†
Error	57(38)‡	23.5	8.4	6.0	1.9	26.0	6.9
Gentoype		Genotype means					
Wear tolerant		%					
99AN-53		69.4	73.3	31.0	33.2	38.4	40.1
B4-128A		73.7	75.0	31.3	33.0	42.4	42.0
Ba-84-140		65.7	69.1	30.8	30.7	34.9	38.4
Baronie		69.4	73.1	32.9	31.8	36.5	41.3
Goldrush		62.6	73.9	32.8	30.3	29.8	43.7
Limousine		71.1	75.8	34.8	33.0	36.3	42.8
Misty		67.7	69.1	29.7	30.1	38.0	39.0
NA-K991		71.3	70.5	31.4	29.6	39.9	40.8
PST-H8-150		70.0	70.2	30.7	29.6	39.3	40.6
Sonoma		70.5	69.7	31.3	29.5	39.2	40.2
Tolerant mean		69.2	72.0	31.6	31.1	37.5	40.9
Wear intolerant							
A96-451		67.6	69.4	31.7	32.0	35.9	37.4
A97-1409		67.7	71.7	30.7	29.9	37.1	41.8
A97-1439		66.7	72.7	29.1	29.8	37.6	42.8
A98-296		66.5	71.2	30.5	30.8	36.0	40.4
Arcadia		73.7	72.5	34.2	30.7	39.5	41.8
BH 00-6003		68.1	72.9	29.9	30.8	38.2	42.1
Langara		68.7	68.5	31.0	31.1	37.6	37.4
PST-York Harbor4		64.0	69.2	31.0	30.9	33.0	38.2
Rita		66.0	71.4	29.4	30.0	36.6	41.5
Unique		72.2	71.9	31.7	30.0	40.5	42.1
Intolerant mean		68.1	71.2	30.9	30.6	37.2	40.6
LSD(0.05) for cultivar		6.9	4.8	3.9	2.3	7.2	4.4
% Range#		15.1	9.6	16.4	11.1	29.7	14.4
CV(%)		7.1	4.1	7.8	4.5	13.7	6.5

‡Number in parenthesis indicates degrees of freedom for field study.

†,*,**,*** Significant at $P \leq 0.10$, 0.05, 0.01, 0.001 levels, respectively

§Single df test for the difference between the combined means for wear tolerant and intolerant genotypes.

¶Test for the differences within wear tolerant or intolerant genotypes

#[(Max-min)/max] × 100

Table 24- Means squares (ms) and means of rooting densities at different depths (cm) measured on 20 genotypes of Kentucky bluegrass representing diverse wear tolerance grown in the greenhouse as space plants and as field plots during 2004.

		Rooting Density					
		Field plots	Greenhouse plants				
Source of variation	df	0-10cm	0-10cm	10-20cm	20-30cm	30-50cm	50-70cm
		ms					
Block	3(2)‡	1.211***	0.166	0.085	0.061*	0.056	0.004
Genotype	19	0.099†	0.387***	0.121***	0.050**	0.098***	0.006*
Tolerant vs. intolerant§	1	0.251*	0.055	0.000	0.002	0.049	0.013*
Among tolerant¶	9	0.076	0.372**	0.102*	0.063**	0.124***	0.002
Among intolerant¶	9	0.105†	0.438**	0.152**	0.042†	0.078*	0.009**
Error	57(38)‡	0.058	0.128	0.047	0.022	0.033	0.003
Gentoype		Genotype means					
Wear tolerant		mg/cm^3					
99AN-53		1.070	1.246	0.661	0.366	0.269	0.026
B4-128A		0.917	0.646	0.376	0.237	0.147	0.022
Ba-84-140		1.304	1.312	0.768	0.627	0.693	0.082
Baronie		1.194	1.636	0.828	0.508	0.490	0.056
Goldrush		1.027	1.099	0.514	0.334	0.334	0.062
Limousine		0.867	1.176	0.627	0.392	0.311	0.016
Misty		1.152	1.236	0.651	0.410	0.231	0.018
NA-K991		1.026	1.293	0.559	0.271	0.119	0.006
PST-H8-150		0.872	0.653	0.326	0.217	0.139	0.022
Sonoma		1.279	0.948	0.486	0.313	0.301	0.038
Tolerant mean		1.070	1.125	0.579	0.367	0.303	0.035
Wear intolerant							
A96-451		1.257	0.645	0.344	0.247	0.203	0.014
A97-1409		1.122	1.232	0.705	0.420	0.499	0.097
A97-1439		1.297	1.001	0.460	0.348	0.362	0.096
A98-296		1.153	1.369	0.675	0.368	0.348	0.038
Arcadia		1.344	0.898	0.464	0.247	0.147	0.004
BH 00-6003		0.885	0.926	0.512	0.346	0.350	0.024
Langara		1.285	0.944	0.551	0.340	0.328	0.056
PST-York Harbor4		1.485	1.453	0.882	0.490	0.502	0.088
Rita		0.911	1.608	0.852	0.541	0.575	0.151
Unique		1.262	0.645	0.326	0.233	0.215	0.034
Intolerant mean		1.200	1.072	0.577	0.358	0.353	0.060
LSD(0.05) for cultivar		0.399	0.507	0.308	0.209	0.257	0.082
% Range#		41.656	60.583	62.984	65.390	82.763	97.369
CV(%)		21.255	32.578	37.658	40.648	55.382	121.587

