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ORIGINAL PAPER

EFFECT OF SPECIES COMPOSITION AND MACRONUTRIENT CONTENT ON FOOTBALL TURF RIGIDITY AND ELASTICITY*

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Abstract

The aim of the experiment was to determine the effect of species composition on the rigidity and elasticity of football pitch turf. The research was conducted for three years on micro-plots of 1 m^2 at the Toya Golf & Country Club (51°20′E, 17°07′N). The variable was M1-M12 lawn grass mixtures with different species composition. Commercially available M1-M5 mixtures were composed with a predominant share of red fescue varieties (*Festuca rubra* L). Mixtures M6-M12, consisting of bluegrass (*Poa pratensis* L.) and perennial ryegrass (*Lolium perenne* L.) varieties, were purposefully composed in the Department of Meadows and Green Area Creation. Rigidity and elasticity determination was assessing the response of sports turf subjected to deforming forces similar to those present during sports events. The assessment was based on a 5-point scale, with 5 points for the highest value and 1 for the least desirable. The highest average rigidity rating was assigned to bluegrass turf and the lowest to fescue turf. In terms of the grass ability to spring back to the upright position after the pressure was removed, the highest aver-

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age elasticity ratings were also recorded for bluegrass turf, and the lowest for perennial ryegrass turf. However, a high variability in turf parameters at different times of the year was recorded, depending on the mixtures. The average elasticity of grass species, i.e. their ability to spring back to an upright position after compression was removed, was ranked in the following order: bluegrass turf> fescue turf > perennial ryegrass and bluegrass dominant turf > ryegrass turf. Of all macronutrients, calcium affected leaf rigidity and elasticity in a statistically significant way.

Keywords: sports turf, functional features, rigidity, elasticity, mixtures of lawn grass species.

INTRODUCTION

Establishing and maintaining natural grass surfaces is a growing, increasingly consolidated sector of the economy in many European and non-European countries. Today, there are more than 700,000 sports fields around the world, generating more than $20 million in revenue per year (Chwala et al. 2018).

All forms of exercise have become a central element in efforts to maintain human health and fitness, consequently, improving the quality of social and economic life. That is why, the number of people engaging in physical activity is increasing. In 2014, as many as 44% of European Union inhabitants declared to be physically active at least once a week (EuroStat 2018). However, an increase in interest in active sports involves a need to build sports infrastructure. Although some activities can be done outdoors or at home, most sports need multifunctional facilities or specialized playing fields (Dugalić, Krsteska 2013). The creation of new sports facilities is desirable to provide an opportunity for specific recreational and sports activities. Properly designed and accessible infrastructure contributes significantly to an overall increase in physical activity among the local community (Xiong 2007, Hallmann et al. 2012).

To a large extent, stadiums and sports facilities are used to play football, considered the most popular sport in the world (Dvorak et al. 2004). Optimal playing conditions are ensured by the use of low compact turf, resistant to heavy use. The correct condition of the grass surface ensures a more spectacular event in visual terms (Wolski et al. 2016), but it also improves the functional value of a football pitch, with better conditions for bouncing and rolling the ball or running after it (Turgeon 2012).

One of the most important aspects when setting up football pitches is the correct selection of grass species and varieties (Fiorio et al. 2012, Pornaro et al. 2016). This is due to the fact that turf should withstand intensive use, and it undergoes numerous maintenance procedures (Trappe et al. 2009, Cereti et al. 2010, Radkowski et al. 2018, 2020). In order to ensure its best visual and functional parameters, a mixture of lawn grasses is often used (Turgeon 2012, Kazimierska et al. 2016). The compositional homogeneity of the mixtures, combined with the appropriate growing techniques, has a significant impact on the functional value of a football pitch (Chrisitans et al. 2016). In addition, a choice of grass mixtures is important from the point of view of a player's safety. Grass species differ in their mechanical properties (Orchard et al. 2013), some of which may affect players' safety, increasing a risk of injury (Orchard et al. 2005). It is said that it is most beneficial to select varieties resistant to stressful conditions, with their rapid self-restoration, elasticity, rigidity and with an even, compact, and smooth surface muffling and cushioning any fall (Brede 2000). Most sports turfs are bentgrass-based and fescue-based (De 2017), which is also noticeable in commercial offers, where mixtures based on fescue grass dominate. However, the selection of mixtures should be strictly dependent on the region in which the turf is planned to be set up (Salman et al. 2011). There is still little information in the literature on the functional value of mixtures with perennial ryegrass (*Lolium perenne* L.) and Kentucky bluegrass (*Poa pratensis*), both of which can be used as the main component of sports turf (Aamlid et al. 2012, Sampoux et al. 2013).

Choosing lawn grass mixtures with the best functional value would significantly increase the quality of natural turf. The research hypothesis states that the functional value, determined by grass rigidity and elasticity, varies within species and sometimes even within varieties. Apart from species composition of a lawn mixture, mineral content has an effect on the above characteristics. Thus, potassium and calcium strengthen plant tissues. As a result of phosphorus deficiency, the rate of growth slows down significantly. Magnesium, on the other hand, affects leaf colour intensity (the amount of chlorophyll) and photosynthesis. Deficiencies of less mobile nutrients (P, Ca) are usually recorded in younger parts of plants, while a deficiency of mobile components (Mg, K) is more often observed in older ones.

The aim of the research was to determine the effect of species composition and macronutrients on the functional value of lawn mixtures used in establishing sports turf on natural grounds.

MATERIALS AND METHODS

Study location and experimental design

The experiment was conducted for three successive years at the Toya Golf & Country Club in Poland (51°20′E, 17°07′N). It was set up in the spring (12.04.2007) as a split-plot design with three replications and a seeding density of 25 g m^{-2}. An experimental unit was a plot of 1 m^2 (dimensions: 1 m × 1 m), and the total area of the experimental field was 72 m^2.

There were 12 mixtures of lawn grasses used in the experiment: Mixtures M1-M5, available commercially, with red fescue (*Festuca rubra* L.)

varieties dominant in their compositions; Mixtures M6-M12 composed in the Department of Meadows and Green Area Creation, with bluegrass (*Poa pratensis* L.) and perennial ryegrass (*Lolium perenne* L.) varieties dominant in their composition. All the mixtures are listed in Table 1.

