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ORIGINAL PAPER

PHYSICOCHEMICAL PROPERTIES OF THE SUBSTRATE AND THE FUNCTIONAL QUALITY OF FOOTBALL TURF*

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Abstract

The paper presents the results of a study investigating the physicochemical properties of the substrate and the functional quality of football turf after complete and professional renovation (in 2018) of the main field in the Municipal Stadium in Olsztyn. Soil samples for physicochemical analyses and plant samples for a detailed botanical analysis by the dry-weight-rank method were collected at five representative sites. The following functional characteristics of football turf were determined in different areas of the football pitch: goal area, penalty area, center circle and sideline area (24 sites), in accordance with the methodology recommended by the Research Center for Cultivar Testing (COBORU): sward density, color, disease prevalence, visual merit (in the spring, summer and fall) on a 9-point scale (1 – unacceptable, 5 – satisfactory, 9 – highly desirable); the functional quality of turf and compaction were also evaluated. It was found that intensive use of the football pitch affected its physical parameters (compaction) and led to changes in the functional characteristics and species composition of turf. The substrate was characterized by high bulk density and relatively low total porosity, high to very high phosphorus content, a high content of calcium, magnesium, copper and zinc, a moderate content of manganese and iron, low to moderate potassium content and low sodium content, and alkaline reaction (pH) that exceeded the optimal range for grasses. Football turf was characterized by satisfactory to high density, a grayish-green, fresh green or green color, very low disease prevalence, and satisfactory or good visual merit. The proportion of *Lolium perenne* L. decreased insignificantly, and monocotyledonous and dicotyledonous weeds, resistant to trampling, emerged spontaneously in the analyzed football turf. Compaction in the vegetation layer exceeded the norm (two-fold on average), which had a negative effect on grass rooting.

Keywords: football pitch, lawn grass species, micro- and macroelements, substrate compaction, available nutrients.

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INTRODUCTION

Sports turf has to meet very high and challenging requirements. The composition of turfgrass species for sports fields has to guarantee resistance to intense use. Species (varieties) of lawn grasses that are resistant to spring and fall frost and summer drought are particularly desirable. Football turf should be short, dense, flexible, dark green in color, and resistant to trampling, wear and tear. It should also create a safe environment for players and provide the optimal traction for ball roll and bounce, regardless of weather conditions (Canaway 1990, Dernoeden et al. 1994, Domański 1998, Kosmala 2004, Russi et al. 2004, Turgeon 2005, Grabowski et al. 2006, Andersson et al. 2007, Brede 2008, Iraba et al. 2013, Chen et al. 2018). Turf sports field surfaces require regular maintenance and sufficient downtime to meet these requirements. Above all, an appropriate substrate (vegetation layer and filter layer) as well as adequate drainage, irrigation and heating systems are needed to keep them in good condition (Canaway, Baker 1993, Gibbs et al. 1993, Mcnitt, Landschoot 2003, Carrow 2004, Magani et al. 2004, Follis et al. 2008, Kowalik, Rajda 2013, Kim 2014, Dixon 2015, Ford, Twomey 2016, Anderson et al. 2018, Chase et al. 2019, Grabowski et al. 2020,). Intensive use of sports fields creates numerous problems, including sward damage, substrate compaction, track marks, footprints, tears and ruts. An increase in substrate compaction often leads to changes in the physical properties of turf, a decrease in sward density, the development of shallow root systems, loss of surface elasticity and springiness, and higher risk of injury. It also contributes to a decrease in the proportion of lawn grass species and the expansion of undesirable plants (weeds) (Douglass, Crawford 1993, Mcauliffe 2005, Huang et al. 2014, Wolski et al. 2015, Ford, Twomey 2016, Chen et al. 2018, Zhu, Li 2018, Patton et al. 2019).

The aim of this study was to determine the physicochemical properties of the substrate and the functional quality of football turf in the first year of use (after transplanting) in the Municipal Stadium in Olsztyn.

