ABSTRACT

TURFGRASS WEAR TOLERANCE

By

Robert C. Shearman

A mechanical turfgrass wear simulator was constructed for small plot investigations. The machine effectively simulated both foot (sled) and vehicular (wheel) wear on turf. Wear tolerance differentials were determined for seven cool-season turfgrass species. Manhattan perennial ryegrass (Lolium perenne L.) was the most wear tolerant to vehicular wear. Kentucky 31 tall fescue (Festuca arundinacea Schreb.) and Merion Kentucky bluegrass (Poa pratensis L.) ranked second. Pennlawn red fescue (F. rubra L.) and Italian ryegrass (L. multiflorum L.) were intermediate. Cascade chewings fescue (F. rubra var. commutata Gaud.) and rough bluegrass (P. trivialis L.) ranked the lowest. Merion was the most wear tolerant to sled wear of the species studied, while rough bluegrass was the least tolerant.

Quantitative methods for determining the degree of turfgrass injury due to wear were studied. The percent verdure remaining after wear injury was determined to be the preferred quantitative method

compared to chlorophyll content, percent total cell wall content (TCW), and visual ratings. The percent verdure remaining after wear treatment gave adequate separation of species wear tolerance differentials more rapidly than the percent TCW determinations or percent chlorophyll content, eliminating arbitrary decisions and potential bias involved in the visual rating system.

Cell wall constituents of the seven cool-season turfgrass species were determined and associations of these characteristics with turfgrass wear tolerance were made in an effort to develop criteria for selecting wear tolerant species and cultivars. The seven species varied significantly in their cell wall components both on a percent dry weight and mg per $dm^2$ basis. Cell wall constituents of the seven species expressed on a percent dry weight basis were not individually correlated to turfgrass wear tolerance. However, total cell wall, lignocellulose (ADF), cellulose, hemicellulose and lignin contents expressed on a weight per unit area basis were significantly correlated at the 5% level. The combined effects of TCW, ADF, cellulose and lignin expressed on a dry weight basis accounted for a significant degree of the variation (96%) in wear tolerance among the seven turfgrass species. The combined effects of cell wall constituents expressed on a per unit area basis accounted for 97% of the observed variation on wear tolerance. TCW expressed on a mg per $dm^2$ basis accounted for 78% of the observed variation in wear tolerance. It required about one-fourth to one-fifth the number of operations involved in the determination of the combined effects of the cell wall constituents, making this procedure best adapted for use as a selection tool in large-scale breeding programs than the other methods studied.

Cell wall constituents were found to vary significantly with plant maturity. The relative ranking of species for content of the various cell wall constituents remained consistent across sampling dates. The percent TCW increased significantly during the period of July to September, but declined in October. Leaf blade contents of TCW, ADF, cellulose, hemicellulose, and lignin ranked significantly lower than those in the leaf sheath for all species.

Certain physiological, morphological, and anatomical characteristics of turfgrasses were associated with species wear tolerance. Significant differences among species were noted for verdure, shoot density, leaf width (LW), load bearing capacity (LBC), leaf tensile strength (LTS), percent moisture content of leaves and stems, and percent relative turgidity of leaf blade tissues. No significant simple correlations were found between these factors and wear tolerance among the species tested. An analysis of the combined relationship of these factors indicated that LTS and LW accounted for a significant portion (96%) of the observed variation in turfgrass wear tolerance. Anatomical comparisons were made between Kentucky 31 tall fescue and rough bluegrass. Sclerenchyma fibers of Kentucky 31 composed 18.6% of leaf and 23.4% of stem cross-sectional areas. The contents for rough bluegrass were 8.9% and 10.3%, respectively. Lignified cells composed 49.8% of the total leaf cross-sectional area for Kentucky 31 tall fescue and 23.4% for rough bluegrass. The percent sclerenchyma fibers and lignified cells were closely related to the wear tolerance observed between these two species.

TCW, lignocellulose, cellulose, hemicellulose, and lignin expressed on a mg per $dm^2$ basis appear most valuable as criteria for wear tolerance evaluation. While TCW, lignocellulose, cellulose, and lignin expressed on a percent dry weight basis were second in importance, both of these procedures require a considerable number of operations to obtain the desired measurements. TCW expressed as mg per $dm^2$ accounted for a major portion (78%) in wear tolerance and could be effectively used to evaluate species' wear differentials. The contents of sclerenchyma fibers and lignified cells were strongly related to wear tolerance. However, more extensive work with these parameters involving more species is necessary before representive conclusions can be made.

# TURFGRASS WEAR TOLERANCE

By

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A DISSERTATION

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To my

wife Linda and son Kipp

for their love, understanding, and sacrifice

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# INTRODUCTION

Turfgrasses have been developed for functional, recreational, and ornamental uses. Turfs utilized for recreational and athletic activities are particularly subjected to injury, thinning, and perhaps complete loss from the effects of concentrated foot and vehicular traffic. Greater demands have been placed on recreational turfgrass areas with increased population and leisure time resulting in increased difficulty for the turfgrass manager to maintain quality turf in these areas. The use of artifical turf has increased in popularity on athletic fields subjected to intensive use and extended playing seasons. This increased popularity has resulted in emphasizing the use of artificial turf over natural grass covers for areas subjected to intensive traffic. Natural turfs make considerable contributions to an improved environment, aesthetic pleasures, and human psychological and physical well-being. The turfgrass agronomist must accept the responsibility to improve turfgrasses for their specific usage through the manipulation of cultural, environmental, and plant factors. This investigation was conducted to develop a better understanding of turfgrass characteristics, contributing to wear tolerance and to develop criteria that could be utilized as selection tools in a breeding program designed to determine turfgrass wear tolerant cultivars.

Turfgrass wear tolerance results from weight or presssure of traffic crushing the leaf, stem, and crown tissues of the plant. Beard (1973) reported that wear tolerance varied according to (a) turfgrass species and cultivar, (b) intensity and type of traffic, (c) the environment, and (d) intensity of culture practiced. Beard reviewed most of the pertinent literature concerning turfgrass wear tolerance. Most of the turfgrass wear information reported is not based on replicated studies, but on field observations that involve more than the response to wear. Turfs may fail to persist under heavily trafficked situations for a number of reasons. Among these are the ability of the turf to (a) resist wear injury, (b) grow in compacted soils, (c) resist increased disease susceptibility, and (d) the species' ability to recover (recuperative potential) from injury. Wear tolerance should be considered as an entity of its own and should be considered aside from the other effects of traffic, especially compaction.

Youngner (1961) reported on the wear tolerance of some warm- and cool-season turfgrasses. His data is the only available information in the literature that reports on wear tolerance differentials among cool-season turfgrasses. Reports by Shildrick (1971), Versteeg (1973), and Wood and Law (1972) on turfgrass species and cultivar wear tolerance differentials involved the overall effects of traffic and not wear alone. Their studies really compared the ability of species and cultivars to persist under traffic. The data reported by Youngner (1961) were obtained under growing conditions more suitable to the warm-season than cool-season turfgrass species. He reported zoysiagrass (*Zoysia* sp.) and bermudagrass (*Cynodon* sp.) to be the most wear tolerant of the warm-season species and tall fescue (*Festuca arundinacea* Schreb.) the most wear tolerant of cool-season species studied. Youngner's relative ranking for wear tolerance of the cool-season species studied were reasonable based on his techniques and general field observations. However, the cool-season species may have performed differently under conditions more suitable to their optimal growth.

There is no information reported in the literature concerning the anatomical, morphological, and physiological characteristics of turfgrasses that contribute to wear tolerance differentials. If such information were available, it could be used as a selection tool in turfgrass breeding programs designed to obtain wear tolerant lines. The objectives of this investigation were to:

(a) Develop a wear simulator that could operate on small plots and adequately determine wear tolerance differentials for species, cultivars, and cultural practices.

(b) Determine the relative wear tolerance of several cool-season turfgrass species and develop quantitative methods that could be used to rapidly evaluate wear injury and readily lend themselves to repeatability by other researchers. Quantitative methods were needed to eliminate arbitrary decisions and bias involved in visual rating systems.

(c) Characterize anatomical, morphological, and physiological characteristics of turfgrass species that are associated with inferior and superior wear tolerance.

(d) Develop criteria based on physiological, morphological, and anatomical plant characteristics that could be utilized as selection tools in turfgrass wear tolerance breeding programs.

CHAPTER I

# A TURFGRASS WEAR SIMULATOR FOR SMALL PLOT INVESTIGATIONS


## Abstract

A mechanical turfgrass wear simulator was constructed for small plot investigations. The machine was constructed for uses on experimental units as small as 1 $m^2$, and of a size and weight to be easily moved by an individual. The machine simulates both foot and tire wear on turf with minimum soil compaction effects.


## Introduction

Turfgrass wear results from the weight or pressure of traffic crushing leaf, stem, and crown tissues of the turfgrass plant. The wear tolerance of turf varies, according to (a) turfgrass species, and cultivar, (b) intensity and type of traffic, and (c) the environment, and (d) the intensity of culture practiced (1). Several mechanical wear and compaction simulators have been developed for investigation of turfgrass wear tolerance (2, 3, 4). In general, these machines have been constructed for use on large experimental units, and are not easily transported from one experimental site to another.

A wear simulator was developed that would meet the following criteria for conducting comparative turfgrass wear tolerance studied:

(a) Provide an action that would separate turfgrass wear aspects from soil compaction.

(b) Operate for extended periods independent of operators.

(c) Operate on experimental units as small as 1 $m^2$.

(d) Be of a size and weight that can be easily transported from one experimental site to another.

## Description

Several models of wear simulators were studied. After considerable discussion and study, one design was adopted for construction. The simulator was constructed in August, 1972. Test runs on various turfs were conducted to develop standard procedures for operation of the machine.

Figures I.1 and I.2 are overall views of the mechanical wear simulator. The machine is constructed to rotate around a pivotal point with an adjustable diameter ranging from 1.0 to 2.7 m. It is anchored by four steel rods (0.75 cm x 75.0 cm) driven through a flat plate (6.25 $dm^2$) at the base of the pivot assembly. The unit weighs 47.2 kg. The weight of the rotating unit is supported by a 10 x 20 cm pneumatic tire, supplying a pressure of 7.2 kg $dm^{-2}$ on the turf. The tire simulates wear aspects similar to golf carts and maintenance equipment. A weighted sled attached to a tow arm and actuated by a cam was adapted to the wear simulator to simulate the tearing and crushing aspects of foot traffic. The cam operates from a lobe on the axle of the wheel and gives a twisting action to the sled. The sled weighs 14.5 kg and supplies a pressure of 1.45 kg $dm^{-2}$ to the turf.

Electrical power is supplied through a cooperband-brush commutator having a slip-ring assembly at the top of the pivotal rod. A 0.25 HP electrical motor drives the wear simulator. The unit is chain driven with a traveling speed of 1.6 km $hr^{-1}$. The number of revolutions required to reach a predetermined wear endpoint was recorded on a counting device at the base of the pivotal assembly. Figures I.2, I.3, and I.4 illustrate the basic components and specifications for construction of the turfgrass wear simulator.

Preliminary experiments demonstrated that the wear simulator can effectively separate wear tolerance differentials among both turfgrass species and cultural practices. A wear endpoint, similar to that reported by Youngner (4), was chosen. The turfgrass wear tolerance was determined as the number of revolutions required to reach a point when all leaf blades were shredded from the sheath and only stems and bare soil remained. Differences in reaching this endpoint ranged from 300 to 750 revolutions for the cool-season species evaluated.

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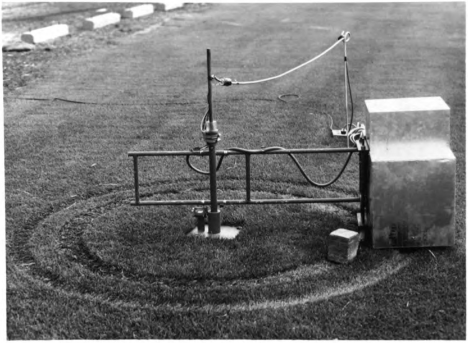


Fig. I.1.--An overall view of the wear simulator showing the two aspects of wear simulated.