‡ Number in parenthesis indicates degrees of freedom for field study.

†,*,**,*** Significant at $P \leq 0.10, 0.05, 0.01, 0.001$ levels, respectively

§Single df test for the difference between the combined means for wear tolerant and intolerant genotypes

¶ Test for the differences within wear tolerant or intolerant genotypes

#[(Max-min)/max] × 100

Table 25- Mean squares (ms) and means for leaf characteristics measured on 20 genotypes of Kentucky bluegrass representing diverse wear tolerance grown in the greenhouse as space plants and as field plots during 2004

		Leaves/shoot		Leaf width		Leaf strength		Leaf angle‡	
Source of variation	df	GH	FD	GH	FD	GH	FD	GH	FD
		ms							
Block	3(2)§	0.116	0.04	0.24	0.13	938.4	5694.1*	0.17	0.05
Genotype	19	0.097†	0.06	0.67***	0.63***	876.8	2179.3	1.60***	1.06***
Tolerant vs. intolerant¶	1	0.034	0.01	0.00	0.10	617.4	2658.1	28.40***	15.00***
Among tolerant#	9	0.125*	0.07	1.05***	0.79***	1538.6**	2920.9	0.16	0.46***
Among intolerant#	9	0.077	0.05	0.37	0.52***	243.9	1384.5	0.06	0.11
Error	57(38)§	0.059	0.07	0.23	0.14	598.3	1719.7	0.13	0.07
Gentoype		Genotype means							
Wear tolerant		no.		mm		g		1 to 4	
99AN-53		3.08	3.11	3.13	2.83	107.3	150.1	2.75	2.22
B4-128A		3.17	3.11	2.21	2.11	98.3	84.9	2.33	2.56
Ba-84-140		3.17	3.22	3.13	2.94	143.7	131.5	2.25	2.11
Baronie		3.58	3.44	3.38	3.55	145.9	178.3	2.50	2.56
Goldrush		3.08	3.33	3.58	3.00	164.6	149.7	2.08	1.89
Limousine		3.00	3.00	2.83	2.11	129.1	107.4	2.42	2.89
Misty		3.42	3.22	4.04	3.39	141.7	146.7	2.50	2.00
NA-K991		3.17	3.22	3.29	3.05	118.2	157.3	2.67	1.56
PST-H6-150		3.08	3.00	2.58	2.22	131.1	111.4	2.33	2.44
Sonoma		3.25	3.00	3.17	2.55	124.6	88.6	2.25	2.00
Tolerant mean		3.20	3.16	3.13	2.78	130.4	130.6	2.41	2.22
Wear intolerant									
A96-451		3.08	3.11	2.92	3.22	131.6	141.2	1.25	1.33
A97-1409		3.42	3.44	3.92	3.17	138.3	131.3	1.17	1.11
A97-1439		3.17	3.33	3.13	2.89	126.9	141.4	1.08	1.00
A98-296		3.25	3.11	2.67	2.78	139.3	140.7	1.00	1.11
Arcadia		3.17	3.22	2.96	2.56	143.5	158.0	1.25	1.33
BH 00-6003		3.25	3.22	3.42	3.44	136.7	161.4	1.42	1.44
Langara		3.33	3.00	2.96	2.22	125.6	126.9	1.17	1.11
PST-York Harbor4		3.17	3.11	3.63	2.56	148.3	184.1	1.33	1.22
Rita		3.50	3.22	3.42	3.33	142.3	149.2	1.17	1.00
Unique		3.08	3.11	2.83	2.44	127.3	104.8	1.33	1.56
Intolerant mean		3.24	3.18	3.12	2.86	136.0	143.9	1.22	1.22
LSD(0.05) for cultivar		0.34	0.44	0.68	0.62	34.6	68.5	0.50	0.44
% Range††		16.27	12.90	45.36	40.62	40.3	53.9	63.63	65.38
CV(%)		7.52	8.45	15.46	13.34	18.4	30.2	19.65	15.51