MATERIALS AND METHODS

The study was conducted on the main field of the Municipal Stadium in Olsztyn, which was established in the 1970s, and was reconstructed and modernized in 2018. The old substrate was replaced, the new substrate was leveled, and drainage, heating and automatic irrigation systems were installed. Turf rolls were produced in Felsőpakony near Budapest, Hungary. A mixture of lawn grasses (26 g m^{-2}), sown on 12 October 2016, had the following composition:

	(%)
Poa pratensis L. Brooklawn	– 32
Poa pratensis L. Yvette	– 32
Poa pratensis L. Julius	– 16
Lolium perenne L. Amadeus	– 8
Lolium perenne L. Verdi	– 6
Lolium perenne L. Conrad	– 6

Pannon Turfgrass Kft. turf rolls with a width of 1.2 m and a length of 10-12 m were laid mechanically on the main field in the first ten days of September 2018. Turf was irrigated daily in the first week after installation, and then every 2-3 days until the establishment of roots, subject to weather conditions.

In 2019, verticutting treatments were performed twice, turf was aerated, top dressed (30 t ha^{-1}), seeded (20 g m^{-2}) with the Vredo disc seeder, and local tears were repaired. During the growing season, turf was irrigated at 5-10 l m^{-2}, depending on weather conditions. Based on nutrient abundance in the substrate, slow-release and quick-release compound fertilizers were applied three times during the growing season (according to the fertilization regime). Turf was mowed to a height of approximately 3 cm with a drum mower or a rotary mower with a bagger attachment, depending on the regrowth rate. In 2019, the football pitch was used 3-4.5 h per week according to recommendations prepared by the general contractor for renovation works.

In accordance with the methodology recommended by the Research Center for Cultivar Testing – COBORU (Domański 1998), the functional characteristics of football turf were determined at 24 representative sites in different areas of the football pitch:

– goal area (sampling sites no. 1, 2, 3, 22, 23 and 24);
– penalty area (sampling sites no. 4, 5, 6, 19, 20 and 21);
– center circle (sampling sites no. 9, 10, 11, 13, 14 and 15);
– sideline area (sampling sites no. 7, 8, 12, 16, 17 and 18).

The following functional characteristics were analyzed: sward density, color, disease prevalence, visual merit (in the spring, summer and autumn on a 9-point scale (1 – unacceptable, 5 – satisfactory, 9 – highly desirable). Compaction was evaluated with the use of a penetrometer. The functional quality of football turf was calculated based on the mean values of three main qualitative traits, using the following formula:

$$FQ = \Sigma\,(0.34 \cdot VM + 0.33 \cdot SD + 0.33 \cdot C)$$

where: FQ – functional quality,
VM – visual merit,
SD – sward density,
C – color.

In the fall, 100 g samples of plant material were collected at five representative points (sampling sites no. 1, 3, 8, 13 and 15) across the field (along a diagonal line) for a detailed botanical analysis by the dry-weight-rank method. Lawn grass species, other grasses and weeds were identified in the collected plant material. Their percentages were determined after drying at a temp. of 105°C and weighing.

Soil conditions, the thickness of the vegetation and filter layers, the length of individual roots and the depth of main root mass were analyzed at the same sampling sites, where samples were also collected to determine the granulometric composition and the physical properties of soil in the vegetation and filter layers, and to perform a proximate analysis of the chemical properties of soil in the vegetation layer. The granulometric composition of soil material was determined by laser diffraction, pH was determined in H_2O and KCl by the potentiometric method, organic carbon (OC) content was measured with a spectrophotometer after oxidation with potassium dichromate according to ISO 14235, and total nitrogen (TN) was measured by the Kjeldahl method.

The content of available phosphorus and potassium was determined using the Egner-Riehm method, according to Standards PN-R-04023:1996 and PN-R-04022:1996, and magnesium content was determined as described by Schachtschabel (PN-R-04020:1994). The concentrations of micronutrients (iron, manganese, zinc and copper) were determined in 1 mol HCl dm^{-3} (Ostrowska et al. 1991), and the content of calcium and sodium was determined by extraction with 0.03% acetic acid. The chemical properties of soil material were analyzed in the Chemical and Agricultural Research Laboratory in Olsztyn. All analyses were performed in duplicate. All results are expressed on an oven-dry soil weight basis (temp. of drying 105°C). The physical properties of soil were analyzed in the Department of Soil Science and Microbiology, University of Warmia and Mazury in Olsztyn:

– soil moisture – after drying to constant weight at 105°C;
– soil bulk density (BD) – in a 100 cm^3 undisturbed core sample after drying to constant weight at 105°C;
– soil specific density (SD) – with a pycnometer;
– total porosity (TP) – using the following equation: $TP = (1 – BD/SD) \cdot 100$;
– the amount of air in the soil – as the difference between total porosity and soil moisture.