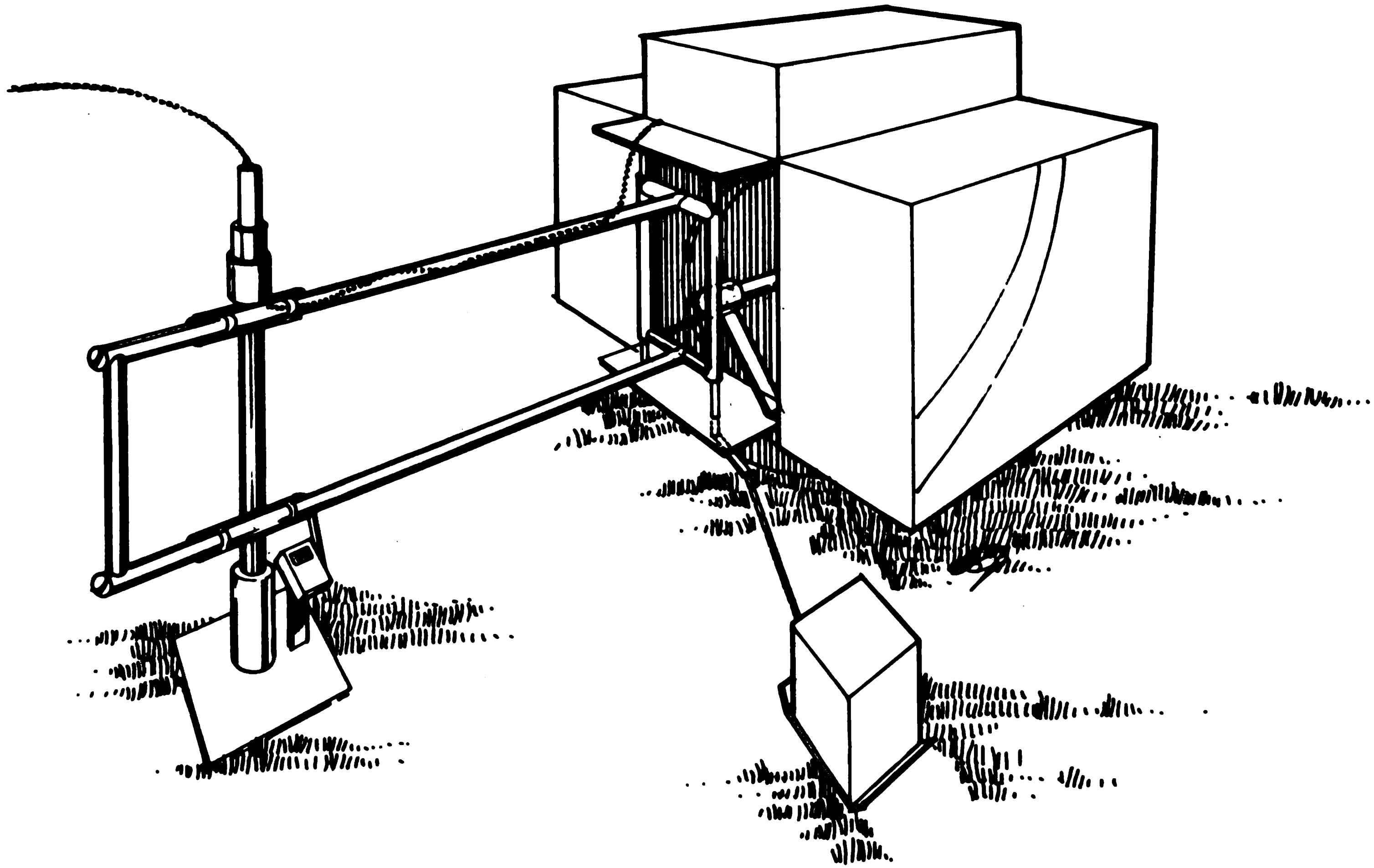


**Fig. I.2.**—A diagrammatic view of the wear simulator showing pivotal assembly and frame connection.

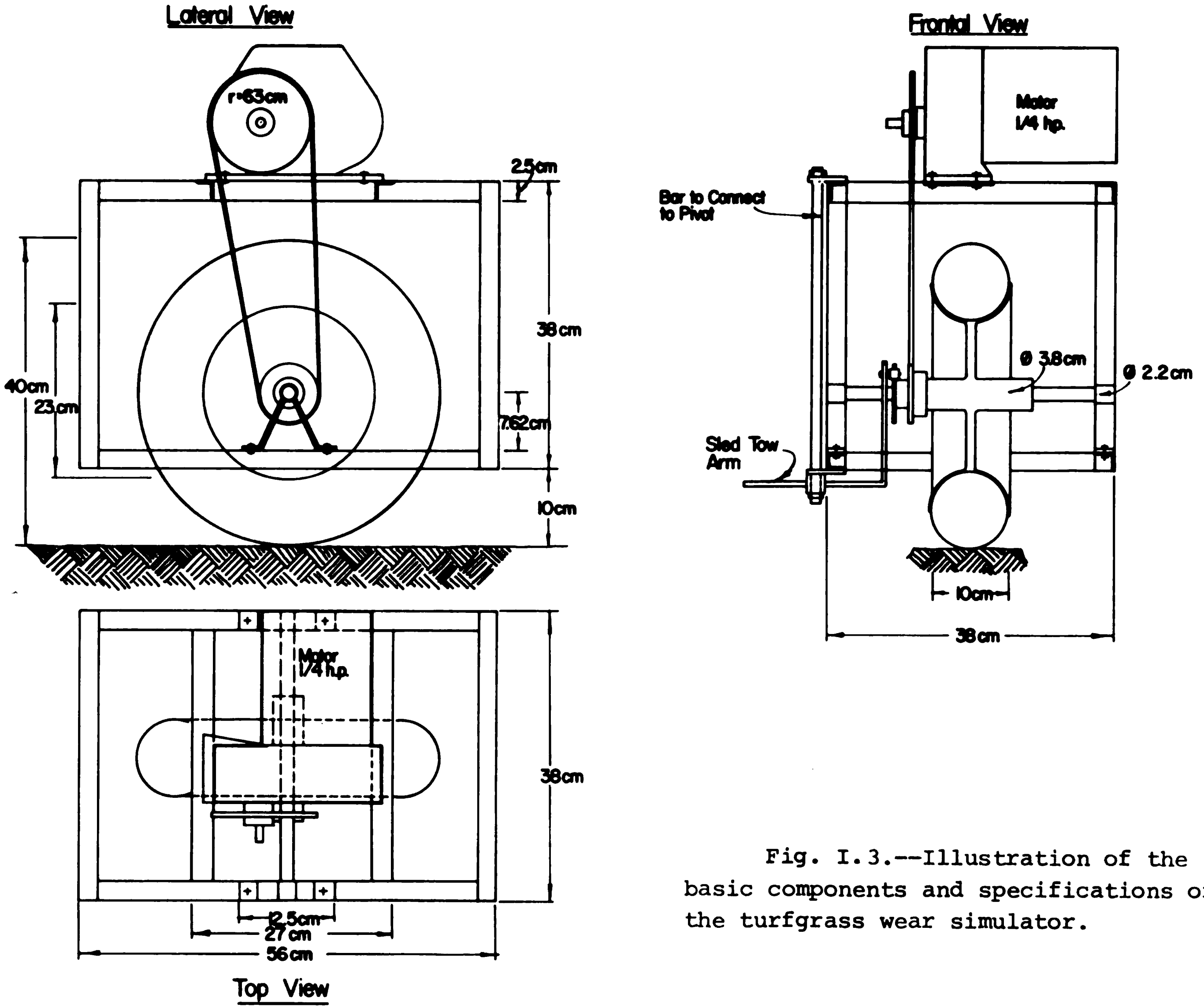
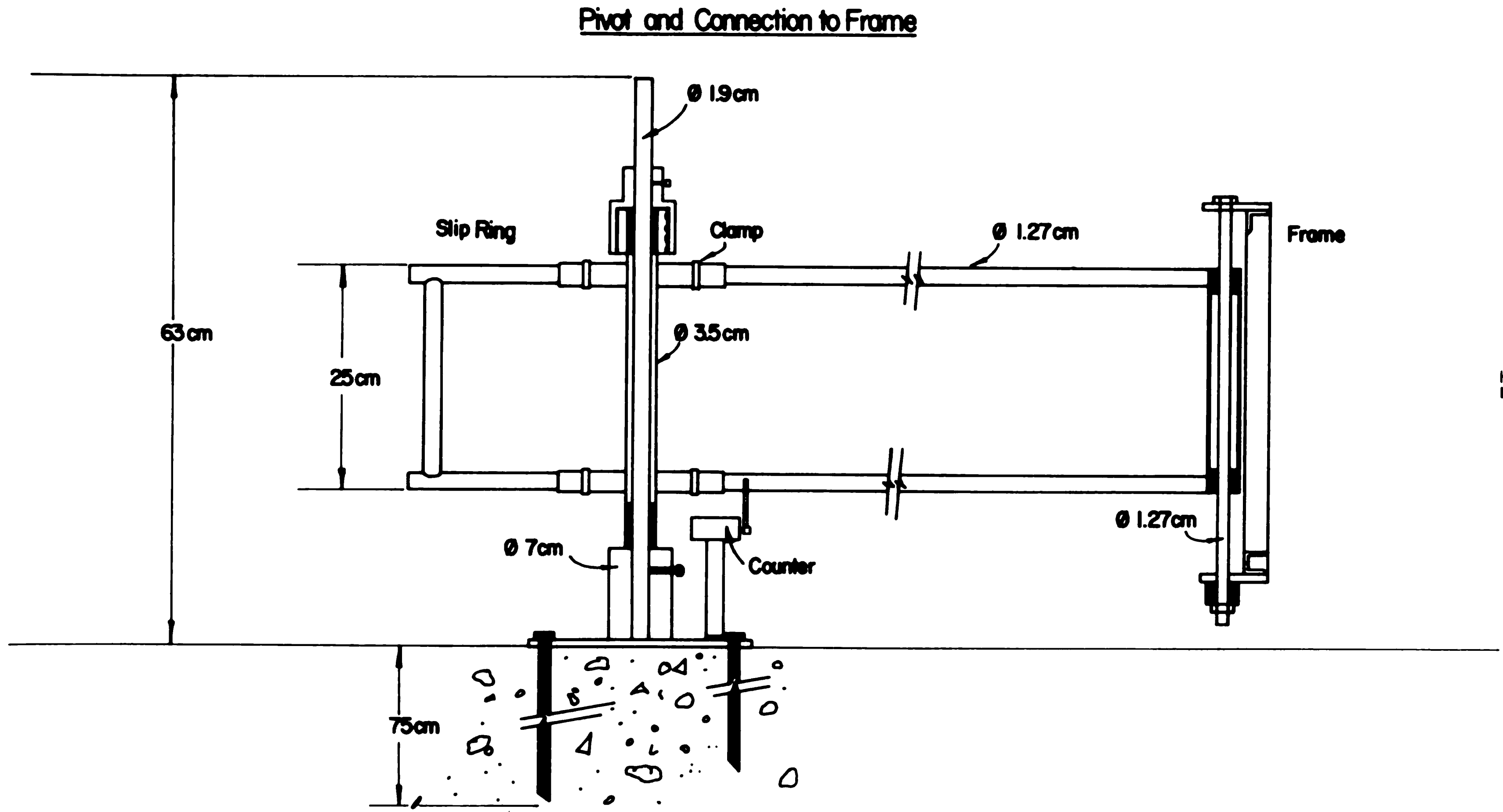



Fig. I.3.--Illustration of the basic components and specifications of the turfgrass wear simulator.

Fig. I.4.--View of the pivotal assembly and frame connection for the turfgrass wear simulator.