‡Rating: 1= horizontal, 2 = semi horizontal, 3 = semi-vertical, 4 = vertical.
§Number in parenthesis indicates degrees of freedom for field study.
†,*,**,*** Significant at $P \leq 0.10$, 0.05, 0.01, 0.001 levels, respectively.
¶Single df test for the difference between the combined means for wear tolerant and intolerant genotypes
Test for the differences within wear tolerant or intolerant genotypes
††[(Max-min)/max] × 100.

Table 26- Mean squares (ms) and means for water related plant characteristics measured on 20 genotypes of Kentucky bluegrass representing diverse wear tolerance grown in the greenhouse as space plants and as field plots during 2004.

		Moisture‡		Relative turgidity§	
Source of variation	df	Greenhouse	Field	Greenhouse	Field
		ms			
Block	3(2)¶	0.894	52.339***	130.848**	653.101***
Genotype	19	7.768***	7.499*	70.828**	35.689
Tolerant vs. intolerant#	1	14.290*	26.101**	230.876**	60.634
Among tolerant††	9	12.012***	9.695**	106.403**	50.794
Among intolerant††	9	2.800	3.235	17.471	17.813
Error	57(38)¶	2.170	3.279	30.130	32.991
Gentoype		Genotype means			
Wear tolerant		%			
99AN-53		82.110	80.085	71.776	68.074
B4-128A		80.053	78.031	73.818	74.026
Ba-84-140		81.103	80.110	78.915	75.316
Baronie		81.812	83.229	75.925	81.985
Goldrush		82.860	78.482	81.397	74.254
Limousine		82.237	80.955	79.795	76.546
Misty		82.740	80.868	84.012	79.164
NA-K991		77.398	80.944	66.857	80.685
PST-H8-150		82.493	82.664	80.332	79.288
Sonoma		83.127	83.180	79.746	79.265
Tolerant mean		81.593	80.855	77.257	76.860
Wear intolerant					
A96-451		83.300	82.984	82.219	78.343
A97-1409		82.180	83.162	84.001	82.096
A97-1439		82.969	82.274	82.300	77.330
A98-296		83.388	83.008	79.566	80.629
Arcadia		81.668	80.273	81.417	76.230
BH 00-6003		81.698	83.187	76.198	81.451
Langara		83.172	81.889	80.743	76.510
PST-York Harbor4		81.705	80.657	79.738	81.784
Rita		81.171	82.565	80.061	78.546
Unique		83.135	81.738	80.307	75.790
Intolerant mean		82.438	82.174	80.654	78.871
LSD(0.05) for cultivar		2.086	2.993	7.772	9.494
% Range‡‡		7.183	6.245	20.420	17.080
CV(%)		1.796	2.221	6.952	7.376

‡Moisture (%) = [(fresh weight - oven dry weight)/fresh weight] × 100.
§ Relative turgidity (%) = [(fresh weight – oven dry weight)/(turgid weight-oven dry weight)] × 100, turgid weight = weight (g) after 12 hours in distilled H_20.
†,*,**,*** Significant at $P \leq 0.10$, 0.05, 0.01, 0.001 levels, respectively.
¶ Number in parenthesis indicates degrees of freedom for field study.
#Single df test for the difference between the combined means for wear tolerant and intolerant genotypes
†† Test for the differences within wear tolerant or intolerant genotypes
‡‡ [(Max-min)/max] × 100.