The results pertaining to the functional quality of football turf were processed statistically in the Statistica 10.0 program (Data Analysis Software System, StatSoft Inc., 2011).

In the year of turf transplanting, the weather conditions were generally favorable for the growth and development of lawn grasses (Table 1). Mean monthly air temperatures in September, October, November and December 2018 exceeded the long-term average. Total precipitation in September

Table 1

Mean air temperature and precipitation total according to the Meteorological Station in Olsztyn

Month	Mean air temperature (°C)			Precipitation total (mm)		
	2018	2019	long-term average (2004-2018	2018	2019	long-term average (2004-2018)
January	-0.3	-2.4	-2.8	40.6	52.7	42.7
February	-4.4	2.2	-2.0	6.6	35.5	27.9
March	-0.8	4.8	1.7	18.3	51.4	32.8
April	11.6	9.3	7.7	34.8	0.0	31.5
May	16.6	11.9	12.9	30.4	134.8	55.6
June	17.8	20.9	16.0	42.0	93.0	73.6
July	19.9	17.3	18.7	129.1	47.1	100.2
August	19.4	18.7	17.8	61.8	70.0	68.3
September	15.1	13.8	13.3	38.2	87.2	54.2
October	9.3	10.0	7.7	95.0	35.6	50.4
November	3.9	5.4	3.7	19.4	29.3	47,8
December	1.0	2.9	0.3	63.5	35.6	41.0
Mean for Apr-Sep	16.7	15.3	14.4	336.3	432.1	383.5
Annual mean (Jan-Dec)	9.1	9.6	7.9	579.7	672.2	626.1

and November was only 2.2-fold to 2.4-fold lower that the long-term average. In 2019, mean annual air temp. (9.6°C) and mean air temp. during the growing season (15.3°C) exceeded the long-term average. February and March were exceptionally warm, and the plants resumed growth at the end of March. Precipitation levels during the growing season and throughout the year exceeded the long-term average. April was relatively dry, and heavy rainfall was noted in May (134.8 mm). A summer drought in July (precipitation was 2.1-fold lower than the long-term average) suppressed plant regrowth. Rainfall deficiency was also noted from October to December, when precipitation levels were 1.1-fold to 1.6-fold lower than the long-term average (Table 1).

RESULTS AND DISCUSSION

According to the classification of granulometric groups (*Particle size distribution*... 2009), the vegetation layer was composed of loose sand. The content of the sand fraction (mostly medium and coarse sand) ranged from 91.74% to 93.02% (92.62% on average), the content of the silt fraction ranged from 6.98% to 8.26% (7.38% on average), whereas the clay fraction was absent (Table 2). The proportion of silt and clay (<0.02 mm) in the vegetation layer ranged from 2.50% to 3.14%, and it did not exceed the average

Table 2

Granulometric composition of the subsoil layer in the analyzed football pitch

Sampling site	Layer type	Depth (cm)	Fraction content (%)							Soil textural classes*
			clay fraction	silt fraction	sand fraction					
			clay	silt	very fine sand	fine sand	medium sand	coarse sand	very coarse sand	
			particle diameter (mm)							
			<0.002	0.002-0.05	0.05-0.10	0.10-0.25	0.25-0.50	0.50-1.00	1.00-2.00	
1	vegetation	0-15	0	7.55	7.44	15.41	26.96	30.40	12.24	pl
3			0	7.10	6.81	15.63	30.66	30.72	9.08	pl
8			0	6.98	6.71	16.67	29.34	28.54	11.76	pl
13			0	8.26	8.27	19.02	31.03	27.17	6.25	pl
15			0	6.99	6.60	17.16	31.47	28.76	9.02	pl
Mean			0	7.38	7.17	16.78	29.89	29.11	9.67	
1	filter	15-30	0	0.25	0.51	7.19	38.05	41.96	12.04	pl
3			0	0.17	0.47	7.42	38.24	42.34	11.36	pl
8			0	0.17	0.56	5.81	37.65	43.61	12.20	pl
13			0	0.37	0.70	6.88	34.07	42.39	15.59	pl
15			0	0.27	0.42	7.92	37.65	41.28	12.46	pl
Mean			0	0.25	0.53	7.04	37.13	42.32	12.73	

* Particle size distribution and textural classes of soils and mineral materials – Classification of the Soil Science Society of Poland, 2008.