The seeds of the lawn grass mixtures were sown by hand, in a crisscross pattern. Afterwards, each plot was raked and rolled.

Table 1

Composition of grass mixtures

Mixtures	Latin name	Cultivar	Share %
M1	*Festuca rubra*	Adio	20
	Festuca rubra	Leo	20
	Festuca rubra	Mirena	20
	Lolium perenne	Gazon	20
	Poa pratensis	Miracle	15
	Agrostis capillaris	Kita	5
M2	*Festuca rubra*	Mirena	30
	Festuca rubra	Leo	20
	Festuca rubra	Adio	20
	Lolium perenne	Natara	30
M3	*Festuca rubra*	Leo	40
	Festuca rubra	Areta	30
	Lolium perenne	Stadion	20
	Poa pratensis	Miracle	10
M4	*Festuca rubra*	Adio	25
	Festuca rubra	Leo	25
	Festuca rubra	Mirena	15
	Lolium perenne	Stadion	25
	Poa pratensis	Miracle	10
M5	*Festuca rubra*	Leo	50
	Festuca rubra	Areta	20
	Festuca arundinacea	Asterix	20
	Poa pratensis	Alicja	10
M6	*Lolium perenne*	Barball	25
	Lolium perenne	Bardorado	25
	Poa pratensis	Bariris	25
	Poa pratensis	Miracle	25
M7	*Poa pratensis*	Bariris	35
	Poa pratensis	Miracle	35
	Lolium perenne	Barball	15
	Lolium perenne	Bardorado	15

cont. Table 1

Mixtures	Latin name	Cultivar	Share %
M8	*Poa pratensis*	Bariris	40
	Poa pratensis	Miracle	40
	Lolium perenne	Barball	10
	Lolium perenne	Bardorado	10
M9	*Poa pratensis*	Bariris	20
	Poa pratensis	Miracle	20
	Lolium perenne	Barball	20
	Lolium perenne	Bardorado	20
	Festuca rubra	Barcrown	10
	Festuca rubra	Barustic	10
M10	*Poa pratensis*	Bariris	25
	Poa pratensis	Miracle	25
	Lolium perenne	Barball	20
	Lolium perenne	Bardorado	20
	Festuca rubra	Barcrown	5
	Festuca rubra	Barustic	5
M11	*Lolium perenne*	Barball	40
	Lolium perenne	Bardorado	40
	Poa pratensis	Bariris	10
	Poa pratensis	Miracle	10
M12	*Lolium perenne*	Barball	20
	Lolium perenne	Bardorado	20
	Poa pratensis	Bariris	20
	Poa pratensis	Miracle	20
	Festuca arundinacea	Asterix	10
	Festuca rubra	Barcrown	5
	Festuca rubra	Barustic	5

Assessment of turf functional parameters

Observations and measurements of lawn grass mixture characteristics were carried out in three seasons: spring (April and May), summer (first half of August), and autumn (first half of October). Two basic functional parameters of the turf were assessed: rigidity (resistance of the stems of the lawn grass to compression) and elasticity (the ability of grass leaves to return to their original position after removal of the deforming force).

The functional method consists in assessing the condition and response of turf subjected to external factors similar to those present during sports events. This method is based on a 5-point scale (1-5), where 5 corresponds to the most and 1 to the least desired value.

In the case of rigidity, an assessment was made on the basis of the percentage of grass stems returning to their original position after removal of the deformation force (a 5 kg cast iron piece of 26 cm diameter) measured after 30 seconds. The following rigidity scale was used: 1 – insufficient (0-40% of grass stems returning to their original position), 2 – sufficient (41-60%), 3 – good (61-70%), 4 – very good (71-90%), 5 – excellent (91-100%).

In the case of elasticity, an assessment was made on the basis of the percentage of grass shoots and leaves returning to their original position after removal of the torsional (180°) deformation force (a 5 kg cast iron pieces of 26 cm diameter), measured after 30 seconds. The following elasticity scale was used: 1 – insufficient (0-40% of grass shoots and leaves returning to their original position), 2 – sufficient (41-60%), 3 – good (61-70%), 4 – very good (71-90%), 5 – excellent (91-100%).

Chemical analyses of plant material

Three samples were collected from each plot of 1 m^2. The plant material was analyzed for its chemical composition and dry matter content (after oven-drying at 105°C). The content of mineral components, i.e. calcium, magnesium, potassium, and sodium, was determined by atomic absorption spectrometry with FAAS atomization (Varian AA240FS Varian Inc., Palo Alto, USA) according to PN-EN 15505:2009 standard. Total phosphorus content was established based on UV-VIS spectrophotometry and staining with ammonium monovanadate (V) and ammonium heptomolybdate following the sample mineralization as described in PN–ISO 13730:1999 standard.

Weather conditions

During the experiment, weather conditions were changeable (Table 2). The highest precipitation at 751.0 mm was recorded in the last year of the experiment. In the same year, June and July had particular high rainfall, with 296.2 mm for both months. In other years, it was significantly lower at 598.1 mm in the first and 549.7 mm in the second experimental year. According to the average daily air temperature, the warmest year was the second one with 10.3°C. The first year of the experiment was slightly colder at 10.2°C. The last year was the coldest (the daily average of 9.3°C), with sub-zero temperatures in January (-2.3°C) and December (-0.4°C).