## CHAPTER II

## WEAR TOLERANCE OF SEVEN COOL-SEASON TURFGRASS SPECIES AND QUANTITATIVE METHODS FOR DETERMINING TURFGRASS WEAR INJURY

### Abstract

The relative wear tolerance of seven cool-season turfgrass species was determined by four methods of evaluation for both sled (foot-like) and wheel (vehicular) wear injury. The four methods of evaluating wear tolerance differentials were (1) visual rating of wear injury, (2) percent total cell wall (TCW), (3) percent verdure, and (4) percent chlorophyll content per unit area remaining after wear treatment. Manhattan perennial ryegrass was the most tolerant to wheel wear; Kentucky 31 tall fescue and Merion Kentucky bluegrass ranked second; Pennlawn red fescue and Italian ryegrass were intermediate; while Cascade chewings fescue and rough bluegrass ranked lowest among the species examined. The relative ranking for sled (foot-like) wear was slightly different from that of the wheel. Visual ratings indicated that Manhattan, Kentucky 31, and Merion

were equally tolerant to sled wear. However, Merion was the most wear tolerant to sled injury, according to ratings based on the percent verdure remaining after treatment. Manhattan and Kentucky 31 ranked second and third, respectively; while, Cascade chewings fescue and rough bluegrass were essentially destroyed by the crushing and tearing action of the sled.

Percent verdure remaining after treatment was determined to be the preferred method for quantitatively evaluating wear tolerance differentials. It eliminated arbitrary decisions that were inherent in the visual rating system, and involved fewer procedural steps than either the percent TCW or chlorophyll content determinations.

## Introduction

The injurious effects of foot or vehicular traffic on the above ground portions of turf are termed wear. Wear injury results from the weight and motion of traffic crushing and tearing the leaves, stems, and crowns of the turfgrass plant. Wear injury should be distinguished from the soil compaction aspects of traffic. Wear tolerance was reported by Beard (1973) to vary, according to the (a) turfgrass species, (b) intensity of turfgrass culture, and (c) intensity and type of traffic. Ferguson (1961), and Burton (1966), emphasized that proper traffic control is essential in minimizing the severity of wear injury and for recuperation of injured turfs.

Warm-season turfgrasses have been reported by Beard (1973) and Youngner (1961) to be more wear tolerant than cool-season turfgrasses. However, information concerning wear tolerance aspects of cool-season turfgrass species is limited. Morrish and Harrison (1948) found Kentucky bluegrass (Poa pratensis L.), Canada bluegrass (P. compressa L.), chewings fescue (Festuca rubra var. commutata Gaud.), sheep fescue (F. ovina L.), and tall fescue (F. arundinacea Schreb.) to be more wear tolerant of vehicular traffic than several common forage grass species. Shildrick (1971) and Wood and Law (1972) have reported wear tolerance variations among Kentucky bluegrass cultivars. Red fescue (Festuca rubra L.) was reported by Versteeg to not persist as well as chewings fescue on intensively trafficked areas.
One basic limitation prevails throughout each of these studies. Evaluations of the persistence of cool-season turfgrasses under traffic is really not a measure of wear injury alone, but a composite of many effects including wear, compaction, and disease susceptibility.

Youngner (1961) conducted extensive investigations on the wear tolerance of warm- and cool-season turfgrass species. He used a wear simulator described by Perry (1958). The machine simulated two aspects of wear, scuffing feet, and a spiked roller. The spiked roller caused the most severe wear damage. Youngner's results indicated that zoysiagrasses (Zoysia japonica Steud., and Z. matrella L.), bermudagrass (Cynodon dactylon L.) and Alta tall fescue were the most wear resistant species tested. In general, the warm-season turfgrass species were more wear tolerant than the cool-season species. Tall fescue was the most wear tolerant of the cool-season species studied. Merion Kentucky bluegrass, common Kentucky bluegrass, and perennial ryegrass (Lolium perenne L.) were intermediate in wear tolerance, while Astoria and Highland colonial bentgrasses (Agrostis tenuis Sibth.) ranked lowest in wear tolerance among the species studied. In many cases, field observations have been the only basis for delineating the relative wear tolerance of cool-season turfgrass species.

This study was conducted as part of an investigation to determine the influence of physiological, morphological, and anatomical characteristics of turfgrasses that are associated with wear tolerance. The objectives of this study were to (1) develop quantitative methods for differentiating wear tolerance among species, and (2) compare the relative wear tolerance of seven cool-season turfgrass species.

## Materials and Methods

Seven cool-season turfgrass species were established in early May, 1972, on a sandy loam soil. A randomized complete block design with two blocks and seven treatments per block was used. The plots were 1.8 x 7.6 m. The turfgrasses utilized were (1) Pennlawn red fescue (Festuca rubra L.), (2) Cascade chewings fescue (F. rubra var. commutata Gaud.), (3) Kentucky 31 tall fescue (F. arundinacea Schreb.), (4) Manhattan perennial ryegrass (Lolium perenne L.), (5) Merion Kentucky bluegrass (Poa pratensis L.), (6) Italian ryegrass (L. multiflorum L.), and (7) rough bluegrass (P. trivialis L.). Each species was established from seed. The seeding rates were based on 15 seeds per 6.25 $cm^2$, or a rate equivalent to 0.454 kg per area of Kentucky bluegrass. The rates were adjusted for percent viable seed, according to the germination and purity percentages for each species.

Seedbed Preparation and Post-Germination Care. A complete fertilizer (12-12-12) was tilled into the upper 5.0 cm of the seedbed at a rate of 0.454 kg actual nitrogen (N) per are. The final seedbed was raked, the seed was applied with a Scotts' gravity spreader, and rolled to insure good seed-soil contact. An application of Tupersan (siduron) at a rate of 0.454 kg per hectare was applied to control annual weedy grasses. The plot area was mulched with straw at a rate of 27.2 kg per are. The mulch was removed three weeks after seedling emergence and an application of 0.225 kg actual N per are of ammonium nitrate (33-0-0) was applied. Subsequent fertilizations of 0.454 kg actual N (33-0-0) were applied on July 25, August 25, and September 15, 1972. The plots were mowed twice weekly at 5.0 cm with a reel mower and the clippings were removed. Irrigation was applied as needed throughout the growing season to prevent visual drouth stress. Broadleaf weeds were controlled by hand weeding the plots.

Determination of Turfgrass Wear Tolerance. On September 20, 1972, a preliminary wear study was conducted using the wear simulator previously described by Shearman et al. (1973) to develop standard operating procedures. Kentucky 31 tall fescue and rough bluegrass established in May were included in this study. A wear endpoint similar to that reported by Youngner (1961) was chosen to evaluate wear tolerance between turfgrass species. The wear tolerance was determined by the number of revolutions necessary to shred all leaf blades from the sheath with only stems and bare soil remaining.

Four alternate methods were chosen to measure wear injury in an attempt to achieve a greater degree of precision in wear testing procedures. The methods selected were (a) percent total cell wall, (b) percent verdure, (c) chlorophyll content on a per unit area basis, and (d) visual ratings. Each method was modified as needed for the specific evaluation of wear. Specific modifications are described in subsequent sections. A second wear study was conducted, utilizing these methods in early June, 1973. All seven turfgrass species were included. Each species was subjected to 600 machine revolutions (600 wear units) for both wheel and sled wear. No apparent disease activity was present at the time of wear treatment or when samples were taken. Samples for the quantitative determinations were made three days after the turf had been treated. The wear damaged tissues desiccated and turned a straw-color within this period of time.

Percent total cell wall. Total cell wall content determinations were made using the method outlined by Goering and Van Soest (1970). The turfs were mowed at 5.0 cm and the clippings were removed. Four, 10 cm diameter plugs were sampled from trafficked (wheel only) and non-trafficked areas within each treatment. The percent total cell wall was determined for the wear injured and uninjured turfs. The total cell wall content for the wear-injured turf was determined after the straw-colored tissues were removed. The percent total cell wall per $dm^2$ value for the injured turf was divided by that obtained for the adjacent uninjured turf. This calculation was multiplied by 100 and converted to a percentage value based on the turf receiving no wear injury. Hence, the larger the calculated value, the greater the wear tolerance of the turf.

Percent verdure. Verdure measurements were made using the method described by Madison (1962). The plots were mowed at 5.0 cm and the clippings removed immediately before evaluations were made. Four, 10 cm diameter plugs were sampled from both the wear-injured (wheel and sled) and uninjured turfs, as described in the percent total cell wall determination procedures. Verdure was expressed in grams of fresh weight per $dm^2$. The value obtained for the wear-injured turf was divided by that obtained for the uninjured. The resultant calculation was multiplied by 100 to obtain a percentage value based on the verdure for the uninjured turf. A large calculated value indicated a great degree of wear tolerance.

Chlorophyll content per unit area. The chlorophyll content of turf has been correlated with visual quality ratings by Madison and Anderson (1963), Mantell and Stanhill (1966), and Wilkinson and Duff (1972). The chlorophyll content per $dm^2$ for wear-injured (wheel only) and uninjured turfs was determined spectrophotometrically using the procedures outlined by Wilkinson and Duff (1972). The turfs were mowed at 5.0 cm and the clippings were removed. Four, 10 cm diameter plugs were sampled from each treatment for both the wear-injured and uninjured turfs as previously described. Chlorophyll content was expressed as mg chlorophyll per $dm^2$. The value obtained for the wear-injured turf was divided by that obtained for the uninjured turf.

This value was multiplied by 100 and expressed as a percentage on an uninjured basis.

Visual rating. Visual ratings of turfgrass wear injury for both wheel and sled were determined. Ratings were based on a scale of 1 to 5. A rating of 1 indicated no injury, while 5 indicated bare soil exposed and only stems remaining. Intermediate ratings were based as follows: a) 2 indicated 25 percent of leaf blades shredded from sheaths, b) 3 indicated 50 percent of leaf blades shredded from sheaths, and c) 4 indicated 75 percent of leaf blades shredded from the sheaths and some exposed soil.

Data Analysis. A randomized complete block design with nested subsamples was used in this study. An analysis of variance was conducted and means were separated by the Duncan's Multiple Range Test. The usefulness of the methods evaluated for measuring wear tolerance differentials was based on correlations with visual quality ratings, and whether satisfactory differentials in wear tolerance could be achieved among species.

## Results and Discussion

The results of a preliminary wear tolerance experiment conducted in the fall of 1972 are shown in Table II.1. Wear tolerance was based on the number of revolutions to reach the predetermined endpoint described in the Materials and Methods section. This procedure satisfactorily differentiated wear tolerance between the two species studied. However, considerable variability between runs existed, making it difficult to determine wear tolerance differentials among closely associated species. In addition, it was recognized that the wear endpoint was rather arbitrary and could be difficult to duplicate when attempted by other researchers. With these disadvantages in mind, alternative methods were sought for quantitatively determining wear tolerance.

Wear tolerance differentiation among the four methods studied was quite significant (Tables II.2-II.6). Manhattan perennial ryegrass was the most wear tolerant species under wheel traffic. Kentucky 31 tall fescue and Merion Kentucky bluegrass ranked second. Pennlawn red fescue and Italian ryegrass were intermediate, while Cascade chewings fescue and rough bluegrass ranked lowest for the species examined. The relative wear tolerance differential based on the percent verdure remaining after sled wear injury differed slightly from that found for the wheel (Table II.2). Sled damage was more severe in all cases. Visual ratings indicated that Manhattan perennial ryegrass, Kentucky 31 tall fescue, and Merion Kentucky bluegrass were equally tolerant of sled wear. Merion was the most wear tolerant to sled injury, according to ratings based on the percent verdure remaining after treatment (Table II.5). Manhattan and Kentucky 31 ranked second and third, respectively. Pennlawn red fescue and Italian ryegrass ranked intermediate to low. While, Cascade chewings fescue and rough bluegrass were completely destroyed by the abrasive, tearing action of the sled wear. Sled injury appeared to be most severe on the stoloniferous and bunch-type species than on the rhizomatous species. Youngner (1961) found Alta tall fescue to be more wear tolerant than Merion Kentucky bluegrass or perennial ryegrass. However, this study was conducted under growing conditions more suitable for warm-season species. Therefore, tall fescue, being a more transitional species, was better suited to these growing conditions than the other cool-season species studied. No statistical comparisons were indicated in Youngner's study.