value for sports fields, 8% (DIN 18035-4. 2016). In the filter layer, the content of the sand fraction (mostly medium and coarse sand) was similar over the entire field, regardless of a sampling site (99.63–99.83%), and the content of the silt fraction ranged from 0.17% to 0.37%. The fractions with particle size <0.002 mm and <0.02 mm were absent, which had a positive influence on permeability and facilitated the removal of excess rain water to the drainage system, in particular under extreme weather conditions, which was also reported by other authors (Follis et al. 2008, Kowalik, Rajda 2013, Huang et al. 2014, Anderson et al. 2018, Grabowski et al. 2020,). The permissible proportion of silt and clay in the vegetation layer is 5% to 16%, although the content of these fractions should not exceed 10% to maintain percolation of ≥ 70 mm (DIN 18035-4. 2016).

The physical properties of the substrate (vegetation and filter layers) were typical of loose sand (Table 3). The bulk density of the analyzed layers was high, from 1.62 Mg m^{-3} in the vegetation layer to 1.63 Mg m^{-3} in the filter layer. The values of bulk density, irrespective of a sampling site, point to high compaction in the analyzed football pitch. The specific density of the vegetation and filter layers was similar, at 2.68 Mg m^{-3} average. The noted values are similar to the specific density of sandy mineral soils with a predomination of quartz with specific density of 2.65 Mg m^{-3}.

The total porosity of the vegetation layer and filter layer ranged from 39.1% to 39.8%, and from 37.6% to 40.5%, respectively. According to Rajda et al. (2011) and Grabowski et al. (2020), soil porosity is shaped by numerous factors, including granulometric composition, humus content, the activity of mesofauna and plant roots, the applied maintenance treatments, fertiliza-

Table 3

Physical properties of the subsoil layer in the analyzed football pitch

Sampling site	Layer type	Depth (cm)	Bulk density (Mg m^{-3})	Specific density (Mg m^{-3})	Total porosity (% vol.)	Actual moisture (% vol.)	Air content (% vol.)
1	vegetation	0-15	1.63	2.68	39.1	27.4	11.7
3			1.63	2.71	39.8	27.2	12.6
8			1.61	2.68	39.5	26.9	12.6
13			1.62	2.67	39.3	27.4	11.9
15			1.62	2.68	39.5	27.0	12.5
Mean			1.62	2.68	39.5	27.2	12.3
1	filter	15-30	1.66	2.66	37.6	26.8	10.8
3			1.65	2.66	38.0	27.1	10.9
8			1.60	2.69	40.5	27.8	12.7
13			1.64	2.68	38.8	27.8	11.0
15			1.62	2.69	39.8	26.9	12.9
Mean			1.63	2.68	38.9	27.3	11.7

tion regime and weather conditions. The optimal total porosity of the vegetation layer in football pitches is 35%-40% (DIN 18035-4. 2016). In the present case, the average total porosity was 39.5%, and it remained within the above rage. The values of actual moisture (vegetation layer – 27.2% on average, filter layer – 27.3% on average) indicate that the analyzed football pitch was characterized by favorable moisture conditions, conducive to the growth of grasses (Table 3). The average air content of the vegetation and filter layers was 12.3% and 11.7%, respectively, which suggests that grasses were not at risk of oxygen deficit even during heavy rainfall or sprinkling.

The content of available nutrients in the vegetation layer of the evaluated football pitch is presented in Table 4. The top layer had an alkaline reaction: pH of 7.62 in KCl and 7.64 in H_2O, which exceeded the recommended range (DIN 18035-4. 2016). The optimal pH values for grass growth and development are slightly acidic (5.5 to 6.5). According to Scheffer and Schachtschabel (2002), an increase in pH value to 7.5 decreases the concentrations of iron, manganese and zinc available to plants.

In the vegetation layer, the amount of TN was correlated with the amount of OC (Table 4). The average C:N ratio was 13.99:1, which points to satisfactory microbial activity. The organic matter content of the vegetation layer ranged from 2.34% to 3.02% (2.76% on average), and it did not exceed