Soil conditions and grass maintenance

The experiment was established on anthropogenic soil developed from loamy sand, belonging to the order of culture earth soils and hortisole type (IUSS Working Group WRB 2015, Kabała et al. 2019). It had adequate structure and grain size for the establishment of football turf on natural soil. The composition of the topsoil was 70% of coarse and medium sand with grain sizes of 0.1-1 mm, with the mean share of the silt fraction (0.1-0.02 mm) exceeding 17%. The share of the smallest fraction with a dia-

Table 2

Monthly precipitation and average daily air temperature for three years of research

Month	Rainfall (mm)				Mean temperature (°C)			
	1st year	2nd year	3rd year	1st-3rd years	1st year	2nd year	3rd year	1st-3rd years
January	52.0	56.7	34.6	47.8	4.9	2.9	-2.3	1.8
February	59.0	20.4	46.4	41.9	2.7	3.9	0.2	2.3
March	48.8	33.0	49.5	43.8	6.5	4.5	4.6	5.2
April	2.7	87.1	30.9	40.2	10.9	8.9	12.0	10.6
May	50.3	37.3	67.5	51.7	15.6	14.3	14.2	14.7
June	69.2	36.5	162.0	89.2	19.2	18.8	15.8	17.9
July	120.6	65.6	134.2	106.8	19.2	19.9	19.5	19.5
August	52.8	94.0	53.5	66.8	18.9	18.8	19.3	19.0
September	46.1	27.9	12.0	28.7	12.9	13.2	14.8	13.6
October	21.7	41.1	76.0	46.3	8.3	9.6	7.9	8.6
November	53.9	29.6	32.5	38.7	2.8	6.1	6.6	5.2
December	21.0	32.5	51.9	35.1	1.0	2.1	-0.4	0.9
Total/mean	598.1	549.7	751.0	636.9	10.2	10.3	9.3	9.9

meter of less than 0.02 mm was two percentage points higher than that assumed by Standard DIN 18035-4 (2007). In the first and last years of the experiment, soil pH was neutral, ranging from 6.8 to 7.0. During each growing period, mineral fertilizers were used with a NPK ratio of 6:2:4 at doses of N – 180 kg ha^{-1}, P – 60 kg ha^{-1}, K – 120 kg ha^{-1}. Fertilizer treatment was carried out monthly from April to September, using the Professional spring-summer fertilizer with a NPK ratio of 17:6:11, also containing MgO, S, and B, and Professional autumn with a NPK ratio of 5:0:25 with S, Ca, Fe, and B. Mowing was carried out when the lawn grass was 8 cm high, with the turf cut 1-2 times a week at a height of 3 cm, and irrigated, depending on the weather, with a dose of 6 L m^{-2} per day.

Statistical analysis

Firstly, the normality of distribution of the observed traits (rigidity, elasticity and macroelement: P, K, Ca, Mg and Na content) was tested using the Shapiro-Wilk normality test. Non-normal traits were transformed using the power (Box-Cox) transformation with lambda (λ) parameter at interval from −2 to 2 (Kozak et al. 2008). Having the variables transformed and normally distributed, it was assumed that the data followed the multivariate normal distribution. The two-way analysis of variance (ANOVA) was carried out to determine the effects of year, and grass mixtures as well as year × grass mixture interactions on the variability of observed traits. The mean values and standard deviations of traits were calculated. The Fisher's least significant differences (LSDs) were calculated for individual traits and on these basis, homogeneous groups were determined. Influence of content of macroelements as P, K, Ca, Mg and Na, on rigidity and elasticity was analyzed by multivariate regression. In all analyses, we used the critical significant level equal to 0.05. All calculations were conducted using the GenStat 18^{th} edition statistical software package.

RESULTS

Rigidity

The rigidity of the pitch surface in the spring seasons of the three successive years is presented in Table 3. In the first year of the experiment, rigidity was not assessed due to the fact that the turf was not fully developed yet. On average, the highest value for all pitches was recorded in the last year, when the rigidity was rated as good (4.08). The highest score of all sports turf was assigned to M8 turf (80% of *Poa pratensis* and 20% of *Lolium perenne*). Its rigidity throughout the study period was rated as excellent (5.00). The other two bluegrass pitches (M7 – 70% of *Poa pratensis* and 30% of *Lolium perenne* and M10 – 50% of *Poa pratensis* and 40% of *Lolium perenne*) and two pitches with a dominant share of bluegrass and perennial ryegrass (M9 and M12) were also rated highly. It is worth noting, however, that apart from one case, the highest ratings (5.00) were recorded in the second year. The lowest degree of rigidity was recorded for fescue turf. The most affected by the deformation force was the turf with Mixture M4 (65% of *Festuca rubra* and 25% of *Lolium perenne*). The average rigidity of this turf throughout the experiment was determined as sufficient (2.79). A slightly higher average score (2.99) was recorded for the M3 mixture (70% of *Festuca rubra* and 20% of *Lolium perenne*).The statistical analysis demonstrated that rigidity assessments during the summer significantly varied throughout the experiment (Table 3). The highest rigidity of sports turf was recorded in the second year of research, when as many as 10 out of 12 mixtures were rated as excellent. The only exception was M3 and M5 fescue turf, whose rigidity was rated as very good (4.00). The lowest resistance of the turf to compression was observed in the first year. During the study period, the highest score was recorded for Mixture M1 with fescue (60% of *Festuca rubra* and 20% of *Lolium perenne*) and for M2 (70% of *Festuca rubra* and 30% of *Lolium perenne*), whose rigidity was rated as very good (4.33). On the other hand, the least resistance to compression was manifested by Mixture M6, with the dominant share of perennial ryegrass and bluegrass. On average, its rigidity was assessed as good (3.42), but it should be noted that in the first year its rating was the lowest, determined as sufficient (2.46). Removing the extreme values, the average ratings for the re-