The relative agreement among the four methods tested was significant. Visual ratings were significantly correlated to percent TCW remaining (r = -0.98), percent verdure remaining (r = -0.97), and percent chlorophyll content per unit area (r = -0.97). The visual ratings were negatively correlated to the other methods due to the fact that larger values for visual ratings indicated more severe wear injury, while the other methods were based on the fact that larger values indicated less severe wear injury. Percent TCW remaining was significantly correlated to the percent verdure (r = 0.98) and percent chlorophyll content per unit area (r = 0.95). Percent verdure was significantly correlated (r = 0.98) to the percent chlorophyll content remaining after wear treatment.

The correlation coefficients indicated satisfactory agreement between the methods tested. Any of the methods used could satisfactorily evaluate wear tolerance differentials among species. However, certain advantages and disadvantages for each method must be weighed. The visual rating system is the least involved procedure of those studied. It has a basic disadvantage in that it relies on arbitrary decisions for determining wear injury as well as the experience and biases of the evaluator. The percent verdure remaining after wear treatment was second to the visual rating method in its simplicity. It was the preferred method for quantitatively determining wear differentials. It eliminated the arbitrary decisions involved in the visual rating system, and involved fewer procedural steps and calculations per determination than either percent TCW or percent chlorophyll content methods.

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TABLE II.1.--Comparison of turfgrass species wear tolerance utilizing the wear machine operated until a comparable endpoint was achieved.

| Turfgrass species | Number of machine revolutions to reach the endpoint | | | | |
|---|---|---|---|---|---|
| | Replication | | | | Avg. |
| | I | II | III | IV | |
| Kentucky 31 tall fescue | 785 | 770 | 725 | 703 | 745.75a* |
| Rough bluegrass | 365 | 425 | 395 | 418 | 400.75b |

*Values with the same letter are not significantly different at the 5% level using Duncan's Multiple Range Test.

TABLE II.2.--Visual ratings of wheel and sled wear injury of seven cool-season turfgrass species made 3 days after wear treatment.

| Turfgrass species | Visual ratings of injury* | |
|---|---|---|
| | Wheel | Sled |
| Manhattan perennial ryegrass | 2.1a** | 2.9a |
| Merion Kentucky bluegrass | 2.5b | 2.9a |
| Kentucky 31 tall fescue | 2.4b | 2.9a |
| Pennlawn red fescue | 3.4c | 4.0b |
| Italian ryegrass | 3.6d | 4.5c |
| Cascade chewings fescue | 4.0e | 5.0d |
| Rough bluegrass | 4.6f | 5.0d |
| LSD .05 = 0.21*** | | |

*Visual ratings based on 1--no injury and 5--stems only with exposed soil. Values are averages of 8 replications.

**Values with the same letter in a column are not significantly different at the 5% level, using Duncan's Multiple Range Test.

***LSD for comparisons between column values only.

TABLE II.3.--Percent total cell wall content for wheel wear injured and uninjured turfs of seven cool-season turfgrass species, and a comparison of percent total cell wall content of green tissues, remaining 3 days after wear treatment.

| Turfgrass species | Total cell wall ($g\ dm^{-2}$) | | % total cell wall remaining |
|---|---|---|---|
| | Injured | Uninjured | |
| Manhattan perennial ryegrass | 0.91 a* | 1.06 ab | 85.6 a |
| Merion Kentucky bluegrass | 0.90 ab | 1.17 a | 76.3 b |
| Kentucky 31 tall fescue | 0.83 ab | 1.12 ab | 75.2 b |
| Italian ryegrass | 0.71 b | 0.94 bc | 66.2 c |
| Pennlawn red fescue | 0.35 cd | 0.61 d | 57.3 d |
| Cascade chewings fescue | 0.48 c | 0.98 b | 48.3 e |
| Rough bluegrass | 0.25 d | 0.78 cd | 33.4 f |
| LSD 0.5 = 0.20** | | | |

*Values with the same letter in a column are not significantly different at the 5% level, using Duncan's Multiple Range Test. Values are averages of 8 replications.

**LSD for comparison between column values only.

TABLE II.4.--Verdure for wheel wear injured and uninjured turfs of seven cool-season turfgrass species, and a comparison of percent verdure remaining 3 days after wear treatment.

| Turfgrass species | Verdure ($g\ dm^{-2}$) | | % Verdure remaining |
|---|---|---|---|
| | Injured | Uninjured | |
| Manhattan perennial ryegrass | 4.73 a* | 5.46 c* | 87.0 a* |
| Merion Kentucky bluegrass | 4.41 b | 5.84 b | 75.5 b |
| Kentucky 31 tall fescue | 4.48 b | 5.98 b | 75.0 b |
| Italian ryegrass | 3.13 c | 5.12 d | 61.0 c |
| Pennlawn red fescue | 2.32 d | 4.58 e | 50.5 d |
| Cascade chewings fescue | 1.64 e | 4.43 e | 36.8 e |
| Rough bluegrass | 1.37 f | 6.64 a | 20.3 f |
| LSD .05 = 0.22** | | | |

*Values with the same letter in a column are not significantly different at the 5% level, using Duncan's Multiple Range Test. Values are averages of 8 replications.

**LSD for comparison between column values only.

TABLE II.5.--Verdure for sled wear injured and uninjured turfs of seven cool-season turfgrass species, and a comparison of the percent verdure remaining 3 days after wear treatment.

| Turfgrass species | Verdure ($g\ dm^{-2}$) | | % Verdure remaining |
|---|---|---|---|
| | Injured | Uninjured | |
| Merion Kentucky bluegrass | 4.50 a* | 5.90 c | 76.2 a |
| Manhattan perennial ryegrass | 3.82 b | 5.89 c | 65.0 b |
| Kentucky 31 tall fescue | 3.66 b | 7.30 a | 50.2 c |
| Pennlawn red fescue | 2.51 c | 5.36 d | 46.8 d |
| Italian ryegrass | 2.11 d | 4.64 e | 45.5 d |
| Cascade chewings fescue | 1.23 e | 4.44 e | 27.6 e |
| Rough bluegrass | 0.35 f | 6.86 b | 5.1 f |
| LSD .05 = 0.13** | | | |

*Values with the same letter in a column are not significantly different at the 5% level, using Duncan's Multiple Range Test. Values are averages of 8 replications.

**LSD for comparison between column values only.

TABLE II.6.--Chlorophyll content (mg $dm^{-2}$) for wheel wear injured and uninjured turfs of seven cool-season turfgrass species and a comparison of percent chlorophyll remaining 3 days after wear treatment.

| Turfgrass species | Chlorophyll Content (mg $dm^{-2}$) | | % Chlorophyll remaining |
|---|---|---|---|
| | Injured | Uninjured | |
| Manhattan perennial ryegrass | 8.90 a* | 11.02 bc | 80.3 a |
| Kentucky 31 tall fescue | 7.32 b | 11.63 b | 63.3 b |
| Merion Kentucky bluegrass | 7.51 b | 11.86 a | 63.2 b |
| Italian ryegrass | 2.98 c | 6.74 e | 44.2 c |
| Pennlawn red fescue | 2.95 c | 8.57 d | 34.6 d |
| Cascade chewings fescue | 0.94 d | 4.28 f | 21.9 e |
| Rough bluegrass | 1.26 d | 10.93 c | 11.4 f |
| LSD .05 = 0.26** | | | |

*Values with the same letter in a column are not significantly different at the 5% level, using Duncan's Multiple Range Test. Values are averages of 8 replications.

**LSD for comparisons between column values only.

# CHAPTER III

# THE EFFECTS OF CELL WALL CONSTITUENTS ON TURFGRASS WEAR TOLERANCE

## Abstract

The cell wall constituents of seven cool-season turfgrass species were quantitatively determined. The percent total cell wall (TCW), lignocellulose (ADF), cellulose, hemicellulose, and lignin were determined on a gram dry weight and mg per $dm^2$ basis. Species differed significantly in cell wall constituents for both methods of determination. The relative ranking of the species based on the content of the various cell wall constituents expressed on a gram dry weight basis was as follows: Cascade chewings fescue > Pennlawn red fescue and Kentucky 31 tall fescue > Manhattan perennial ryegrass > Merion Kentucky bluegrass > Italian ryegrass > rough bluegrass. However, this ranking was somewhat different when the cell wall components were expressed on mg per $dm^2$. The species ranked as follows: Kentucky 31 > Manhattan and Merion > Pennlawn and Italian ryegrass > Cascade > rough bluegrass. Cell wall constituents reported on a gram

per dry weight basis were not correlated individually to wear tolerance. However, the combined effects of TCW, ADF, cellulose, and lignin accounted for a high percentage of the variation of the observed wear tolerance among the seven turfgrass species studied. TCW, ADF, cellulose, and hemicellulose contents expressed as mg per $dm^2$ were significantly correlated to wear tolerance on an individual basis. Total cell wall content expressed on mg per $dm^2$ basis accounted for 78% of the variation in wear tolerance among the seven turfgrass species evaluated.

Cell wall constituents were found to increase significantly with plant maturity with the exception of hemicellulose. Hemicellulose content was quite variable among species. Total cell wall increased significantly during the period of July to September, but declined for all species in October. The cell wall constituents were compared between leaf blade and leaf sheath. Leaf blade contents of TCW, ADF, cellulose, hemicellulose and lignin were significantly less than leaf sheath contents for all species.

## Introduction

Beard (1973), Shildrick (1971), Wood and Law (1972), and Youngner (1961) reported that turfgrass wear tolerance varies among turfgrass species and cultivars. Various physiological, morphological, and anatomical characteristics of the plant have been suggested to correspond with turfgrass wear tolerance differentials. Turfgrass wear tolerance was reported by Beard (1973) to be influenced by (a) degree of tissue hydration, (b) quantity and location of sclerenchyma fibers, (c) coarseness of stems and leaves, (d) shoot density, and (e) lignin content. However, little or no data have been reported in the turfgrass literature to verify these associations.

The objective of this investigation was to determine the relative importance of various turfgrass physiological characteristics that contribute to turfgrass wear tolerance. Major emphasis was placed on determining criteria upon which turfgrass wear tolerance could be based. This information would serve as a useful tool for selecting wear tolerant cultivars in turfgrass breeding programs.

## Materials and Methods

Field study. Seven cool-season turfgrass species were established in early May, 1972, on a sandy loam soil, as reported by Shearman and Beard (1973) in an earlier paper. A randomized complete block design with two blocks and seven treatments per block was used.

The turfgrass species studied were (1) Pennlawn red fescue (*Festuca rubra* L.), (2) Cascade chewings fescue (*F. rubra* var. *commutata* Gaud.), (3) Kentucky 31 tall fescue (*F. arundinacea* Schreb.), (4) Manhattan perennial ryegrass (*Lolium perenne* L.), (5) Italian ryegrass (*L. multiflorum* L.), (6) Merion Kentucky bluegrass (*Poa pratensis* L.), and (7) rough bluegrass (*P. trivialis* L.). The turfs were fertilized with 2.1 kg of actual nitrogen (N) per are per growing season. A complete fertilizer (12-12-12) was applied at a rate of 0.454 kg actual nitrogen per are at establishment time. Three weeks after seedling emergence 0.225 kg N (33-0-0) per are was applied. Subsequent fertilizations of 0.454 kg N per are were applied on July 25, August 25, and September 15, 1972. The turfs were mowed twice weekly at 5.0 cm with the clippings removed. Irrigation was applied throughout the growing season as needed to prevent visual drouth stress.

Evaluation of changes in percent total cell wall content during the growing season were made. Cell wall constituents for each species were determined on a mg per $dm^2$ basis. Procedures for percent total cell wall content are explained in detail in the description of analytical procedures for cell wall constituents.

*Growth Chamber Studies*. Turfs of the seven cool-season turfgrasses used in the field wear study were established in a controlled environment chamber for comparison of the various cell wall constituents. The environmental conditions were (a) 32,280 lux light intensity, (b) a 20/15 C day/night temperature regime, and (c) a 14 hour photoperiod. The turfs were established in 10 cm diameter plastic pots in a sandy loam soil. They were seeded at a rate of 15 seeds per 6.25 $cm^2$ with numbers based on viable seed, according to percent germination and purity. The seedling turfs were grown for 14 days under an automatic sprinkling system in the greenhouse before being transferred to the growth chamber. A randomized complete block design with 4 blocks and seven treatments per block was used.