Table 4

Chemical properties of the subsoil layer in the analyzed football pitch

Specification	Sampling site					Mean
	1	3	8	13	15	
pH_{KCl}	7.60	7.60	7.60	7.70	7.60	7.62
pH_{H_2O}	7.61	7.60	7.60	7.57	7.83	7.64
TN (%)	0.145	0.107	0.106	0.116	0.103	0.115
OC (%)	1.75	1.35	1.71	1.62	1.56	1.60
Organic matter (%)	3.02	2.34	2.95	2.80	2.69	2.76
OC:TN	12.07	12.62	16.13	13.97	15.15	13.99
Salinity (g dm^{-3})	0.30	0.26	0.26	0.27	0.25	0.27
Content of available nutrients						
P (mg kg^{-1})	104.6	89.4	97.2	98.1	84.1	94.7
K (mg kg^{-1})	70.6	54.0	62.3	66.4	58.1	62.3
Ca (mg dm^{-3})	3900.0	4150.0	4000.0	4175.0	4175.0	4080.0
Mg (mg kg^{-1})	56.0	53.0	50.0	50.0	53.0	52.4
Na (mg dm^{-3})	20.0	20,0	20.0	20.0	20.0	20.0
Cu (mg kg^{-1})	3.5	3.0	3.1	3.1	3.2	3.2
Mn (mg kg^{-1})	194.0	136.0	118.0	120.0	120.0	137.6
Fe (mg kg^{-1})	1760.0	1440.0	1380.0	1360.0	1510.0	1490.0
Zn (mg kg^{-1})	11.5	9.5	8.9	9.1	10.2	9.8

the norm for football pitches according to the German Standard DIN 18035-4. The total organic matter content of the substrate should range from 1% to 3% to ensure the optimal water-holding capacity, water permeability and bearing capacity. According to Kim (2014), organic matter affects soil structure, aeration, moisture content, nutrient availability and ecosystem longevity. Adams and Saxon (1979) demonstrated that the excessive accumulation of organic matter in the root zone leads to macropore blockage and deterioration in physical properties, including drainage, aeration and water retention, which can compromise root formation and increase the susceptibility of grasses to diseases. According to Carrow (2004), the organic matter content of the top layer in sports fields should not exceed 3-4%.

Apart from the humus content, substrate fertility in a sports field is also determined by the concentrations of plant-available macro- and micronutrients (*Fertilizing recommendations*. 1990). In the analyzed football pitch, the phosphorus content ranged from 84.1 to 104.6 mg P kg^{-1}, i.e. from high (site no. 15) to very high (sites no. 1, 3, 8 and 13). The potassium content ranged from 54.0 to 70.6 mg kg^{-1}, i.e. from low (sites no. 3, 8 and 15) to moderate (sites no. 1 and 13). The calcium content of the vegetation layer ranged from 3900 to 4175 mg dm^{-3}, and the magnesium content ranged from 50.0 to 56.0 mg kg^{-1}, which can be regarded as high. The sodium content was relatively low (20 mg dm^{-3}) and sodium did not exert a toxic effect on the growth and development of lawn grasses. Regardless of a sampling site, the vegetation layer of the analyzed football pitch had a high content of copper and zinc, and a moderate content of iron and manganese (Table 4).

The results of a detailed botanical analysis by the dry-weight-rank method revealed that in the first year after turf transplanting, monocotyledonous and dicotyledonous weeds emerged spontaneously in the analyzed football turf. *Poa pratensis* L. predominated in the turf, and the proportion of *Lolium perenne* L. (the second component of the mixture) decreased insignificantly (Table 5). The proportion of undesirable grass species, *Poa annua* L. and/or *Poa trivialis* L. did not exceed the permissible level of 1% (DIN 18035-4). Dicot, short, rosette-forming weeds resistant to trampling were also encountered sporadically (Table 6).

The dominance of *Poa pratensis* L. in the examined turf indicates that this species is highly suitable for intensively used sports surfaces (Diesburg et al. 1997, Grabowski et al. 2006, Koh et al. 2006, Chen et al. 2018, Patton et al. 2019). The species is characterized by high persistence, ability to form dense swards, high winter survival rates and high resistance to adverse habitat conditions with respect to water availability and air temperatures (Grabowski et al. 2006, Brede 2008, Wolski et al. 2015). *Lolium perenne* L. is another popular grass species used in sports fields and recreational areas (Grabowski et al. 2006, Iraba et al. 2013, Wolski et al. 2015, Straw et al. 2019). In the present study, water deficit and thermal stress (summer dry spells, spring frost and winter cold) led to a minor decrease in the proportion of *Lolium perenne* L. in the analyzed turf. According to the literature

Table 5

Species composition of football turf (% DM)