Table 3

The effect of grass mixture composition on turf rigidity

Mixture (M)	Year (Y)		Mean	Year (Y)			Mean	Year (Y)			Mean
	2nd year	3rd year		1st year	2nd year	3rd year		1st year	2nd year	3rd year	
	spring			summer				autumn			
M1	2.99*f**	4.00*d*	3.50*g*	4.00*f*	5.00*a*	4.00*f*	4.33*a*	5.00*a*	5.00*a*	4.00*d*	4.67*a*
M2	3.31*e*	4.00*d*	3.65*f*	4.00*f*	5.00*a*	4.00*f*	4.33*a*	4.67*b*	5.00*a*	4.00*d*	4.54*c*
M3	2.96*f*	2.99*f*	2.99*h*	2.82*l*	4.84*b*	4.00*f*	3.84*g*	3.84*e*	5.00*a*	4.00*d*	4.28*f*
M4	2.99*f*	2.62*g*	2.79*i*	2.99*k*	5.00*a*	4.00*f*	3.96*ef*	3.17*g*	5.00*a*	4.00*d*	4.04*g*
M5	4.00*d*	4.00*d*	4.00*e*	3.50*h*	4.49*c*	4.00*f*	4.00*e*	3.84*e*	5.00*a*	4.00*d*	4.28*f*
M6	4.00*d*	4.00*d*	4.00*e*	2.46 m	5.00*a*	2.99*k*	3.42*h*	2.82*h*	5.00*a*	4.00*d*	3.88*h*
M7	5.00*a*	4.84*b*	4.93*b*	3.65*g*	5.00*a*	4.00*f*	4.20*b*	4.00*d*	5.00*a*	4.00*d*	4.33*e*
M8	5.00*a*	5.00*a*	5.00*a*	4.33*d*	5.00*a*	2.99*k*	4.08*d*	4.33*c*	5.00*a*	4.00*d*	4.45*d*
M9	5.00*a*	4.67*c*	4.84*c*	4.00*f*	5.00*a*	2.99*k*	3.96*ef*	4.00*d*	5.00*a*	4.00*d*	4.33*e*
M10	4.00*d*	5.00*a*	4.49*d*	3.17*j*	5.00*a*	3.65*g*	3.92*f*	3.65*f*	5.00*a*	5.00*a*	4.54*c*
M11	3.31*e*	4.00*d*	3.65*f*	4.00*f*	5.00*a*	3.50*h*	4.16*bc*	3.10*g*	5.00*a*	5.00*a*	4.33*e*
M12	5.00*a*	4.00*d*	4.49*d*	4.16*e*	5.00*a*	3.31*i*	4.12cd	4.93*a*	5.00*a*	4.00*d*	4.62*b*
Mean	3.92*b*	4.08*a*	4	3.57*c*	4.97*a*	3.61*b*	4	3.92*c*	5.00*a*	4.16*b*	4.37
$LSD_{0.05}$ for:	Y=0.07, M=0.06, Y×M=0.11			Y=0.02, M=0.05, Y×M=0.08				Y=0.03, M=0.04, Y×M=0.07			

* In columns, means followed by the same letters are not significantly different.

maining turf ranged from 3.84-4.20. During the autumn season, statistically significant differences were observed between grass rigidity assessments throughout the experiment (Table 3). In the second year, excellent rigidity (5.00) was noted on each plot, regardless of the grass mixture. In the remaining years of research, turf rigidity was at a very good level, but a slightly lower parameter value (3.92) was recorded in the first year. Throughout the experiment, rigidity assessment ranged from 3.88 to 4.67. The highest was scored by M1, with the highest shear of red fescue, rated as excellent in the first and second years. On the other hand, the lowest (good) score was assigned to M6 turf with two grass species, with its rigidity defined as sufficient in the first year. On average, of all the seasons, the greatest rigidity of the turf was in the autumn, when across the years of research it was rated as very good (4.37). In the other seasons, rigidity also remained at a very good level, but the score was slightly lower (4.00 both in the spring and summer). Among the grass mixtures, the average rigidity assessments were as follows: bluegrass turf (4.44) > turf with perennial ryegrass and bluegrass dominant (4.18) > ryegrass turf (4.05) > fescue turf (3.95). It was noted that fescue and ryegrass turf tended to increase their rigidity in time during the same growing season (Figure 1). The situation is different in the

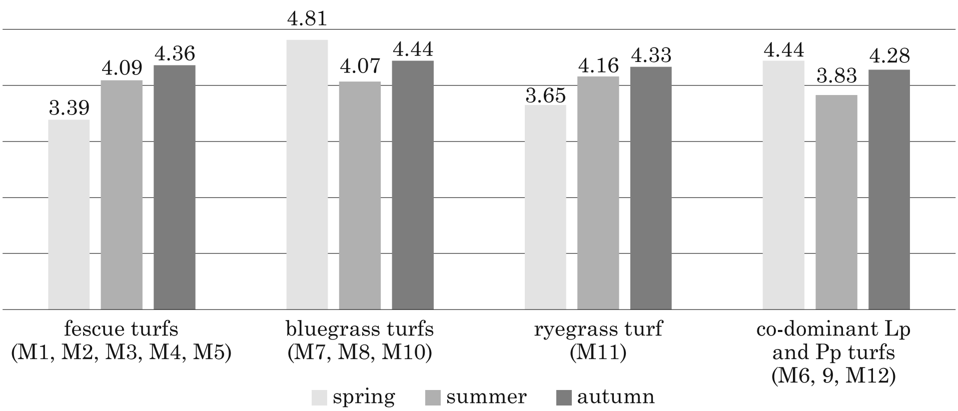


Fig. 1. Seasonal variation of turf rigidity

case of bluegrass-based turf. In this case, the highest values of rigidity were recorded in the spring and the lowest in the summer. The same relationship can be observed for pitches planted with dominant equal shares of *Poa pratesnsis* and *Lolium perenne* species. This may be due to the high share of bluegrass in the mixture.