The turfs were mowed weekly at 5.0 cm with the clippings removed. A complete nutrient solution with a N-P-K ratio of 4:1:2 was applied biweekly. Micronutrients were supplied in concentrations comparable to a complete Hoagland's nutrient solution. The conductance of the nutrient solution was 0.875 mmhos $cm^{-1}$. Turfs were irrigated daily to prevent drouth stress.

Comparisons of cell wall constituents for the seven cool-season species, during the 10 week period after seedling emergence as well as between leaf blade and leaf sheath were the basic data collected in this study. Comparisons of leaf and sheath cell wall constituents were made 3 months after establishment when the study was terminated. Cell wall constituents were determined, according to the methods outlined in the analytical procedures section.

Analytical Procedures. Cell wall constituents were determined using the procedures outlined by Goering and Van Soest (1970). Determinations for each procedure were replicated four times. The neutral-detergent fiber (NDF) procedure was used to determine the percent total cell wall content on a dry weight basis. Lignocellulose was determined by the acid-detergent fiber (ADF) method. The difference between the NDF and ADF contents was used to estimate the percent hemicellulose. ADF was used as a preparatory step for lignin, and cellulose determinations.

The residue from the ADF was treated with the permanganate procedure described by Van Soest and Wine (1968) to determine lignin, and cellulose contents. The permanganate lignin determination is an alternative method to the acid-detergent lignin (ADL) procedure. It is a more rapid procedure for lignin determination than ADL and the residue can be reserved for cellulose, and silica determinations. In the permanganate procedure lignin is oxidized with an excess of acetic acid-buffered potassium permanganate solution, containing trivalent iron and monovalent silver as catalysts. Manganese and iron oxides formed in this process were dissolved with a demineralizing solution, containing ethanol, oxalic acid, and hydrochloric acid. The residue that remained consisted of cellulose and insoluble minerals (primarily silica). Lignin was measured as the weight lost after the potassium permanganate treatment. Cellulose was determined as the weight lost during ashing of the remaining residue. Silica was determined by treating the ash with hydrobromic acid and weighing the remaining residue. Unfortunately, silica contents obtained were not of a sufficient quantity to adequately use the silica determination procedure.

Permanganate lignin values are less affected by heat-damage artifacts than ADL, resulting in more valid lignin values. Van Soest (1964) reported that lignin and ADF content increased as temperature was increased above 50 C. Hemicellulose content tends to decrease while the lignin contents increase. This is possibly due to precipitation of a portion of the hemicellulose into the lignin fraction. Tissue samples in this study were dried in a forced-air oven at 50 C for 24 hours. The samples were ground through a 40 mesh screen in a Wiley mill.

Data Analysis. An analysis of variance was conducted on the data for each of the studies and means were separated with the Duncan's Multiple Range Test. The plant cell wall constituents were correlated to the wear tolerance of each species. A stepwise regression procedure, discussed by Draper and Smith (1966), was used to determine the plant characteristics that were most clearly related to the wear tolerance observed.

## Results and Discussion

Comparison of Cell Wall Constituents for Species. The total cell wall content (TCW) expressed as mg per $dm^2$ are indicated in Table III.1. There were significant differences among species. Total cell wall contents in mg per $dm^2$ range from 414.8 to 805.6 mg. Kentucky 31 had the largest value per unit area. Manhattan and Merion ranked second. While, Pennlawn, Italian ryegrass, and Cascade ranked in an intermediate grouping. Rough bluegrass had the lowest value. TCW expressed on a weight per unit area basis was preferred to the TCW on a gram dry weight basis as a measure of turfgrass wear tolerance. TCW on a weight per unit area basis was significantly correlated ($r = 0.88$) to turfgrass wear tolerance.

Comparisons of the percent total cell wall (TCW) content on a gram dry weight basis for seven cool-season turfgrass species, during the first 10 weeks after seedling emergence are given in Table III.2. Significant differences in percent TCW were found among species. Percent TCW ranged as high as 52.5% and as low as 40.4% in the tenth week after seedling emergence. Sullivan (1969) reported that TCW constituents composed 40-80% of the dry matter of forages with the higher percentages found in the grasses and the lower in legumes. The percent TCW in this study fell primarily in the lower portion of this expected range due to the fact that the tissues samples were relatively young. Sullivan (1969) also reported that the higher TCW percentages are common in mature forages. A trend of increasing percent TCW with increasing seedling maturity was noted among the species tested with the exception of Italian ryegrass and Merion Kentucky bluegrass. Italian ryegrass leveled off, during weeks 8 and 10. Merion Kentucky bluegrass showed a trend of increasing TCW content through week eight and then a significant drop in week 10. No causative effect was found to explain the decline for Merion. The percent TCW on a gram dry weight basis was not correlated (r = 0.33) to wear tolerance. Multiple correlation and regression analysis of TCW and the other cell wall constituents studied on a dry weight basis with wear tolerance will be discussed in a later section of this paper.

The cellulose contents expressed on a mg per $dm^2$ basis are given in Table III.1. Significant differences in cellulose content per unit area were noted among species. Values ranged from 393.9 mg for Kentucky 31 tall fescue to 208.7 mg for rough bluebrass. Kentucky 31 had the greatest content. Manhattan and Merion ranked second. While Cascade, Pennlawn, and Italian ryegrass were intermediate to low in ranking. Rough bluegrass had the lowest cellulose content. Cellulose content expressed on a per unit area was significantly (r = 0.85) associated with the observed wear tolerance reported by Shearman and Beard (1973) in an earlier paper.

Table III.3 compares the percent cellulose content on a gram dry weight basis of seven cool-season species and the effect of turfgrass maturity on cellulose content. Significant differences were found between species and within a species across harvest dates. Cellulose contents on a gram dry weight basis ranged from 26.9% for Cascade to 18.5% for rough bluegrass in the tenth week. Rough bluegrass was the only species that had a slight decline in cellulose content through the tenth week after seedling emergence. However, four species did level-off during the eighth and tenth weeks. The percent cellulose content did not correlate (r = 0.27) with the wear tolerance of the species. The relationship of cellulose and the other cell wall constituents to wear tolerance will be discussed later.

Fahn (1967) reported cellulose to be the largest component of the cell wall constituents. This was the case for all the species in this study. Armstrong, Cook, and Thomas (1950) reported cellulose contents to be higher in grasses than legumes. They also reported an increase in cellulose content with maturity of the forage. Sullivan (1969) found that cellulose may range from 20 to 40% of the dry weight of forages. Kentucky bluegrass was reported by Phillips et al. (1954) to increase from 22% to 30%, during progression from the vegetative stage to the time of flowering. Sullivan (1956) reported an average cellulose content of 23% for Kentucky bluegrass grown as a forage grass and cut successively over the summer. The cellulose content of tall fescue was reported by Patton (1943) to be 18.5% for immature plants and 46.8% for mature, dry plants.

The percent hemicellulose content expressed on a gram dry weight basis was the most variable cell wall constituent of those examined for both comparisons among species and within species across harvest dates (Table III.4). The variability noted was most likely due to the procedure for determining hemicellulose. Hemicellulose is determined indirectly as the difference between the total cell wall content and the lignocellulose complex. The percent hemicellulose values for this study varied from 21.5% to 17.5%. The wear tolerance of the species tested was not associated with the percent hemicellulose. The hemicellulose content expressed on a unit area basis was less variable than the gram dry weight basis (Table III.1) and was significantly correlated ($r = 0.88$) to wear tolerance. Kentucky 31 and Merion had the greatest hemicellulose content followed closely by Manhattan. Italian ryegrass and Pennlawn red fescue were intermediate, while Cascade and rough bluegrass had the lowest contents of the species studied. Fahn (1967) reported hemicellulose to be the second largest cell wall component. This was the case for the species tested in this study. Sullivan (1969) found that hemicellulose contents ranged from 12 to 20% on a dry weight basis with higher percentages common for grasses and lower for legumes. The results of this study agreed with Sullivan's findings.

The lignin content of the seven cool-season species studied was expressed on a weight per unit area basis (Table III.1). There were significant differences among species. Kentucky 31 tall fescue had the greatest quantity of lignin per unit area with 97.7 mg $dm^{-2}$. Rough bluegrass was the lowest with 30.3 mg $dm^{-2}$. The lignin values obtained on the weight per unit area basis more closely agreed to the wear tolerance observed than those determinations based on a gram per dry weight basis. Lignin was significantly correlated ($r = 0.76$) to wear tolerance at the 10% level but not the 5%.

The lignin contents expressed as a percentage on a dry weight basis are indicated in Table III.5. There were significant differences in lignin content between species. Cascade chewings fescue had the highest lignin content with 6.2% and rough bluegrass had the lowest with 2.6%. Bonner and Varner reported that lignin is a major component of woody plants with values ranging from 22-34% on a dry weight basis. Sullivan (1969) reported lignin to be the least abundant of the cell wall constituents. The lignin content in leaves, stems, and heads of orchardgrass (Dactylis glomerata L.), bromegrass

(Bromus inermis Leyss.) and wheatgrass (Agropyron spp.) reported by Soluski, Patterson, and Law (1960) were 5.3, 7.8, and 8.9%, respectively. Phillips et al. (1954) reported the percentage of lignin in Kentucky bluegrass ranged from 3.4% to 7.1% as the plants matured. Patton (1943) reported lignin in tall fescue to increase from 4 to 20% as the plant matured under forage conditions. A composite sample of Kentucky bluegrass, red fescue, and colonial bentgrass was reported by Ledeboer and Skogley (1967) to have a lignin content of 14.8%. Van Soest (1964) questioned the validity of large lignin values due to the possibility of heat damage and the potential for reporting heat artifacts rather than true lignin values. He found that lignin values could be increased as much as three times for plant tissues dried between 80-100 C compared to those dried at 50 C or lower. Lignin values in this study agree with those reported by individuals previously cited, working with forage grasses. Wear tolerance of the species studied was not correlated (r = 0.23) to the lignin content expressed on a dry weight basis.

Comparison of Cell Wall Constituents for Leaf vs. Sheath. Comparisons of percent total cell wall (TCW), lignocellulose (ADF), cellulose, hemicellulose, and lignin contents of leaf blades and leaf sheaths of seven cool-season turfgrass species are shown in Table III.6. Leaf blades consistently had lower levels of the various cell wall constituents than did the leaf sheaths. The relative rankings of the species within blade and sheath determinations were the same. Martin (1970) reported similar results comparing cell wall constituents of leaf, sheath, and root for Kentucky bluegrass, and red fescue. However, he reported no difference between leaf blades and leaf sheaths TCW for creeping bentgrass (*Agrostis palustris*, Huds.). He also reported hemicellulose to exceed cellulose in the blades and sheaths of creeping bentgrass and Kentucky bluegrass, but not for red fescue. This was not the case in this investigation. There was not a good association between cell wall constituents and wear tolerance of the species tested for either leaf blade or sheath tissues when expressed on the gram dry weight basis.

Variations in Total Cell Wall Content over a Growing Season. The total cell wall contents of seven cool-season turfgrass species were compared during four months within a growing season under field conditions (Table III.7). Significant differences in percent TCW on a gram dry weight basis were noted among species within harvest dates. The trends in terms of relative ranking of species were consistent across harvest dates. Cascade chewings fescue consistently ranked highest in percent TCW and rough bluegrass ranked the lowest. There were significant differences within species across harvest dates. The general trend for the species was to increase in percent

TCW during the months of July, August, and September and then decrease in October. The decrease in October cannot be readily explained. Perhaps the decline in TCW was due to hardening-off and decrease in moisture content of the turfgrass tissues during this period. Barth, McLaren, and Lane (1972) reported on monthly changes in cell wall constituents for grass-legume forage mixtures. They noted no differences among months for either orchardgrass-clover or tall fescue-lespedeza mixtures. However, they did note differences in lignin content for both mixtures, with orchardgrass-clover increasing from 4.8 to 5.9% during the period of May to August, and fescue-lespedeza increasing from 3.7 to 5.2% during May to August. They also reported a decline in the acid-detergent fiber (lignocellulose) and lignin contents during September, indicating similar trends to those found in this study.

