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Anatomical and morphological factors affecting wear tolerance of turfgrass

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ABSTRACT

One of the main criterions in turfgrass breeding selection is good wear tolerance, which means the plant's ability to withstand forces that crush leaves, stems, crowns and roots. In the present study the relationship between the anatomical and morphological traits and wear tolerance of 37 cultivars of seven turfgrass species was investigated. The wear tolerance of turf was determined using a Brinkman traffic simulator during a field trial over a two-year period from 2012 to 2013. The experimental plots were established with three replications in a randomized block design. The anatomical and morphological characteristics of the above-ground part of grasses were analyzed. Based on the quantitative data obtained, a new index reflecting turf appearance, and in particular turf cover (TCI), quality (TQI) and shoot density (SDI) has been proposed. These new wear tolerance indexes created could be a very helpful and useful tool for breeding and research purposes. Standardized trait mean values were used to perform principal component and hierarchical cluster analysis. The relationship between leaf parameters and turf indexes was analyzed using multiple linear regression in a stepwise procedure.

According to the TCI, the most wear-resistant cultivars were those of *Lolium perenne*, Ilso Nira and Oxiana (−0.04 in average). As turf quality was considered, all cultivars of *L. perenne* and *Poa pratensis* were characterized as high quality after BTS compaction with the TQI below 0.1. The shoot density of untreated turf cultivars varied in a wide range from 2.23 to 6.18 shoots per cm^2. For most of the cultivars the BTS compaction reduced shoot density by 27% on average. The increase in the number of vascular bundles, leaf width, leaf cross-section area and leaf angle were associated with better wear tolerance. Wider leaves with a higher number of vascular bundles together with the higher angle between the leaf and tiller axis, improved the wear resistance. It was also observed that higher tillering does not favour wear tolerance. This information concerning the relationships between turf traits and wear tolerance is of use to the plant breeder as a tool for the selection of appropriate turfgrass cultivars.

1. Introduction

Numerous grass cultivars are designed to be used on sports fields, namely football pitches, golf course fairways, greens, etc. One of the main criterions in the turfgrass breeding selection is good wear tolerance, which means the ability to withstand forces that crush the leaves, stems, crowns and roots of the plant. In selection schemes, wear treatment is routinely applied to turf plots that are implemented for progeny testing by most breeders (Sampoux et al., 2012). Mechanical injuries to turfgrass are usually caused by intensive foot and vehicular traffic. The degree of damage to turfs depends mostly on the turfgrass species, environmental factors, intensity of traffic and turfgrass management activities, namely mowing, fertilization, irrigation, aeration, etc. Some agronomical practices are known to improve wear tolerance and turfgrass recovery, such as nitrogen and potassium fertilization, irrigation, overseeding or even the application of plant growth regulators (Deaton and Williams, 2010; Hoffman et al., 2010; Thoms et al., 2011). However, the most important approach is breeding new cultivars with improved wear tolerance. From this point of view, it is essential to understand the plant characteristics that contribute to the wear tolerance capacities of turfgrass.

Wear tolerance can be improved by the special anatomical and morphological traits of grass stems and leaves. The components of cell walls are the most important among these traits, particularly in regard to the amount of sclerenchyma fibres. The lignin and

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cellulose content provides the structural stability because of the principal constituent determining the vascular integrity and the tensile strength of the tissue in a wide range of grasses (Greenberg et al., 1989; Lulli et al., 2011; Shearman and Beard, 1975a,b; Trenholm et al., 2000). Vincent (1991) confirmed that the strength of the leaves is linearly related to the amount of sclerenchyma and lignin, because lignified fibres from a range of grasses had identical mechanical properties. These investigations suggested that wear tolerance corresponds with anatomical and morphological plant characteristics, namely total cell wall content, quantity of sclerenchyma fibres, tiller density, tiller dry weight, leaf width, leaf tensile strength and shoot density (Hoffman et al., 2010; Shearman and Beard, 1975a,b; Trenholm et al., 2000). This relationship was also confirmed by Dowgiewicz et al. (2011) for *Agrostis* sp. Similar results were also obtained by Zhang et al. (2004) who detected significant correlations between tensile strength and a cross-sectional area and a number of major vascular bundles in leaves of forage grasses. According to Brosnan et al. (2005) the wear tolerant genotypes of *Poa pratensis* were associated with a more vertical leaf angle, greater total cell wall and lignocellulose content, and a lower shoot moisture content and leaf turgidity.

The wear tolerance of turfgrass is also reliant on certain physiological parameters, namely modified acid detergent fibre (Canaway, 1981), sucrose phosphate synthase and sucrose synthase activity, stem and leaf moisture (Babb and Haigler, 2001; Bayrer et al., 2006; Trenholm et al., 2000), leaf flexibility (Sun and Liddle, 1993), the evapotranspiration rate, leaf chlorophyll concentration, membrane permeability, leaf peroxidase activity, spectral reflectance, tissue potassium (Carrow and Petrovic, 1992) and silica concentration (Trenholm et al., 2001). Unfortunately, the data collected to-date only covers a narrow range of cultivars or forage cultivars or C4 type plants. Even C3 species show very low recuperative, wear resistance capability, and studies on these types of plant are important for a better understanding of this feature. Very little is known about the interaction of different anatomical and morphological traits of C3 cool-season turfgrasses. Therefore, this kind of analysis in relation to their wear tolerance on a wide selection of species and cultivars from different breeders is of considerable value. Information obtained may serve as important selection criteria for breeding turfgrasses with improved wear tolerance.