Elasticity

According to the statistical analysis, during the spring season (Table 4) the elasticity of sports turf varied throughout the experiment. As with rigidity, elasticity was not determined in the year of lawn establishment because the turf was not sufficiently developed. On average, turf elasticity recorded in the second year was good (3.84), with the highest rating (4.49) assigned to M7 (70% of *Poa pratensis* and 30% of *Lolium perenne*). It was assessed as excellent in the second year and very good a year later. On the other hand, the highest resistance to the torsional force was recorded for the M11 ryegrass surface. In both the second and third years, the parameter was assessed as sufficient (2.99). The elasticity assessments of the remaining pitches were relatively similar and ranged from 3.31 to 4.00. The elasticity of sports turf during the summer season also significantly varied over the years of research (Table 4). The highest was recorded in the second year (4.62), with half of the surfaces rated as excellent (5.00). In the first and third years, elasticity was at a similar level with 3.57 and 3.65, respectively. The highest four elasticity ratings ranged from 4.33 to 4.37. These included two bluegrass mixtures (M7, M8), the M11 ryegrass one, and M12 double-species turf. By far, the lowest elasticity was reported for the M6 two-species mixture (3.17), which was rated as insufficient in the last year of research. According to the results, autumn elasticity ratings varied over the years of research (Table 4). The highest elasticity was recorded in the second year (4.93), when the response of 11 of the 12 sports pitches to the torsional force was rated as excellent. The exception was the M6 two-species mixture, the elasticity of which was assessed as good. In the following years of research, it remained at a similar level, rated as good (3.69 in the first year and 3.88 in the third). During the research, the highest rating was assigned to M2 fescue turf (4.62), which for the first two years was rated as excellent. On the other hand, the smallest elasticity (3.20) was recorded for the turf with *Lolium perenne* and *Poa pratensis* as dominant species. Elasticity strongly varied, depending on the grass mixture. It is worth noting that the average rating of the parameter increased across the growing season. In the spring, the average value of 3.69 was recorded, in the summer 3.92, and in the autumn as much as 4.16. In terms of the ability of the grass to return to its original position, the average elasticity ratings were as follows: bluegrass turf (4.23) > fescue turf (3.88) > turf with perennial ryegrass and bluegrass dominant (3.81) > rye turf (3.75). Bluegrass and fescue turf indicated a clear tendency to increase elasticity over the growing season (Figure 2). Pitch surfaces with both bluegrass and perennial ryegrass were assigned similar elasticity ratings. Another regularity was observed for the ryegrass turf surface, where the highest, very good elasticity was recorded in the summer and the lowest, rated as sufficient, in the spring.

Content of macroelements

Microelement content was determined across mixtures, years and seasons (Table 5). Values of P ranged from 3.163 for M1 to 4.106 g kg^{-1} DM for M11 (Table 5, Figure 3). Values of K varied from 20.19 for M2 to 22.66 g kg^{-1} DM for M12 (Table 5, Figure 4). Values of Ca content varied from 4.855 for M7 to 8.931 g kg^{-1} DM for M11 (Table 5, Figure 5). The content of Mg

Table 4

The effect of grass mixture composition on turf elasticity

Mixture (M)	Year (Y)		Mean	Year (Y)			Mean	Year (Y)			Mean
	2nd year	3rd year		1st year	2nd year	3rd year		1st year	2nd year	3rd year	
	spring			summer				autumn			
M1	4.00*b**	4.00*b*	4.00*b*	4.00*e*	4.49*c*	2.99*i*	3.80*e*	4.67*c*	5.00*a*	2.99*k*	4.16*d*
M2	3.50*e*	3.84*c*	3.65*e*	3.84*f*	4.49*c*	3.50*h*	3.92*d*	4.84*b*	5.00*a*	4.00*f*	4.62*a*
M3	4.00*b*	2.99*f*	3.50*f*	2.62*k*	4.16*d*	3.50*h*	3.39*g*	3.84*b*	5.00*a*	4.49*d*	4.45*b*
M4	2.99*f*	3.65*d*	3.31*g*	3.50*h*	5.00*a*	2.99*i*	3.80*e*	2.99*k*	5.00*a*	4.00*f*	3.96*e*
M5	4.00*b*	3.65*d*	3.84*c*	3.50*h*	4.49*c*	4.00*e*	4.00*c*	2.72*l*	5.00*a*	4.00*f*	3.84*f*
M6	4.00*b*	4.00*b*	4.00*b*	2.82*j*	5.00*a*	1.99*l*	3.17*h*	2.31 m	4.00*f*	3.50*i*	3.20*g*
M7	5.00*a*	4.00*b*	4.49*a*	3.84*f*	5.00*a*	4.16*d*	4.33*a*	4.00*f*	5.00*a*	4.33*e*	4.45*b*
M8	4.00*b*	4.00*b*	4.00*b*	4.00*e*	5.00*a*	4.00*e*	4.33*a*	4.33*e*	5.00*a*	4.00*f*	4.45*b*
M9	4.00*b*	3.50*e*	3.72*d*	3.50*h*	4.00*e*	3.65*g*	3.72*f*	4.00*f*	5.00*a*	3.50*i*	4.16*d*
M10	4.00*b*	2.99*f*	3.50*f*	2.99*i*	5.00*a*	4.67*b*	4.16*b*	3.50*i*	5.00*a*	4.49*d*	4.33*c*
M11	2.99*f*	2.99*f*	2.99*h*	4.00*e*	4.00*e*	5.00*a*	4.33*a*	3.17*j*	5.00*a*	3.65*h*	3.92*e*
M12	4.00*b*	2.99*f*	3.50*f*	4.49*c*	5.00*a*	3.65*g*	4.37*a*	4.67*c*	5.00*a*	3.65*h*	4.41*b*
Mean	3.84*a*	3.53*b*	3.69	3.57*c*	4.62*a*	3.65*b*	3.92	3.69*c*	4.93*a*	3.88*b*	4.16
$LSD_{0.05}$ for:	Y=0.03, M=0.06, Y×M=0.08			Y=0.04, M=0.05, Y×M=0.09				Y=0.05, M=0.06, Y×M=0.11			

* In columns, means followed by the same letters are not significantly different.