Multiple Correlation and Regression Analysis of Cell Wall Constituents to Wear Tolerance. A stepwise least squares program was used to estimate the best relationship between wear tolerance (dependent variable) and the cell wall constituents (independent variables). The total cell wall content (TCW) expressed on a mg per $dm^2$ basis accounted for 78% of the variation in observed wear tolerance among the species studied. The coefficient of determination with all five variables present accounted for 97% of the variation. Procedures for determining all five variables involved more procedural steps and calculations than simply determining TCW on a mg per $dm^2$ basis. Therefore, TCW expressed on a mg per $dm^2$ basis would be a potential tool for selecting wear tolerance differentials among cultivars. Total cell wall constituents on a gram dry weight basis could also be used as a selection tool. However, determination of TCW, lignocellulose, cellulose, and lignin would be necessary to give the best relationship between cell wall constituents and turfgrass wear tolerance.

The objective of this investigation was to determine the importance of various physiological characteristics of turfgrass plants that contribute to wear tolerance. Emphasis was placed on determining criteria upon which turfgrass wear tolerance could be based. Cell wall constituents based on a mg per $dm^2$ basis gave the best relationship to wear tolerance. TCW content expressed as mg per $dm^2$ accounted for 78% of the variation in observed wear tolerance. Percent total cell wall, lignocellulose, cellulose, hemicellulose, and lignin on a gram dry weight basis were not correlated to wear tolerance on an individual basis. These cell wall constituents expressed on the weight per unit area basis were correlated. However, the combined relationship of percent TCW, lignocellulose, cellulose and lignin were significantly related. The relative ranking of cell wall constituents among species was quite consistent across harvest dates as the species developed into mature turfs.

The results of this investigation indicated that the best criteria based on the relationship between cell wall components and turfgrass wear tolerance was the combined effects of all cell wall components expressed on a mg per $dm^2$ basis. The combined relationship of TCW, lignocellulose, cellulose, and lignin reported on percent dry weight basis was the next best criteria. However, TCW expressed as mg $dm^{-2}$ accounted for a significant portion of the observed variation in turfgrass wear tolerance. TCW would be the preferred method for utilization. It is a more simple and rapid determination, involving fewer procedural steps and calculations than the others discussed. A rapid procedure of this nature is essential for efficiently screening large numbers of selections or cultivars in turfgrass breeding programs.

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TABLE III.1.--A comparison of total cell wall (TCW), lignocellulose (ADF), cellulose, hemicellulose, and lignin content based on mg $dm^{-2}$ for seven cool-season turfgrass species grown in a controlled environment chamber.

| Turfgrass species | TCW | ADF | Cellulose | Hemi-cellulose | Lignin |
|---|---|---|---|---|---|
| Manhattan perennial ryegrass | 726.1 b* | 421.3 b | 350.5 b | 304.9 b | 68.4 b |
| Merion Kentucky bluegrass | 739.4 b | 418.7 b | 351.5 b | 320.6 a | 68.9 b |
| Kentucky 31 tall fescue | 805.6 a | 489.6 a | 393.9 a | 316.0 ab | 97.7 a |
| Italian ryegrass | 499.5 cd | 301.2 d | 239.6 d | 198.3 c | 62.8 c |
| Pennlawn red fescue | 506.7 c | 303.7 d | 249.7 cd | 210.7 c | 60.9 c |
| Cascade chewings fescue | 482.0 d | 322.2 c | 257.5 c | 177.2 d | 61.1 c |
| Rough bluegrass | 414.8 e | 238.6 e | 208.7 e | 176.2 d | 30.3 d |

*Values with the same letter in a column are not significantly different at the 5% level, using Duncan's Multiple Range Test. Values are averages of 4 replications.

TABLE III.2.--Comparison of percent total cell wall content of seven cool-season turfgrass species, during the first 10 weeks after seedling emergence.

| Turfgrass species | Percent total cell wall content | | | |
|---|---|---|---|---|
| | week 4 | week 6 | week 8 | week 10 |
| Cascade chewings fescue | 48.48 b*z** | 49.62 ay | 50.72 ax | 52.55 aw |
| Pennlawn red fescue | 49.76 axy | 49.01 ay | 50.01 abx | 51.10 bw |
| Kentucky 31 tall fescue | 46.42 cz | 47.62 by | 49.50 bx | 50.46 bw |
| Manhattan perennial ryegrass | 43.22 dy | 45.13 cx | 45.25 dx | 48.38 cw |
| Merion Kentucky bluegrass | 26.08 gz | 38.22 ey | 46.53 cw | 44.72 ex |
| Italian ryegrass | 39.97 ey | 41.63 dx | 45.42 dw | 46.18 dw |
| Rough bluegrass | 34.96 fz | 37.73 ey | 38.34 exy | 40.36 fw |

*Values with the same letter (a, b, c . . . f) in a column are not significantly different at the 5% level, using Duncan's Multiple Range Test. Values are averages of 4 replications.

**Values with the same letter (w, x, y, z) across dates are not significantly different at the 5% level, using Duncan's Multiple Range Test.

TABLE III.3.--Comparison of percent cellulose content of seven cool-season turfgrass species, during the first 10 weeks after seedling emergence.

| Turfgrass species | Percent cellulose content | | | |
|---|---|---|---|---|
| | week 4 | week 6 | week 8 | week 10 |
| Cascade chewings fescue | 26.20 a*xy** | 25.94 ay | 26.23 awx | 26.86 aw |
| Pennlawn red fescue | 23.47 bx | 24.34 bw | 24.97 bw | 24.74 bw |
| Kentucky 31 tall fescue | 23.36 bx | 24.12 bw | 24.27 cw | 24.52 bw |
| Manhattan perennial ryegrass | 22.34 cx | 22.82 cwx | 23.07 dw | 23.02 cw |
| Merion Kentucky bluegrass | 17.26 fz | 18.25 ey | 22.34 ex | 24.22 bw |
| Italian ryegrass | 20.44 dy | 22.01 cx | 22.04 ex | 22.84 cw |
| Rough bluegrass | 18.45 ex | 19.16 dw | 19.41 fw | 18.48 dx |

*Values with the same letter (a, b, c . . . f) in a column are not significantly different at the 5% level, using Duncan's Multiple Range Test. Values are averages of 4 replications.

**Values with the same letter (w, x, y, z) across dates are not significantly different at the 5% level, using Duncan's Multiple Range Test.

TABLE III.4.--A comparison of percent hemicellulose content of seven cool-season turfgrass species, during the first 10 weeks after seedling emergence.

| Turfgrass species | Percent hemicellulose content | | | |
|---|---|---|---|---|
| | week 4 | week 6 | week 8 | week 10 |
| Cascade chewings fescue | 20.56 a*w** | 20.64 aw | 18.27 cy | 19.95 bx |
| Pennlawn red fescue | 18.98 bx | 18.52 cx | 18.95 bx | 21.54 aw |
| Kentucky 31 tall fescue | 19.36 bx | 19.18 bx | 19.19 bx | 21.05 aw |
| Manhattan perennial ryegrass | 17.53 cy | 18.81 bcx | 17.80 cdy | 21.48 aw |
| Marion Kentucky bluegrass | 17.44 cx | 17.54 dx | 19.84 aw | 17.45 ex |
| Italian ryegrass | 16.72 dy | 15.76 ez | 17.53 dx | 19.26 cw |
| Rough bluegrass | 14.19 ey | 16.25 ex | 16.12 ex | 19.41 bcw |

*Values with the same letter (a, b, c . . . e) in a column are not significantly different at the 5% level, using Duncan's Multiple Range Test. Values are averages of 4 replications.

**Values with the same letter (w, x, y, z) across dates are not significantly different at the 5% level, using Duncan's Multiple Range Test.

TABLE III.5.--A comparison of percent lignin content of seven cool-season turfgrass species, during the first 10 weeks after seedling emergence.

| Turfgrass species | Percent lignin content | | | |
|---|---|---|---|---|
| | week 4 | week 6 | week 8 | week 10 |
| Cascade chewings fescue | 4.62 a*y** | 4.64 ay | 5.74 ax | 6.22 aw |
| Pennlawn red fescue | 4.67 ay | 4.54 ay | 5.48 bx | 6.15 aw |
| Kentucky 31 tall fescue | 3.79 bz | 4.32 by | 4.89 cx | 6.05 aw |
| Manhattan perennial ryegrass | 3.35 cy | 3.50 cy | 3.87 dx | 4.37 cw |
| Merion Kentucky bluegrass | 2.38 ey | 2.42 ey | 3.05 ex | 4.33 cw |
| Italian ryegrass | 2.81 dy | 2.85 dy | 4.08 dx | 5.85 bw |
| Rough bluegrass | 2.33 ex | 2.31 ex | 2.47 fwx | 2.63 dw |

*Values with the same letter (a, b, c, . . . f) in a column are not significantly different at the 5% level, using Duncan's Multiple Range Test. Values are averages of 4 replications.

**Values with the same letter (w, x, y, z) across dates are not significantly different at the 5% level, using Duncan's Multiple Range Test.

TABLE III.6.--A comparison of cell wall constituents of leaf blade and leaf sheath for seven cool-season turfgrass species grown for 3 months in a controlled environmental chamber.

| Turfgrass species | % Total cell wall | | % Lignocellulose | | % Cellulose | | % Hemicellulose | | % Lignin | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Leaf | Sheath | Leaf | Sheath | Leaf | Sheath | Leaf | Sheath | Leaf | Sheath |
| Cascade chewings fescue | 50.72 a* | 64.79 a | 32.46 a | 45.8 a | 26.23 a | 35.14 a | 18.27 bc | 18.94 c | 6.22 a | 10.71 a |
| Pennlawn red fescue | 50.01 a | 65.67 a | 31.12 b | 42.85 b | 24.97 b | 32.35 bc | 18.95 ab | 22.48 b | 6.15 a | 10.50 a |
| Kentucky 31 tall fescue | 49.50 a | 58.62 b | 30.32 c | 41.90 c | 24.27 c | 32.49 b | 19.19 ab | 16.72 e | 6.05 ab | 9.41 b |
| Manhattan perennial ryegrass | 45.25 c | 55.32 c | 27.45 d | 38.94 e | 23.07 d | 30.74 e | 17.80 c | 16.38 e | 4.37 c | 8.20 c |
| Merion Kentucky bluegrass | 46.53 b | 55.75 c | 26.68 e | 39.56 de | 22.34 e | 31.74 cd | 19.84 a | 16.21 e | 4.33 c | 7.83 d |
| Italian ryegrass | 45.42 bc | 57.77 b | 27.89 d | 39.83 d | 22.04 e | 31.64 d | 17.53 c | 17.94 d | 5.85 b | 8.19 c |
| Rough bluegrass | 38.34 d | 51.67 d | 22.23 f | 27.91 f | 19.41 f | 21.58 f | 16.12 d | 23.76 a | 2.63 d | 6.33 e |
| LSD .05 =** | 1.38 | | 0.613 | | 0.617 | | 0.757 | | 0.275 | |

*Values in columns with the same letter are not significantly different at the 5% level, using Duncan's Multiple Range Test. Values are averages of 4 replications.

**LSD values for comparisons between column values only.

TABLE III.7.--Determination of changes in total cell wall content (TCW) for seven cool-season turfgrass species during four months of the growing season (field study).

| Turfgrass species | Percent TCW (dry weight basis) | | | |
|---|---|---|---|---|
| | July | August | September | October |
| Cascade chewings fescue | 48.43 ab*z** | 57.58 aw | 52.55 ax | 50.59 ay |
| Pennlawn red fescue | 47.96 bz | 55.39 bw | 51.11 abx | 49.97 axy |
| Kentucky 31 tall fescue | 49.76 aw | 50.31 cw | 50.80 bw | 45.80 bx |
| Manhattan perennial ryegrass | 47.49 bcw | 48.46 dw | 48.71 cw | 45.13 bx |
| Merion Kentucky bluegrass | 42.77 ey | 45.47 fx | 48.05 cdw | 41.97 cy |
| Italian ryegrass | 45.37 dwx | 46.74 ew | 44.57 ex | 39.08 dy |
| Rough bluegrass | 39.87 fx | 45.34 fw | 40.69 fx | 36.55 ey |

*Values in columns with the same letter (a, b, c, . . . f) are not significantly different at the 5% level, using Duncan's Multiple Range Test. Values are averages for 4 replications.