Table 27- Means squares (ms) and means of vertical budleaf extension rates (mm d^{-1}) measured on 20 genotypes of Kentucky bluegrass representing diverse wear tolerance grown in the greenhouse as space plants and as field plot clipping yield in 2004.

		Field plots	Greenhouse plants		
Source of variation	df	clipping yield	3 wks	5 wks	7 wks
		ms			
Block	3(2)‡	0.040	1.369	1.109	1.618
Genotype	19	0.050	3.366†	5.804	2.661†
Tolerant vs. intolerant§	1	0.023	0.450	4.875	0.450
Among tolerant¶	9	0.063	2.695	6.440	2.359
Among intolerant¶	9	0.040	4.361*	5.271	3.209*
Error	57(38)‡	0.039	2.063	4.573	1.613
Gentoype		Genotype means			
Wear tolerant		mg/cm^2	mm d^{-1}		
99AN-53		0.559	3.688	6.375	5.250
B4-128A		0.724	2.875	4.438	3.688
Ba-84-140		0.561	4.125	5.625	4.375
Baronie		0.615	5.063	7.125	6.000
Goldrush		0.522	3.938	6.438	5.313
Limousine		0.653	3.813	4.625	3.500
Misty		0.782	4.688	5.250	4.188
NA-K991		0.636	5.875	8.688	4.250
PST-H8-150		1.000	4.000	5.688	4.375
Sonoma		0.800	4.250	5.250	4.625
Tolerant mean		0.685	4.231	5.950	4.556
Wear intolerant					
A96-451		0.783	2.500	3.625	4.750
A97-1409		0.711	3.563	5.000	4.438
A97-1439		0.551	4.875	5.438	5.375
A98-296		0.667	3.875	5.188	4.500
Arcadia		0.598	3.438	5.438	4.500
BH 00-6003		0.924	3.188	5.125	3.625
Langara		0.675	4.938	6.313	4.313
PST-York Harbor4		0.883	5.125	7.625	6.063
Rita		0.718	5.183	6.563	6.063
Unique		0.739	3.500	4.250	3.438
Intolerant mean		0.724	4.081	5.456	4.706
LSD(0.05) for cultivar		0.325	2.033	3.028	1.799
% Range#		47.867	51.063	58.275	43.298
CV(%)		27.880	34.561	37.496	27.425

‡Number in parenthesis indicates degrees of freedom for field study.
†,*,**,*** Significant at $P \leq$ 0.10, 0.05, 0.01, 0.001 levels, respectively.
§Single df test for the difference between the combined means for wear tolerant and intolerant genotypes
¶ Test for the differences within wear tolerant or intolerant genotypes
#[(Max-min)/max] × 100.

Table 28- Mean squares (ms) and means of root lengths (mm) and number of rhizomes measured on 20cultivars of Kentucky bluegrass representing diverse wear tolerance grown in the greenhouse as space in 2004

Source of variation	df	Rhizome number	Root Length 3 wks	5 wks	7 wks
		ms			
Block	3	70.21*	524.1	3923.3	8397.8
Genotype	19	50.84**	1866.1**	5516.6**	15674.5***
Tolerant vs. intolerant§	1	0.20	6661.3**	13520.0*	33948.8*
Among tolerant¶	9	68.28**	1484.1†	6024.3*	14645.0*
Among intolerant¶	9	39.03†	1715.4*	4119.6†	14674.0*
Error	57	19.98	774.7	2316.2	5458.3
Gentoype		Genotype means			
Wear tolerant		no.	mm		
99AN-53		6.50	105.0	229.8	368.3
B4-128A		4.75	103.8	216.3	339.3
Ba-84-140		4.75	149.5	298.8	486.0
Baronie		15.75	113.5	263.5	458.8
Goldrush		12.25	119.0	299.8	456.5
Limousine		5.50	95.5	221.5	396.5
Misty		9.25	111.8	275.3	420.0
NA-K991		3.25	77.0	176.0	290.8
PST-H8-150		8.50	98.3	244.8	400.8
Sonoma		12.75	123.5	257.0	447.8
Tolerant mean		8.33	109.7	248.3	406.4
Wear intolerant					
A96-451		8.00	137.3	251.5	386.0
A97-1409		14.00	150.0	311.3	513.5
A97-1439		5.75	140.0	304.8	524.5
A98-296		9.25	122.5	256.8	401.3
Arcadia		9.75	83.8	216.5	346.3
BH 00-6003		6.00	102.0	252.8	413.0
Langara		6.25	126.8	274.3	455.8
PST-York Harbor4		4.50	147.8	317.8	510.3
Rita		12.50	135.8	293.0	484.0
Unique		6.25	133.5	264.0	442.0
Intolerant mean		8.23	127.9	274.3	447.6
LSD(0.05) for cultivar		6.33	39.4	68.2	104.6
% Range#		79.37	48.6	44.6	44.6
CV(%)		54.02	23.4	18.4	17.3