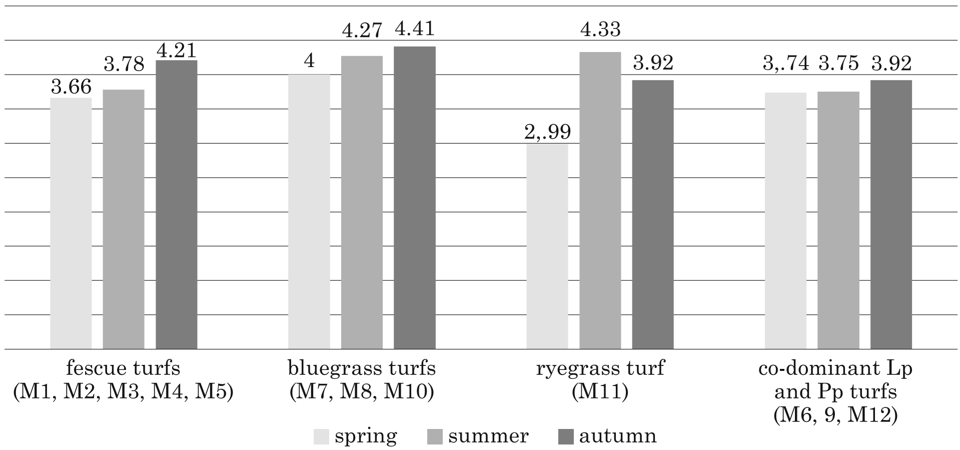


Fig. 2. Seasonal variation of turf elasticity.

varied from 1.661 for M3 to 2.258 for M11 (Table 5, Figure 6). The content of Na varied from 1.391 for M2 to 2.735 g kg^{-1} DM for M6 (Table 5, Figure 7).

Relationships between macroelements content and turf rigidity and elasticity

The content of K, Ca and Mg affected rigidity in the summer of the first year (Table 6). Percentage variance (R^2×100) accounting for rigidity obtained with a statistical model with these three elements was 49.1%. Only Ca and Na affected rigidity in the autumn of the first year (R^2×100=38.7%). In the second year, statistical significance for rigidity was recorded only in the spring: K, Ca, Mg and Na determined 63.4% of the variation of rigidity (Table 6). In the third year, K (in the autumn), Ca (in the summer) and Mg (in the summer and autumn) affected rigidity (Table 6).

All five macroelements determined elasticity in the summer of the first year (R^2×100=76.2%). Ca and Na affected elasticity in the autumn of the first year (R^2×100=17.1%), and Ca and Mg in the spring of the second year (R^2×100=13.5%). Negative effects of Na on elasticity was observed in the autumn of the second year (R^2×100=22.9%). In the third year, elasticity was determined by P and K in the spring (R^2×100=36.8%), P and Ca in the summer (R^2×100=33.3%), and K, Ca and Mg in the autumn (R^2×100=25.7%) – Table 6.

DISCUSSION

Sports surfaces must meet not only aesthetic but also technical requirements so the evaluation of their quality, in addition to the assessment of their visual aspect, also consists in the assessment of their functional properties.

Table 5

Mean values and standards deviations (SD) of macroelements

Source of variation		P (g kg^{-1} DM)		K (g kg^{-1} DM)		Ca (g kg^{-1} DM)		Mg (g kg^{-1} DM)		Na (g kg^{-1} DM)	
		mean	SD	mean	SD	mean	SD	mean	SD	mean	SD
Mixture	M1	3.163	0.455	20.24	2.346	5.444	0.203	1.824	0.105	1.969	0.235
	M2	3.413	0.510	20.19	2.970	5.100	0.377	1.901	0.209	1.391	0.327
	M3	3.551	0.333	21.26	2.899	6.760	1.526	1.661	0.227	1.498	0.359
	M4	3.718	0.470	22.42	3.966	5.895	0.897	1.726	0.274	2.354	0.310
	M5	3.496	0.382	22.07	2.688	4.947	0.356	1.661	0.091	2.119	0.313
	M6	3.912	0.666	22.26	2.874	8.507	1.174	2.057	0.375	2.735	0.206
	M7	3.520	0.704	21.33	2.636	4.855	0.575	1.791	0.135	2.311	0.392
	M8	3.286	0.250	21.41	2.406	6.768	1.614	2.019	0.262	1.519	0.550
	M9	3.912	0.410	22.60	3.167	7.603	1.287	2.214	0.201	1.648	0.308
	M10	3.989	0.343	22.00	3.385	7.079	0.849	2.198	0.265	1.412	0.446
	M11	4.106	0.380	22.34	3.297	8.931	1.296	2.258	0.442	2.525	0.100
	M12	3.694	0.673	22.66	0.882	5.977	1.248	1.824	0.180	2.440	0.109
$LSD_{0.05}$		0.454		2.70		0.988		0.235		0.308	
Year	1	4.174	0.402	20.91	3.241	5.948	0.804	1.864	0.195	1.990	0.528
	2	3.478	0.399	21.41	2.501	6.281	1.649	1.745	0.226	2.182	0.421
	3	3.288	0.347	22.88	2.437	7.237	2.008	2.174	0.339	1.808	0.656
$LSD_{0.05}$		0.179		1.29		0.734		0.122		0.254	
Season	spring	3.567	0.540	21.93	3.358	6.333	1.605	1.893	0.306	1.941	0.543
	summer	3.632	0.510	21.69	2.922	6.475	1.666	1.924	0.322	1.997	0.567
	autumn	3.742	0.566	21.58	2.234	6.658	1.706	1.967	0.324	2.043	0.580
$LSD_{0.05}$		0.252		1.34		0.776		0.148		0.263	

On football pitches, natural turf serves among other purposes as a shock-absorbing cushion during a game (Mathew et al. 2016) so that the likelihood of a player becoming injured is much lower than on harder surfaces or on synthetic turf (Williams et al. 2011). In recent years, there has been a noticeable increase in physical and technical parameters in professional football. Players pass the ball more often, sprint violently, and run longer distances than ever before (Barnes et al. 2014). One of the factors that facilitates this rapid evolution of the game is the progress in the setting up and maintenance of sports turf (Thomson, Rennie 2016). It should therefore be recognized that the selection of suitable species and their varieties is an important element in the establishing of a football pitch with good surface conditions, ensuring players' safety (Reicher et al. 1999).