**Values across harvest dates with the same letter (w, x, y, z) are not significantly different at the 5% level, using Duncan's Multiple Range Test.

## CHAPTER IV

## PHYSIOLOGICAL, MORPHOLOGICAL, AND ANATOMICAL CHARACTERISTICS ASSOCIATED WITH TURFGRASS WEAR TOLERANCE

### Abstract

This investigation was conducted to assess the relationship of various turfgrass physiological, morphological, and anatomical characteristics to wear tolerance. Comparisons were made among seven cool-season turfgrass species. No significant correlations between verdure, shoot density, leaf width, load bearing capacity, leaf tensile strength, percent moisture, or percent relative turgidity and species wear tolerance were noted, although significant differences in these factors were noted among species. An analysis of the combined relationship of these factors to wear tolerance indicated that leaf tensile strength and leaf width contributed significantly to the variation in turfgrass wear tolerance for the seven species studied.

Sclerenchyma tissues of Kentucky 31 tall fescue composed 18.6% of leaves and 23.4% of stems based on a percent of the total

cross-sectional area of leaf blades and stems. The contents for rough bluegrass were 8.9% and 10.3%, respectively. The percent of lignified cells of Kentucky 31 tall fescue were estimated as 49.8% based on total leaf cross-sectional area, while the estimate for rough bluegrass was 21.4%. Rough bluegrass showed very little affinity in the epidermal cells for the safranin stain indicating lignified cells compared to Kentucky 31 tall fescue. The percent sclerenchyma fibers and lignified cells were closely associated to the wear tolerance observed for the two species.

## Introduction

Various physiological, morphological, and anatomical turfgrass characteristics have been proposed as factors contributing to turfgrass wear tolerance. Beard (1973) reported in a review of pertinent literature that turfgrass wear tolerance was influenced by (a) degree of tissue hydration, (b) quantity and location of sclerenchyma fibers, (c) lignin content, (d) coarseness of leaves and stems, and (e) shoot density. Most of these associations are based on field observations by various workers and not quantitative measurements.

Youngner (1962) found that cutting height affected turfgrass wear tolerance. He reported that turfs mowed at 1.3 cm for three years and then returned to 3.8 cm for 4 weeks prior to wear treatment had a significantly reduced wear tolerance compared to turfs maintained at 5.0 cm. The conclusion was that close mowing restricted the turfs ability to resist wear by affecting the development of the turfgrass plant.

The relative importance of cell wall constituents, influencing turfgrass wear tolerance was reported by Shearman and Beard (1973). Esau (1965) discussed the importance of sclerenchyma fibers as mechanical protectants for plants. Sclerenchyma fibers enable plants to withstand pressure from bending, stretching, and weight without undue damage to soft, thin-walled cells of the plant. Gramineae have sclerenchyma fibers that form prominent sheaths around the vascular bundles and the epidermis. Esau (1965) also reported the importance of lignin to plant structural strength and indicated that the lignification of leaf epidermal cells of grasses is common. The characteristics of these plant tissues leads one to conclude that they would be associated with wear tolerance in turfgrasses.

This investigation was conducted to determine the effect of various turfgrass morphological and anatomical characteristics on wear tolerance. The influence of verdure, shoot density, leaf width, load bearing capacity, leaf tensile strength, percent moisture, and percent relative turgidity were studied. Comparisons of percent sclerenchyma tissues and percent lignified cells were also related to turfgrass wear tolerance.

## Materials and Methods

Plant materials for this investigation were grown under the same conditions and with the same cultural practices as those outlined previously by Shearman and Beard (1973). Seven cool-season turfgrass species were studied: a) Cascade chewings fescue (Festuca rubra var. commutata Gaud.), b) Pennlawn red fescue (F. rubra L.), c) Kentucky 31 tall fescue (F. arundinacea Schreb.), d) Manhattan perennial ryegrass (Lolium perenne L.), e) Italian ryegrass (L. multiflorum L.), f) Merion Kentucky bluegrass (Poa pratensis L.), and g) rough bluegrass (P. trivialis L.). The pots were seeded at a rate of 15 seeds per 6.25 $cm^2$. Seeding rates were adjusted according to percent viable seed based on percent germination and purity.

Verdure and Shoot Density. Webster defined verdure as the greenness of growing vegetation. The verdure in this study was measured utilizing the methods described by Madison (1962). The turfs were mowed at 5.0 cm with the clippings being removed immediately before sampling for verdure determinations. Four, 10 cm diameter pots of turf were sampled from each species studied. The living green plant tissues were harvested, including leaves, stems, and stolons. Verdure was expressed as grams fresh weight per $dm^2$. Shoot densities were determined by counting the number of shoots per pot and converting to numbers per $dm^2$. The treatments for verdure and shoot density determinations were replicated 4 times.

Load Bearing Capacity (LBC). A device was developed to determine the load bearing capacity of turf (Figure IV.1). It was constructed from a 10.5 x 25.0 cm plexiglass cylinder. A platform was designed (Figure IV.1A) to fit within the cylinder. The platform rested on the turf and was constructed to hold American standard, number-eight, lead shot. The lead shot was allowed to flow through a funnel with a 1.3 cm opening and onto the platform from a height of 20 cm until it was weighted and lowered to a predetermined point (Figure IV.1B). The weight necessary to reach this point was recorded in grams and reported as the LBC of the turf. The LBC of each of the seven cool-season turfgrass species studied was recorded. Determination of LBC was based on the average value of four replications.

Leaf Blade Tensile Strength. Leaf blade tensile strength was studied with procedures similar to those reported by Salmon (1931) and Coorts et al. (1970). A triple beam balance was modified so that leaf blades could be anchored to the base of the scale and the balance arm. A beaker was placed on the balance platform and number-eight lead shot was allowed to flow into the beaker from the funnel device with a shut-off valve described in the LBC study. The shot fell from a height of 20 cm into the beaker until sufficient weight was obtained to reach the breaking point of the leaves. Preliminary experiments indicated that leaf tensile strength was affected by leaf size and maturity. Therefore, leaves were selected from a size range of 1 to 2 mm and only the youngest, most-fully expanded leaves were chosen for testing. The leaf tensile strength was based on an average value for three leaves per determination and eight replications per treatment.

Percent Moisture and Relative Turgidity. Percent moisture of leaf blades and stems were determined on a wet weight basis for the seven cool-season turfgrass species studied. Relative turgidity measurements were made by procedures similar to those outlined by Weatherly (1950), and Namken and Lemon (1960). In this study 0.5 cm leaf sections were cut from the midportion of the youngest, most-fully expanded leaf. Seventy-five sections were cut and weighed for each determination, allowed to float for 4 hrs on distilled water, excess moisture removed by blotting with paper toweling, and weighed to determine the turgid weight. They were then oven dried to determine the dry weight. The percent relative turgidity was calculated as follows:

$$\% \text{ R. T.} = \frac{\text{fresh wt.} - \text{dry wt.}}{\text{turgid wt.} - \text{dry wt.}} \times 100$$

Anatomical Procedures. Leaf blade and stem cross-sections of Kentucky 31 tall fescue and rough bluegrass were prepared for anatomical studies. A microtome developed by Hooker (1967) for sectioning fresh plant tissues was used. The Hooker microtome was developed to section living tissues quickly and without extensive preparation. Thinness of cross-sections obtained with this procedure is limited only to the inherent ability of the plant tissues to hold together after cutting. Support for tissues was provided by placing the material on a thin slice of carrot during sectioning. The tissue sections were in the thickness range of 20 to 24 $\mu$. Sections were fixed in an FAA (ethyl alcohol, glacial acetic acid, formaldehyde and water) solution and stained with safranin-fast green, according to procedures outlined by Sass (1966).

Kentucky 31 tall fescue and rough bluegrass were selected for study as representatives of wear tolerant and intolerant species, respectively. The combined areas of vascular bundles per total cross-sectional area of leaf and stem were calculated. Areas were determined from line drawings traced from photomicrographs of tissue sections by weighing the corresponding areas and relating them to the total cross-sectional area. Schank, Klock, and Moore (1973) used a similar procedure to study the relationship of forage digestibility to the combined areas of vascular bundles in leaf sheaths of the species studied. The percentages were determined by dividing the cross-sectional area of vascular bundles by that of the total cross-sectional area of the leaf or stem and multiplying by 100. The percentage of lignified cells was calculated in the same manner. All sections were examined at 40 X magnification.

## Results and Discussion

Comparisons of verdure, leaf width (LW), shoot density, load bearing capacity (LBC), and leaf tensile strength (LTS) are shown in Table IV.1. Significant differences in verdure were noted among species. Rough bluegrass had the greatest verdure of the seven species studied. Kentucky 31 tall fescue and Merion Kentucky bluegrass ranked second. Manhattan perennial ryegrass was third. Italian ryegrass, Pennlawn red fescue, and Cascade chewings fescue ranked intermediate to low. Verdure was not correlated (r = 0.14) to wear tolerance. The species varied significantly in leaf width. Italian and Kentucky 31 had the coarsest textured leaves of the species tested. Manhattan, Merion, and rough bluegrass were intermediate in texture. Pennlawn and Cascade had the finest texture. Leaf width was not correlated (r = 0.40) to turfgrass wear tolerance. Shoot density was not associated (r = -0.64) with wear tolerance among the species studied. Rough bluegrass had the greatest shoot density and Italian ryegrass had the least. Species varied significantly in load bearing capacities. Kentucky 31 had the greatest LBC among the species. LBC was not correlated (r = 0.69) to species wear tolerance. Leaf tensile strength differences were also noted among species. Kentucky 31 and Italian ryegrass had the largest LTS among the species. Manhattan and Merion were second. Rough bluegrass was intermediate, while Pennlawn and Cascade ranked the lowest. LTS was significantly correlated (r = 0.73) at the 10% level.

The combined effects of LTS and LW accounted for 97% of the observed variation in turfgrass wear tolerance for the species examined. Beard (1973) reported that wear tolerance was related to coarseness of leaves and stems. These results indicated that the leaf coarseness was not simply related to wear tolerance. Esau (1965) indicated that tensile strength was a notable characteristic of mechanical cells of monocots, particularly those of extra-xylary fibers. This relationship between structural strength and tensile strength could result in the subsequent importance of this factor in contributing to the observed species wear tolerance.

Comparisons of percent moisture content for leaf blades and stems of the seven species studied are shown in Table IV.2. The species did vary significantly in moisture content. Leaf blades of all species had greater moisture contents than stems. Although the percent moisture contents varied significantly among species for leaves and stems, there was no significant correlation (r = -0.51, and r = -0.26) to wear for percent moisture of either leaves or stems. The same trend was true for relative turgidity measurements and wear tolerance among the species examined (Table IV.2). The species were bunched in two groups according to their percent relative turgidity measurements. Pennlawn red fescue, Manhattan perennial ryegrass, and Cascade chewings fescue had the greatest percent relative turgidities. While Merion Kentucky bluegrass, Italian ryegrass, and rough bluegrass ranked in a significantly lower group. Kentucky 31 was in between both groups. There was no correlation (r = 0.25) between percent relative turgidity and wear tolerance. The coefficients of determination did not account for a significant degree of the observed variation in species wear tolerance.