†,*,**,*** Significant at $P \leq$ 0.10, 0.05, 0.01, 0.001 levels, respectively

§Single df test for the difference between the combined means for wear tolerant and intolerant genotypes.

¶ Test for the differences within wear tolerant or intolerant genotypes.

#[(Max-min)/max] × 100

Table 29- Correlations between the means of various plant characteristics measured in field plots in 2004

	Leaf strength	Leaf width	Leaves /shoot	Shoots /cm^2	Fresh weight	Dry weight	Leaf angle	Moisture	Turgidity	Root density	T. cell wall	Ligno. cell.	Hemi. cell.
Leaf strength													
Leaf width	0.507***												
Leaves/shoot	0.318*	0.367**											
Shoots/cm^2	-0.392**	-0.446***	-0.112										
Fresh weight	-0.022	0.159	0.184	0.422***									
Dry weight	-0.067	0.091	0.159	0.539***	0.837***								
Leaf angle	-0.215†	-0.260*	-0.074	0.188	-0.158	-0.039							
Moisture	0.079	0.090	0.009	-0.259*	0.160	-0.400**	-0.189						
Turgidity	0.199	0.003	-0.062	-0.316*	0.084	-0.347**	-0.110	0.785***					
Root Density	-0.064	0.062	0.146	0.160	0.221†	0.388**	-0.252†	-0.326*	-0.463***				
Total cell wall	0.106	-0.014	0.061	0.041	-0.033	0.105	0.204	-0.272*	-0.186	-0.273*			
Lignocellulose	0.149	-0.171	-0.071	-0.051	-0.256*	-0.266*	0.294*	0.028	0.099	-0.359***	0.299**		
Hemicellulose	0.042	-0.063	0.095	0.066	0.082	0.231‡	0.078	-0.295*	-0.238‡	-0.119	-0.900***	-0.144	

†,*,**,*** Significant at $P \leq$ 0.10, 0.05, 0.01, 0.001 levels, respectively

Table 30 - Correlations between the means of various plant characteristics measured in greenhouse space plants in 2004

	Leaf strength	Leaf width	Leaves /shoot	Shoots /cm^2	Fresh weight	Dry weight	Leaf angle	Moisture	Turgidity	Root density	Rhizomes	T. cell wall	Ligno. cell.	Hemi. cell.
Leaf strength														
Leaf width	0.646***													
Leaves/shoot	-0.033	0.139												
Shoots/cm^2	0.093	0.217†	-0.041											
Fresh weight	0.155	0.183	0.199†	0.611***										
Dry weight	0.160	0.151	0.191†	0.574***	0.974***									
Leaf angle	-0.125	0.040	-0.154	-0.022	-0.011	0.029								
Moisture	0.107	0.223*	0.032	0.174	0.137	-0.063	-0.216†							
Turgidity	-0.037	0.062	0.018	-0.114	0.004	-0.125	-0.137	0.644***						
Root Density	0.281*	0.380***	0.214†	0.313**	0.359**	0.396***	0.065	-0.091	-0.153					
Rhizomes	0.303**	0.290**	0.163	0.191†	0.225*	0.219†	-0.073	0.062	-0.124	0.369***				
Total cell wall	-0.502***	-0.513***	0.103	-0.257*	-0.205†	-0.192†	0.090	-0.161	-0.088	-0.342**	-0.223*			
Lignocellulose	0.094	-0.066	-0.234*	-0.085	-0.074	-0.110	0.118	0.177	0.126	-0.060	0.153	-0.051		
Hemicellulose	-0.488***	-0.191†	0.192†	-0.190†	-0.149	-0.121	0.028	-0.218†	-0.132	-0.276*	-0.263*	0.903***	-0.474***	