Specification	Sampling site				
	1	3	8	13	15
Lawn grasses:					
Poa pratensis L.	79.9	80.3	79.5	78.5	79.8
Lolium perenne L.	19.7	19.3	18.9	19.9	19.1
Other grasses:					
Poa annua L.	0.3	0.1	0.7	0.9	0.5
Poa trivialis L.	+	+	+	+	+
Weeds:					
Plantago lanceolata L.	0.1	0.3	0.9	0.7	0.6
Plantago media L.	+	·	+	+	+
Bellis perennis L.	+	+	·	+	·
Potentilla anserina L.	+	·	+	+	83
Total	100.0	100.0	100.0	100.0	100.0

Table 6

Assessment of the root system of grasses

Sampling site	Thickness of the sand layer (cm)	Thickness of thatch (cm)	Depth of the main root mass (cm)	Length of individual roots (cm)
1	2.50	0.30	5.50	6.50
3	1.50	0.40	6.50	9.50
8	0.70	0.30	4.50	7.00
13	1.30	0.50	5.50	11.50
15	1.80	0.30	6.00	8.00
Mean	1.56	0.36	5.60	8.50

(Thorogood 2003, Orchard et al. 2005, Iraba et al. 2013) this species is not highly resistant to low temperatures, which decreases its persistence, particularly in northern regions. The presence of *Poa annua* L. in the examined turf can be explained by its spontaneous emergence in the process of natural plant succession because the species reproduces by self-pollination and adapts easily to changing environmental conditions (Chen et al. 2018, Patton et al. 2019). According to Beard et al. (1978), *Poa annua* L. is one of the most common weeds in intensively used sports fields in the USA.

A gradual decrease in turf quality is a natural and widely observed phenomenon in intensively used sports facilities (Magani et al. 2004, Follis et al. 2008, Anderson et al. 2018, Thanheiser et al. 2018). Pakeman and Small (2005) reported that bare patches in the sward are colonized by seedlings that develop from seeds from the soil seed bank, shedding seeds (seed rain) and seeds from vegetatively reproducing plants. Studies conducted by other authors (Gibbs et al. 1993, Dernoeden et al. 1994, McAuliffe 2005, Brede 2008, Rajda et al. 2011, Huang et al. 2014, Kim 2014) confirmed that the rate of plant growth and development is determined by the specific biological characteristics of a genotype, but it is also modified by changing habitat conditions during the growing season. Therefore, the presence of undesirable plant species (weeds) in the sward can testify to excessively intensive field use, compaction of the vegetation layer and deterioration in the physical properties of the substrate (Beard et al. 1978, Pakeman, Small 2005, Rajda et al. 2011, Wolski et al. 2015, Grabowski et al. 2020).

In the current study, the functional characteristics of natural turf installed in the fall of 2018 were evaluated in the spring, summer and fall. The analyzed characteristics differed depending on a season and field area (Figures 1-4). The values of sward density were very high or high in the sideline area (7.6 points on average on the 9-point scale, significant differences relative to the other areas). Similar cover with grass shoots and leaves was

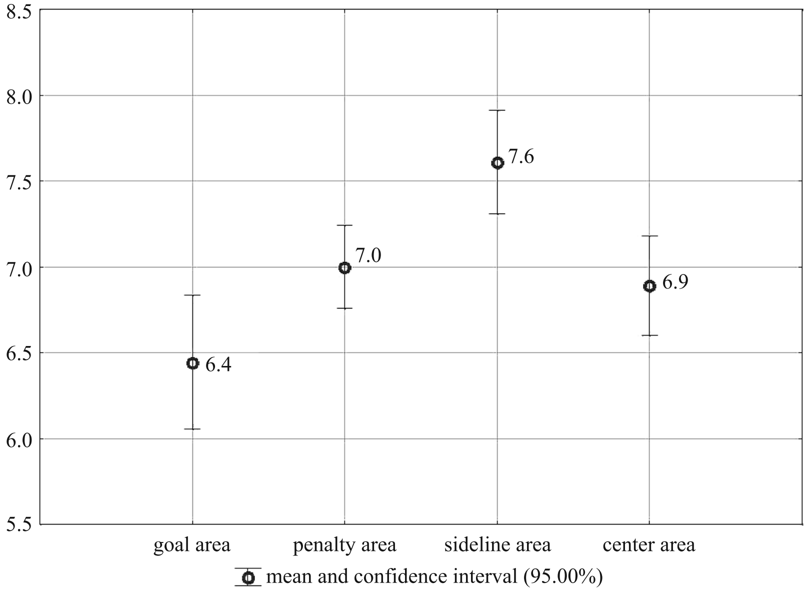

Fig. 1. Sward density in the analyzed football pitch (9-point scale)

noted in the penalty area and the center circle (6.9-7.0 points on average on the 9-point scale). The goal area was characterized by satisfactory or high values of sward density (6.4 points on average on the 9-point scale) – Figure 1.