The objective of this research was to identify the relationship between the anatomical and morphological features of leaves and the quality of the turf after wear simulation. The following hypotheses were tested: (i) turfgrass cultivars differ in their leaf morphological and anatomical characteristics; (ii) there is a correlation between the wear resistance of grass leaves and their morphological and anatomical traits.

2. Materials and methods

2.1. Plant material and experimental site

The study was conducted as a field experiment at the Krakow Valley Golf and Country Club near Krakow, southern Poland (50°10 N, 19°39 E, 440 m a.s.l.) over a two-year period from 2012 to 2013. The climate of the experimental site is temperate-continental. The average pluriannual (1966–1999) precipitation reaches 579 mm per year with the highest monthly sum of 97 mm in June and the lowest in February, 32 mm. The pluriannual mean daily temperature is 11.0 °C, with July as the warmest month (17.5 °C) and January as the coldest one (−3.3 °C). During the study period the annual sum of precipitation was 552 mm in 2011 and 622 mm in 2012. The annual mean temperatures were 8.7 and 8.5 °C in 2011 and 2012, respectively. The experiment was established on a 15 cm soil mixture as a rootzone with a texture of loamy sand (81% sand, 14% silt and 5% clay). The plots were mowed three times per week at a height of 25 mm, with clippings returned, using a Jacobsen triplex mower (Ransomes Jacobsen Ltd., Ipswich, Suffolk, UK). An automatic irrigation system (Perrot, Althengstett, Germany) was installed before grass sowing. The system was based on soil moisture measurements with a setpoint of 75% of the water content at field capacity. Turf was fertilized with 250 kg N ha^{-1}, 60 kg P_2O_5 ha^{-1} and 120 kg K_2O ha^{-1} per year.

Experimental plots (1 m^2) were established with three replications in a randomized split-plot design with the cultivar as the main factor and traffic as a subplot. The total number of plots was 222. The seven grass species used were: *Festuca arundinacea* Schreb., *F. rubra* L., *F. ovina* L., *Agrostis capillaris* L., *A. stolonifera* L., *P. pratensis* L. and *Lolium perenne* L. The names of the cultivars are listed in Table 1. The seedbed was prepared and 37 grass cultivars were sown in April of 2011 to establish the turfgrass. The rate of seedling was 50 g m^{-2} for cultivars of *F. arundinacea* and *L. perenne*, 30 g m^{-2} for *F. rubra*, *F. ovina* and *P. pratensis*, 5 g m^{-2} for *A. capillaris* and *A. stolonifera*.

According to Brosnan et al. (2005), measurements from unmowed spaced-plants are not always the most reliable for predicting the turfgrass performance of mowed turf stands. Plant material for laboratory analysis was collected at the field trial in order to obtain plants grown in typical exploitation conditions.

2.2. Traffic simulation

Traffic treatments were applied as a strip within replicates using a Brinkman traffic simulator (BTS). The BTS weighed 336 kg and had two heavy, studded rollers geared to move at different speeds and impose both compactive and tearing forces on the turf (Cockerham and Brinkman, 1989). Each roller had a 29.2 cm diameter and was 100 cm wide. The BTS produced a unit pressure of 33.6 kPa. Traffic treatments were applied every year from the beginning of April to the end of November. Six passes were made at one time in once-a-week applications. This BTS traffic intensity corresponds to typical foot-traffic frequency at sports fields. Similar traffic treatments were used by other authors in their investigations into the wear resistance of sports turfgrasses (Kowalewski et al., 2013; Martiniello, 2007; Vanini et al., 2007).

2.3. Measurements of wear tolerance

Turf cover was estimated using digital image analysis (Richardson et al., 2001). Images were obtained with a Canon 1000D digital camera (Canon Inc., Tokyo, Japan) mounted on a tripod specifically designed to allow the camera to be positioned directly above the plot. Just before taking photos the camera was calibrated using a ColorChecker Passport (X-Rite Inc., Grand Rapids, USA). The collected images were saved in the tiff format, and then processed using an Aphelion 3.2 system (ADCIS S.A. and Amerinex Applied Imaging, Herouville Saint-Clair, France). The number of selected pixels that corresponded to the turf cover in each image was divided by the total pixel count of the image in order to determine the turf coverage percentage in the image. The wear resistance of turfgrass cultivars was estimated using the turf cover index (TCI) calculated using the following equation (Eq. (1)):

$$TCI = \frac{TC_0 - TC_{BTS}}{TC_0 + TC_{BTS}} \quad (1)$$

where TC_0 is turf cover (%) at the control, untreated plot, TC_{BTS} is turf cover (%) at the BTS treated plot. The turf quality was visually rated at each plot using a 1–9 scale integrating all quality aspects, namely: overall appearance, turf colour, uniformity, density, mowing quality, reduced rate of vertical growth, leaf texture, and freedom from insects and disease damage. The lowest level (1) defines very poor