†,*,**,*** Significant at $P \leq 0.10$, 0.05, 0.01, 0.001 levels, respectively

Table 31 - Correlations between the pooled means averaged over year (2003 and 2004) of various plant characteristics measured in field plots and greenhouse space plants in 2003 and 2004

	Greenhouse space plants												
Field Plots	Leaf strength	Leaf width	Leaves /shoot	Shoots /cm^2	Fresh weight	Dry weight	Leaf angle	Moisture	Turgidity	Root density	Total cell wall	Ligno-cell	Hemi-cell
Leaf strength	0.379†												
Leaf width		0.723***											
Leaves/shoot			0.539*										
Shoots/cm^2				0.571**									
Fresh weight					0.094								
Dry weight						-0.187							
Leaf angle							0.616**						
Moisture								0.367					
Turgidity									0.138				
Root Density(10cm)										0.126			
Total cell wall											0.391†		
Lignocellulose												-0.125	
Hemicellulose													0.060

†, *, **, *** Significant at P≤ 0.10, 0.05, 0.01, 0.001 levels, respectively

Table 32-2004 Greenhouse Temperature Data (Celsius)

Date	Average Temp.	Max. Temp.	Min Temp
22-Jan	20.6	24.7	16.6
23-Jan	21.4	25.8	17.1
24-Jan	20.7	26.7	14.8
26-Jan	21.6	27.2	16.1
27-Jan	18.8	21.2	16.5
28-Jan	22.4	22.9	16.0
29-Jan	22.2	28.2	16.3
30-Jan	21.9	27.5	16.4
31-Jan	22.9	29.8	16.0
1-Feb	22.9	29.8	16.0
2-Feb	22.6	29.0	16.3
3-Feb	20.8	25.4	16.3
4-Feb	24.4	32.6	16.3
5-Feb	22.0	27.6	16.4
6-Feb	27.8	39.0	16.8
7-Feb	21.4	26.6	16.2
8-Feb	21.4	26.6	16.2
9-Feb	21.0	25.4	16.6
10-Feb	23.3	30.2	16.4
11-Feb	22.1	28.2	16.1
12-Feb	21.2	26.3	16.2
15-Feb	21.2	26.5	16.0
16-Feb	20.9	25.6	16.3
17-Feb	22.6	29.0	16.3
18-Feb	22.1	27.9	16.3
19-Feb	19.9	22.6	16.6
22-Feb	22.1	27.9	16.3
23-Feb	22.7	29.2	16.3
24-Feb	20.7	25.1	16.3
25-Feb	21.7	27.1	16.3
26-Feb	21.4	26.6	16.3
29-Feb	21.8	27.5	16.1
1-Mar	21.7	27.0	16.4
2-Mar	21.8	27.0	16.6
3-Mar	21.4	26.6	16.3
4-Mar	19.4	22.7	16.1
7-Mar	22.0	29.8	15.8
8-Mar	19.2	22.7	15.8
9-Mar	23.2	30.5	15.9
10-Mar	22.0	28.3	15.8
11-Mar	33.1	51.0	15.2
12-Mar	18.6	21.6	15.6
15-Mar	23.4	31.5	15.4
16-Mar	23.9	32.1	15.7
17-Mar	19.6	23.3	16.0
18-Mar	18.9	21.4	16.4
20-Mar	21.9	28.0	15.8
21-Mar	23.1	30.2	16.1
22-Mar	24.0	33.5	16.1
23-Mar	26.7	31.2	16.0
24-Mar	22.2	27.1	16.8
25-Mar	18.9	21.2	16.2
26-Mar	25.1	33.3	17.0
27-Mar	26.0	36.8	16.4
Mean	**22.2**	**28.0**	**16.2**
Standard Dev.	**2.4**	**4.8**	**0.4**

BIBLIOGRAPHY

Adams, W.A., C. Tanavud, and C.T. Springsguth. 1985. Factors influencing the stability of sports turf rootzones. p. 391-399. ln F. Lemaire (ed.) Proc. 5th Int. Turfgrass Res. Conf., Avigon, France. 1-5 July. Ist. Nat. de la Recherche Agron., Paris.