Due to the type of its use, sports turf must meet special requirements in terms of its quality parameters. In a sport grass surface assessment, one

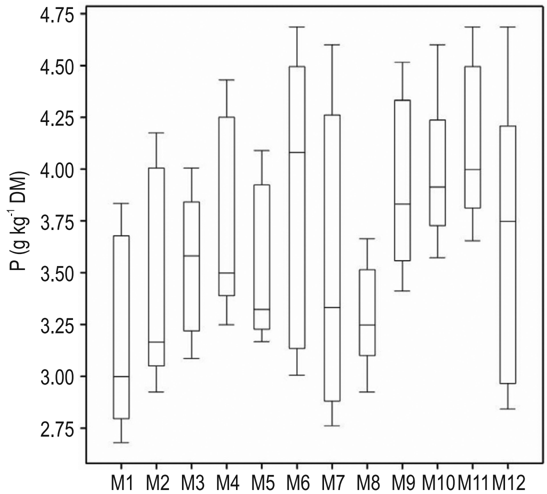


Fig. 3. Box-and-whisker diagram of the values of P, classified by the mixtures

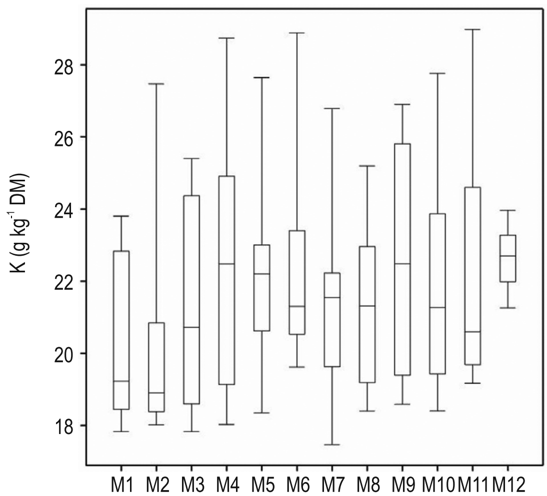


Fig. 4. Box-and-whisker diagram of the values of K, classified by the mixtures

of the most important features is grass surface hardness, with turf elasticity and rigidity (CAPLE et al. 2012, ALDAHIR, MCELROY 2014). Until now, however, most researchers have used a different methodology than the one proposed by TURGEON (2012) and focused directly on soil rather than grass. Typically, a Clegg hammer (TWOMEY et al. 2014) or penetrometer (TAKEMURA et al. 2007, STRAW et al. 2016) is used to measure hardness of natural turf surface. It is worth noting that these devices do not measure the same characteristics (the Clegg hammer measures deceleration of the falling hammer when it strikes the soil while the penetrometer measures soil penetration resistance), but the results are positively correlated (PETRASS, TWOMEY 2013).

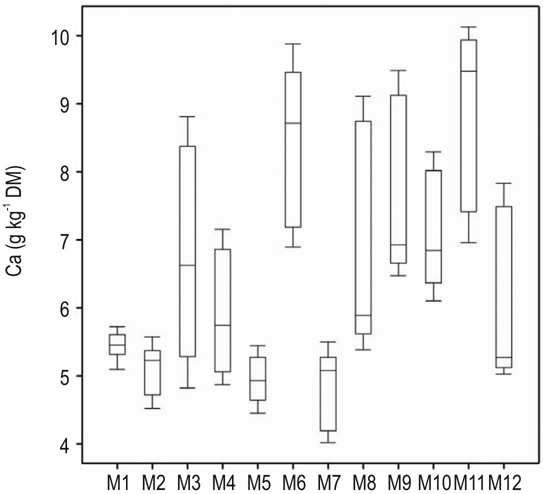
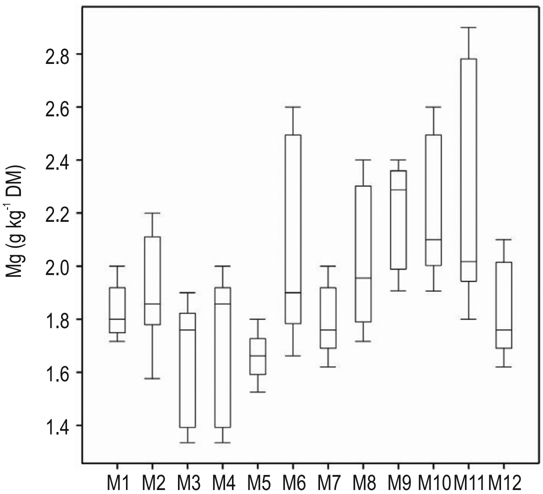


Fig. 5. Box-and-whisker diagram of the values of Ca, classified by the mixtures



Figu. 6. Box-and-whisker diagram of the values of Mg, classified by the mixtures

In terms of testing sports turf for players safety, Straw et al. (2020) reported that *in-situ* biomechanical tests were done taking into account the conditions of the ground (Stiles et al. 2009, Rennie et al. 2016), but they were too complicated to analyse due to differences between football pitches. One of the main obstacles was different species composition of the turf. The author also emphasised a clear need to include specific characteristics of the pitch, including turf species composition and soil texture in future studies on the assessment of sports surface safety. The present research may therefore constitute an essential reference source to study the relationship between species composition of the turf and its elasticity and rigidity. The usefulness of