Anatomical studies were conducted on Kentucky 31 tall fescue and rough bluegrass. The cross-sectional area of vascular bundles, sclerenchyma tissues and lignified cells were compared to the total cross-sectional area for stems and leaves. The comparisons were expressed as a percent of the total cross-sectional area. Vascular bundles of leaves of Kentucky 31 tall fescue comprised 10.6% of its cross-sectional area, and 8.4% of rough bluegrass (Figures IV.2 and IV.3). Leaves of Kentucky 31 had 18.6% sclerenchyma tissues and rough bluegrass had 8.9%. The total lignified cells were also estimated for both species. Kentucky 31 tall fescue had 49.8% lignified cells based on total cross-sectional area. Total lignified cells for rough bluegrass were estimated at 21.4%. Sclerenchyma fibers composed 23.4% of the total stem cross-sectional area of Kentucky 31 tall fescue, while rough bluegrass had 10.3%. The epidermal cells of the abaxial and adaxial leaf surfaces of Kentucky 31 were more extensively lignified that those for rough bluegrass (Figures IV.2a and IV.2b). Rough bluegrass showed a very low affinity for safranin stain, indicating low lignin content in tissues. Sclerenchyma fibers were associated extravascularly on the uppermost surface of the veins on the Kentucky 31 tall fescue, contributing to strengthening and stiffness of the leaves. This characteristic was not true for rough bluegrass. The results of these anatomical studies and the wear tolerance studies previously conducted indicated that there was an excellent association between turfgrass wear tolerance and the percent sclerenchyma and lignified tissues. However, more extensive investigations are needed, involving a comparison of a number of species before more representative conclusions can be made among species.

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TABLE IV.1.--Comparisons of original verdure, leaf width (LW), shoot density, load bearing capacity (LBC), and leaf tensile strength (LTS) of seven cool-season turfgrass species grown in controlled environment chamber.

| Turfgrass species | Verdure (gm $dm^{-2}$) | LW (mm) | Shoot density (number $dm^{-2}$) | LBC (gm $dm^{-2}$) | LTS (gm $leaf^{-1}$) |
|---|---|---|---|---|---|
| Manhattan perennial ryegrass | 5.46 c* | 2.0 b | 234 c | 874 b | 635 b |
| Merion Kentucky bluegrass | 5.84 b | 2.0 b | 239 c | 687 d | 635 b |
| Kentucky 31 tall fescue | 5.98 b | 2.6 a | 160 d | 990 a | 722 a |
| Italian ryegrass | 5.12 d | 2.9 a | 151 e | 843 c | 696 a |
| Pennlawn red fescue | 4.58 e | 1.0 c | 317 a | 625 e | 305 d |
| Cascade chewings fescue | 4.43 e | 1.0 c | 318 a | 636 e | 269 e |
| Rough bluegrass | 6.64 a | 2.0 b | 306 b | 635 e | 412 c |

*Values with the same letter in a column are not significantly different at the 5% level, using Duncan's Multiple Range Test. Values are averages for 4 replications with the exception of LTS that are averages of 8 replications.

TABLE IV.2.--Comparison of percent moisture content of leaf blades and stems, and percent relative turgidity of leaf tissues for seven cool-season turfgrass species grown in a controlled environment chamber.

| Turfgrass species | Percent moisture content | | Percent relative turgidity |
|---|---|---|---|
| | Leaves | Stems | |
| Manhattan perennial ryegrass | 76.0 b* | 69.2 d | 90.3 a |
| Merion Kentucky bluegrass | 75.4 b | 70.9 c | 87.2 b |
| Kentucky 31 tall fescue | 77.3 b | 74.5 b | 88.2 ab |
| Italian ryegrass | 83.1 a | 77.9 ab | 83.8 b |
| Pennlawn red fescue | 76.8 b | 68.3 d | 93.1 a |
| Cascade chewings fescue | 75.0 b | 65.6 d | 90.2 a |
| Rough bluegrass | 84.9 a | 80.5 a | 83.6 b |
| LSD .05 = 1.54** | | | |

*Values with the same letter in a column are not significantly different at the 5% level, using Duncan's Multiple Range Test. Values are averages of 4 replications.

**LSD for comparison between column values only.

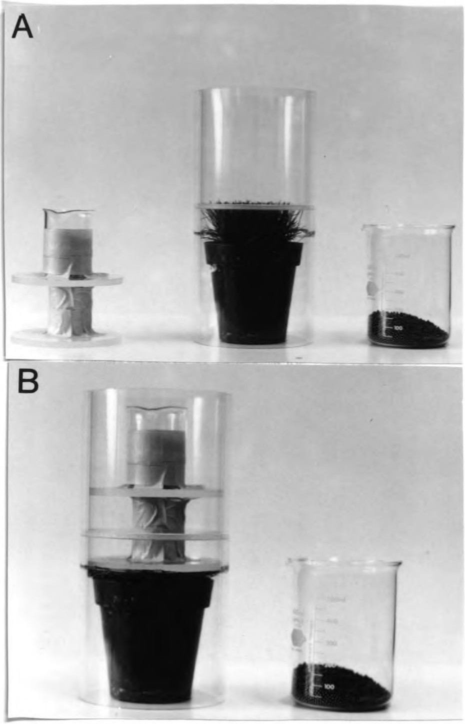


Fig. IV.1.--A device to evaluate the load bearing capacity (LBC) of turfs: (A) shows the platform, plexiglass cylinder, potted turf, and lead weights; (B) Shows the weighted platform resting on the turf at the predetermined endpoint for LBC determinations.

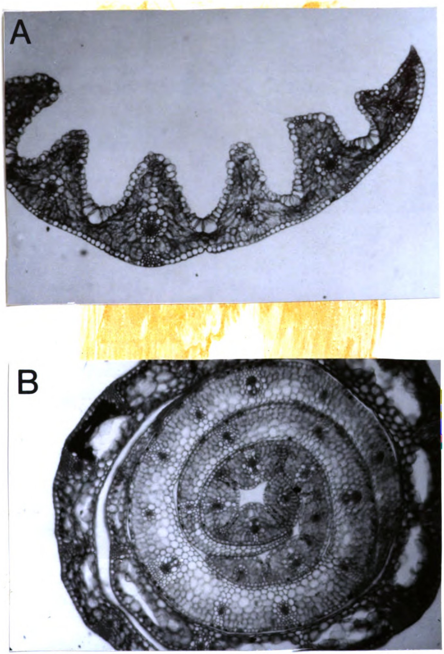


Fig. IV.2.--Leaf blade (A) and leaf sheath (B) cross-sections of Kentucky 31 tall fescue showing vascular bundles, lignified cells, and extravascular sclerenchyma fibers.

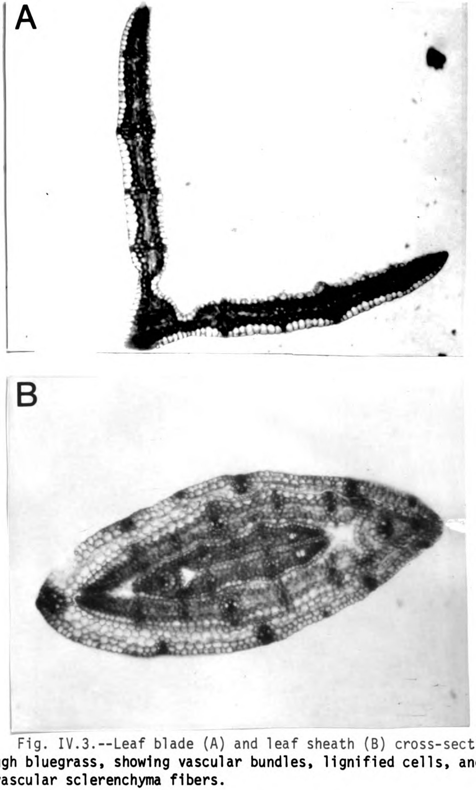


Fig. IV.3.--Leaf blade (A) and leaf sheath (B) cross-sections of rough bluegrass, showing vascular bundles, lignified cells, and extravascular sclerenchyma fibers.

# CONCLUSIONS

The following conclusions can be made regarding the wear tolerance studies conducted in this investigation:

1. The wear simulator worked effectively on small plots and adequately separated species wear tolerance differentials.

2. Turfgrass species were found to vary significantly in wear tolerance in the following order: Manhattan perennial ryegrass > Kentucky 31 tall fescue and Merion Kentucky bluegrass > Italian ryegrass > Pennlawn red fescue > Cascade chewings fescue > rough bluegrass.

3. Percent verdure, total cell wall content (TCW), and chlorophyll content per unit area remaining after wear treatment can be used to quantitate wear tolerance differentials among species.

4. Percent verdure remaining after wear treatment was determined to be the preferred method of measuring wear injury. It involved fewer procedural steps and calculations, making it a

a more rapid determination than either TCW or chlorophyll content.

5. Turfgrass species varied significantly in TCW, lignocellulose, cellulose, hemicellulose, and lignin contents expressed on a dry weight and on a mg $dm^{-2}$ basis.

6. Cell wall components expressed as a percent on a dry weight basis do not correlate with species wear tolerance.

7. TCW, lignocellulose, cellulose, hemicellulose, and lignin contents expressed on a mg per $dm^2$ basis were significantly correlated to wear tolerance.

8. The combined effects of TCW, lignocellulose, cellulose, and lignin on the dry weight basis accounted for a significant portion (96%) of the variation in wear tolerance among the seven turfgrass species.

9. The combined effects of TCW, lignocellulose, cellulose, hemicellulose, and lignin expressed as mg $dm^{-2}$ accounted for 97% of the observed variation in wear tolerance among the species tested.

10. The TCW on a mg $dm^{-2}$ basis accounted for 78% of the variation observed.

11. Cell wall constituents increased with plant maturity for the turfgrass species tested. Plant age can influence wear tolerance differentials.

12. Percent total cell wall content varied significantly during the growing season. Date of treatment could influence wear tolerance studies.

13. Leaf blade cell wall constituents were significantly less than leaf sheath cell wall constituents for all species examined.

14. The original verdure, shoot density, leaf width, load bearing capacity, leaf tensile strength, leaf blade and stem moisture contents, and percent relative turgidity of leaf tissues were not significantly correlated with interspecies turfgrass wear tolerance.

15. The combined effects of leaf width and leaf tensile strength had a significant positive correlation with wear tolerance.

16. Sclerenchyma fiber and lignified cell contents based on percentages of the total cross-sectional area of leaves and

stems were directly proportional to the observed species wear tolerance.

# SUMMARY

The results of this investigation have substantiated the association of various physiological, morphological, and anatomical characteristics with turfgrass wear tolerance. Cell wall constituents expressed on a mg per $dm^2$ basis accounted for 97% of the observed variation in wear tolerance for the species examined. Total cell wall content expressed on a weight per unit area basis accounted for 78% of this variation. Leaf width, leaf tensile strength, percent sclerenchyma fibers, and percent lignified cell also significantly contributed to wear tolerance. Many of the aspects such as verdure, shoot density, load bearing capacity, percent moisture content of leaf blades and stems, and percent relative turgidity of leaf tissues commonly associated with wear tolerance were found not to account for the variation observed in turfgrass species wear tolerance. Prior to this investigation, information of this type was not available in the turfgrass literature.

The information obtained in this investigation can be applied to develop criteria for selection of wear tolerant cultivars without utilizing a wear simulator or other wear device to determine

differentials. This would eliminate a considerable time factor involved in a mechanical wear testing program. A breeding program designed to delineate wear tolerant turfgrass cultivars could use the following criteria as a selection tool: a) total cell wall content expressed as mg per $dm^2$, b) leaf tensile strength, c) leaf width, d) percent sclerenchyma fibers, and e) percent lignified cell content. Wear tolerance differentials can be satisfactorily determined with these criteria. The total cell wall content expressed on a mg per $dm^2$ basis could adequately be applied to large-scale screening programs, offering satisfactory separation of species wear tolerance differentials.

Many aspects of turfgrass wear tolerance involving the effects of cultural, environmental, and species and cultivar factors could be studied utilizing the wear simulator and quantitative measures developed in this investigation. Some of the factors determined not to contribute significantly to the variation observed in wear tolerance among species may be of greater importance among cultivars of a single species. Additional testing in this area is needed. In addition studies involving cultivar differences in total cell wall content expressed as mg per $dm^2$ and wear tolerance should be conducted to compliment the findings in this investigation. Studies of this nature would validate the criteria for selection developed in this investigation.

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