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. Proc. of the 44th Ann. Michigan Turf. Conf., East Lansing. 15-16 Jan. 1974. Vol 3: 1-2

Bell, M.J., Baker, S.W. and P.M. Canaway. 1985. Playing quality of sports surfaces; a review. J Sports Turf Res. Inst. 61: 26-45

Bonos, S.A., E. Watkins, J.A. Honig, M. Sosa, J.A. Murphy, and W.A. Meyer. 2001 Breeding cool-season turfgrasses for wear tolerance using a wear simulator. International Turfgrass Society Research Journal. Volume 9. p. 137-145.

Bourgoin, B. and p. Mansat. 1977. Comparisons of micro-trials and space planted nurseries with dense swords as a means for evaluating turfgrass genotypes. p. 3-9. ln J.B. Beard (ed.) Proc. 3rd Int. turfgrass Res. Conf., Munich, Germany. 11-13 July. Int. Turfgrass Soc., ASA, CSSA, SSSA, Madison, WI.

Brede, A.D. and J.M. Duich. 1982. Cultivar and Seeding Rate Effects on Several Physical Characteristics of Kentucky Bluegrass Turf. Agron. J. 74: 865-870.

Canaway, P.M. 1976. A differential slip wear machine (D.S.1) for the artificial simulation of turfgrass wear. J. Sports Turf Res. Inst. 52:92-99

Canaway, P.M. 1982. Simulation of fine turf wear using the differential slip wear machine and quantification of wear treatments in terms of energy expenditure. J. Sports Turf Res. Inst. 58:9-15

Canaway, P.M. 1983. The effect of rootzone construction on the wear tolerance and playability of eight turfgrass species subjected to football type wear. J. Sports Turf Res. Inst. 59:107-123

Canaway, P.M. and M.J. Bell. 1986. Technical Note: An apparatus for measuring traction and friction on natural and artificial playing surfaces. J. Sports Turf Res. Inst. 62: 211-214

Carrow, R.N. and G. Weicko. 1989. Soil Compaction and wear stresses on turfgrasses. Future research direction. P. 37-42. ln H. Takatoh (ed.) Proc 6th Int. Turfgrass Res. Conf., Tokyo, Japan. 31 July-5Aug. Jpn. Soc. Turfgrass Sci., Tokyo.

Carrow, R.N. and A.M. Petrovic. 1992. Effects of traffic on turfgrass. P. 285-330. ln Turfgrass (eds.) D.V. Waddington, R.N. Carrow, and R.C. Shearman. Agronomy Monogr. 32. ASA, CSSA, and SSSA, Madison, WI.

Cockerham, ST., V.A. Gibeault, J. Van Dam, and Leonard, J.K. 1990. Tolerance of several cool-season turfgrass to simulated sport traffic. ln Natural and Artificial playing Fields, Schmidt, American Society for Testing and Materials. STP 1073:85-95

Contreras Lara, D. 1999. Two techniques doe measuring neutral detergent (NDF) and acid detergent fibers (ADF) in forages and by products. Arch. Zootec. 48: 351-354.

Dahlsson, S. 1973. Cutting height and wear tolerance of turf. Weibulls Gräs-tips, 16: 23-30

Ebdon, J.S. and A.M. Petrovic. 1998. Morphological and growth characteristics of low and high water use Kentucky bluegrass cultivars. Crop Sci. 38:143-152

Esau, K. 1965. Plant Anatomy. John Wiley & Sons, Inc., New York. p.767

Goering, H.K. and P.J. Van Soest. 1970. Forage fiber analysis (apparatus, reagents, procedures, and some applications). USDA Agric. Handb. 379. U.S. Gov. print. Office, Washington, DC.

Gramckow, J. 1968. Athletic field quality studies. Cal-Turf, Camarillo, CA

Komarek, A.R., Robertson, J.B., and P.J. Van Soest. 1994. A comparison of methods for determining ADF using the filter bag technique versus conventional filtration. ASAS/ADSA Meetings. USA.

Lehman, V.G. and M.C. Engleke. 1985. A rapid screening technique for genetic variability in turfgrass root systems. p. 770-776. ln F. Lemaire (ed.) Proc. 5th Int. Turfgrass Res. Conf., Avigon, France. 1-5 July. Ist. Nat. de la Recherche Agron., Paris.