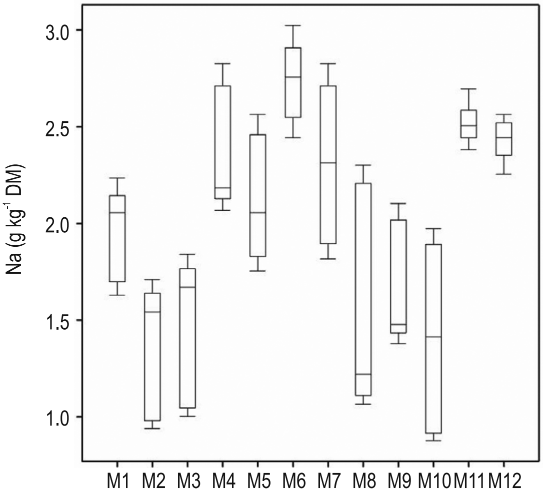


Fig. 7. Box-and-whisker diagram of the values of Na, classified by the mixtures

these parameters has also been confirmed in the literature (HARIVANDI et al. 2008). What can significantly contribute in the future to minimising the risk of a player becoming injured is the determination of what functional parameters of grass species are, which has so far been most often associated with surface hardness (STILES et al. 2011, TWOMEY et al. 2012, GRABOWSKI et al. 2020). However, in order to confirm this hypothesis, further research is necessary, as recommended by STRAW et al. (2020). In the present experiment, in addition to the standard commercial mixtures of lawn grasses in which *Festuca rubra* varieties dominated, it was decided to evaluate seven grass mixtures based on perennial ryegrass and bluegrass varieties. According to studies conducted in Slovakia, an increasing number of sports stadiums, regardless of the game or play, decide to plant turf with mixtures in which these two grass species dominate (CURK et al. 2017). The results of the present studies indicated that the best functional characteristics were assigned to turf with bluegrass mixtures. The highest values of the parameters were obtained on these surfaces. Moreover, relatively low elasticity and rigidity values, compared to other mixtures, were recorded for fescue mixtures. Although the surfaces with the latter mixtures were of very good elasticity, with bluegrass turf being rated higher, in terms of rigidity they were rated the lowest. In addition, two-species mixtures with perennial ryegrass and bluegrass were assigned elasticity by only 0.42 lower and rigidity by only 0.26 lower than corresponding ratings for bluegrass turf.

The quality of turf is largely determined by the content of nutrients in plants. They affect the visual aspect of grass and turf parameters. Apart from influencing turf appearance, micronutrients are structural components of plants and their deficiencies can be easily noticed. In addition, they help overcome drought-related stress (RADKOWSKI et al. 2018).

Table 6

Regression analysis for relationships between macroelements and rigidity and elasticity

Source of variation	1st year		2nd year			3rd year		
	summer	autumn	spring	summer	autumn	spring	summer	autumn
Rigidity								
Constant	0.64	7.92	-9.00*	n.s.	n.s.	n.s.	5.232***	4.59**
P	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
K	0.163*	n.s.	0.428**	n.s.	n.s.	n.s.	n.s.	-0.070*
Ca	-0.707*	-0.520*	-0.448*	n.s.	n.s.	n.s.	-0.071*	n.s.
Mg	2.117*	n.s.	2.84*	n.s.	n.s.	n.s.	-0.504*	0.523*
Na	n.s.	-0.395*	1.010*	n.s.	n.s.	n.s.	n.s.	n.s.
Percentage variance accounted for	49.1	38.7	63.4				24.8	51.1
F model	4.54*	4.47*	5.77*				3.93*	6.74*
Elasticity								
Constant	1.29	7.32**	2.65*	n.s.	5.704***	5.81***	-1.45	10.89**
P	-0.916*	n.s.	n.s.	n.s.	n.s.	0.207*	2.059*	n.s.
K	0.185**	n.s.	n.s.	n.s.	n.s.	-0.127*	n.s.	-0.194*
Ca	-0.663**	-0.394*	-0.211*	n.s.	n.s.	n.s.	-0.227*	0.221*
Mg	2.585*	n.s.	1.454*	n.s.	n.s.	n.s.	n.s.	-1.912*
Na	0.788*	-0.570*	n.s.	n.s.	-0.351*	n.s.	n.s.	n.s.
Percentage ariance accounted for	76.2	17.1	13.5		22.9	36.8	33.3	25.7
F model	8.04*	2.13*	1.85*		4.27*	4.20*	3.75*	2.27*

* P<0.05, ** P<0.01, *** P<0.001, n.s. – not significant

Grass chemical compositions affects plant health considerably. Depending on biological and genotypic properties, grass species have diverse abilities to take up mineral components from the soil. Certain amounts of nutrients are needed by any living organism, otherwise a mineral imbalance might negatively affect life processes. Quantitative change in the content of mineral components is determined by factors such as the species, developmental stage or weather conditions during plant growth and development. Adequate distribution of minerals in the plant is also important. It is therefore necessary to systematically control plant chemical composition (RADKOWSKI et al. 2020). Of main macronutrients, nitrogen gives plants green colour, stimulating their growth, phosphorus stimulates root development and energy use and potassium increases resilience to environmental stress and pathogens (Radkowski et al. 2018).

Significant effects of calcium on leaf elasticity and rigidity were recorded in the present experiment. This may be due to the fact that the cell wall structure is largely dependent on its content, which provides rigidity and firmness of grass stalks (St. John et al. 2013). Inadequate amounts of calcium affects structure, functioning and integrity of cell membrane, diminishing nutrient and water uptake by roots (Palta 1996). Built into cellular walls, calcium has low mobility in plants, which is why its deficiency is common mostly in the apical region of both roots and shoots. Research on gene expressions indicates that cell walls actively respond to nutrient availability (Wege et al. 2016, Henríquez-Valencia et al. 2018). Plant cells are surrounded by a protective and strengthening structure, i.e. the cell wall, the cell wall structure affects elasticity and rigidity of the grass, its water content and its overall state.

The results of grass mixture elasticity and rigidity assessment can make a significant contribution to raising the standard of natural turf in Europe and worldwide. The assessment results allow listing the best lawn grass mixtures in terms of functionality, while using such species to plant sports turf will lead to better condition during football matches. Thanks to increased elasticity and rigidity of the grass, a player's safety can be improved, making rolling the ball easier (Reyneri, Bruno 2004).

CONCLUSIONS

In conclusion, rigidity of sports grass surfaces varied at different times of the year, depending on the mixtures. The highest average rating was assigned to turf in the autumn season. In terms of rigidity, i.e. grass ability to resist compression, the average assessments were in this order: bluegrass turf > perennial ryegrass and bluegrass dominant in turf > perennial ryegrass turf > fescue turf. Red fescue and perennial ryegrass turf tended to increase their elasticity during the growing season. Another regularity was observed for bluegrass turf, with its highest elasticity parameters recorded in the spring and the lowest in the summer. The average elasticity of grass species, i.e. their ability to spring back to an upright position after compression was removed, was ranked in the following order: bluegrass turf> fescue turf > perennial ryegrass and bluegrass dominant turf > ryegrass turf. Of all macronutrients, a significant effect of calcium on leaf rigidity and elasticity was recorded.

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