Madison, J.H. 1962. Turfgrass Ecology. Effects of mowing, irrigation, and nitrogen treatments of *Agrostis palustris* Huds., ‘Seaside’ and *Agrostis tenuis* Sibth., ‘Highland’ on population, yield, rooting and cover. Agron. J. 54: 407-412

Minner, D.D, J.H. Dunn, S.S. Bughrara, and B.S. Fresenburg. 1993. Traffic tolerance among cultivars of Kentucky bluegrass, tall fescue, and perennial ryegrass. International Turfgrass Society Research Journal. Volume 7. p. 687-694

Myer, W.M, J.A. Murphy, and D.A. Smith. 1997 Response of cool-season turfgrasses to a novel traffic simulator. In Agronomy Abstracts. ASA, Madison, WI.

Perry, R.L. 1958. Standardised wear index for turfgrasses. S. Calif. Turfgrass Culture. 8, 4: 30-31

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

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. and J.B. Beard. 1975a. Turfgrass wear mechanisms: I. Wear tolerance of seven turfgrass species and quantitative methods for determining wear injury. Agron. J. 67:208-211.

Shearman, R.C. and J.B. Beard. 1975b. Turfgrass wear mechanisms: II. Effects of cell wall constituents on turfgrass wear tolerance. Agron. J. 67:211-215

Shearman, R.C. and J.B. Beard. 1975c. Turfgrass wear mechanisms: III. Physiological, morphological, and anatomical characteristics associated with turfgrass wear tolerance. Agron. J. 67:215-218.

Shearman, R.C. 1988. Improving sports turf wear tolerance. Proc. Of the 58th Ann. Michigan Turf. Conf. Vol. 17: 153-155.

Sheffer, K.M., T.L. Watschke, and J.M. Duich. 1978 Effect of mowing height on leaf angle, leaf number, and density of 62 Kentucky bluegrasses. Agron. J. 70:686-688

Shildrick, J.P. 1971. Grass variety trials. J. Sports Turf Res. Inst. 47: 86-127

Shildrick, J.P. 1973. Trials of perennial ryegrass and timothy cultivars. J. Sports Turf Res. Inst. 49: 66-102

Sorochan, J.C., J.N. Rogers, III, J.C. Stier, and D.E. Karcher. 2001. Fertility and simulated traffic effects on Kentucky bluegrass/supina bluegrass mixtures. p.941-946. ln K. Carey (ed.) Proc. 9th Int. Turfgrass Res. Conf., Toronto, ON Canada. 15-21 July. Int. Turfgrass Soc., and Royal Canadian Golf Assoc., Oakville, ON.

Sun, D., and M.J. Liddle. 1993. Trampling Resistance, stem flexibility, and leaf strength in nine Australian grasses and herbs. Biol. Conserv. 65:35-41

Taiz, L. and Zeiger, E. 1972. Plant Physiology, Second Edition. Sinauer Associates. Sunderland, MA.

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.

U.S. Department of Agriculture. 1993. 1990 Kentucky bluegrass test. NTEP No. 94-6. USDA-ARS and National Turfgrass Federation, Inc. Beltsville, MD.

U.S. Department of Agriculture. 2000. 1995 Kentucky bluegrass test. NTEP No. 01-12. USDA-ARS and National Turfgrass Federation, Inc. Beltsville, MD.

Van der Horst, J.P. 1970. Sports turf research in the Netherlands. J. Sports Turf Res. Inst. 46: 46-57

Van Soest, P.J. 1994. Nutritional Ecology of the Ruminant. Cornell University Press, Ithaca, NY.

Vos, H. 1972. Zuchtziele für Rasengräser im maritimen Klimabereich. Rasen-Turf-Gazon. 3: 74-77

Waddington, D.V. 1992. Soils, soil mixtures, and amendments. p. 331-383. ln Turfgrass (eds.) D.V. Waddington, R.N. Carrow, and R.C. Shearman. Agronomy Monogr. 32. ASA, CSSA, and SSSA, Madison, WI.

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

Zebarth, B.J. and R.W. Sheard, 1985. Impact and shear resistance of turfgrass racing surfaces for Thoroughbreds. Am. J. Vet. Res. 46: 778-784.