In sports fields, sward density is shaped by various factors such as substrate preparation, selection of grass species (varieties), irrigation, fertilization, mowing frequency, intensity of use, maintenance treatments and weather conditions (Canaway 1990, Kosmala 2004, Russi et al. 2004, Turgeon 2005,Thanheiser et al. 2018). According to Anderson et al. (2018), sports turf

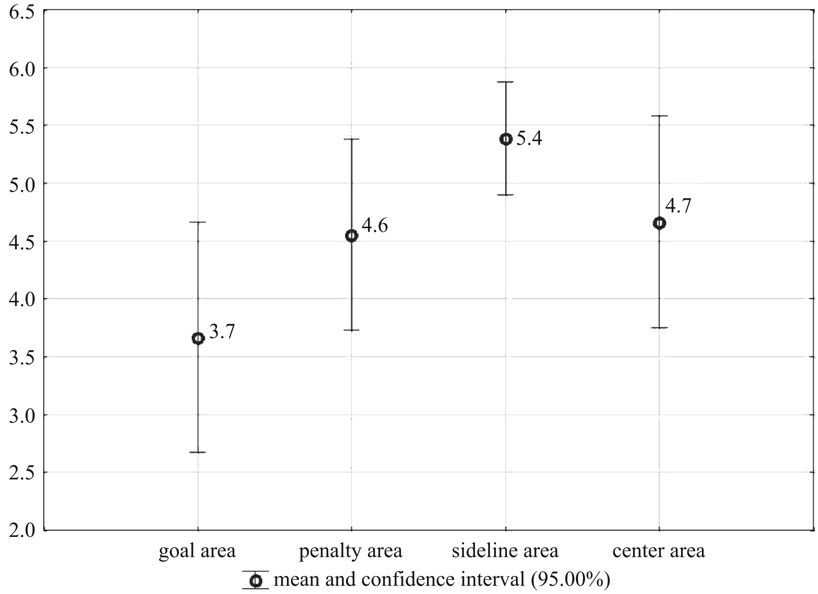

Fig 2. Color of football turf (9-point scale)

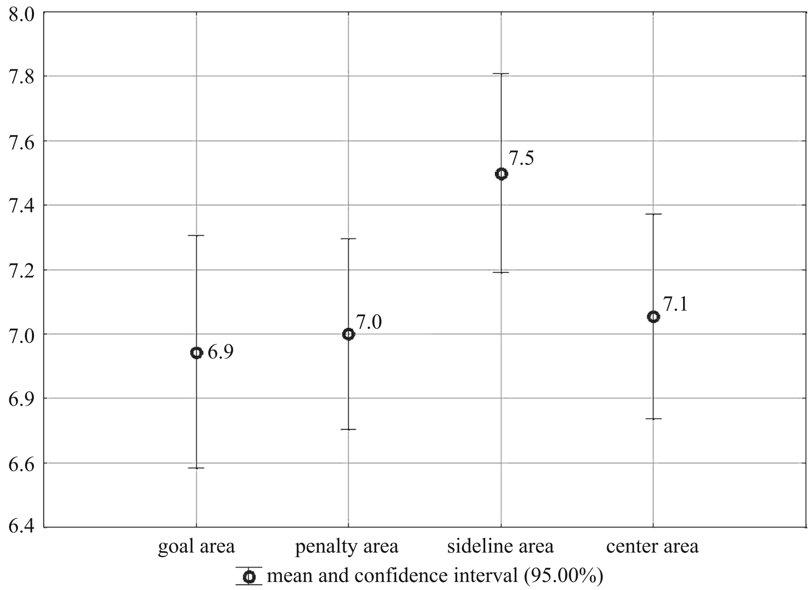

Fig. 3. Health status of football turf (9-point scale)

is susceptible to damage under large surface forces caused by intensive movements of football players. STRAW et al. (2019) reported that within-field variations observed in natural turfgrass sports fields, including differences in turf coverage, resistance to mowing, surface hardness and evenness, affect playability and increase the risk of injury. According to LAUDAŃSKI et al.

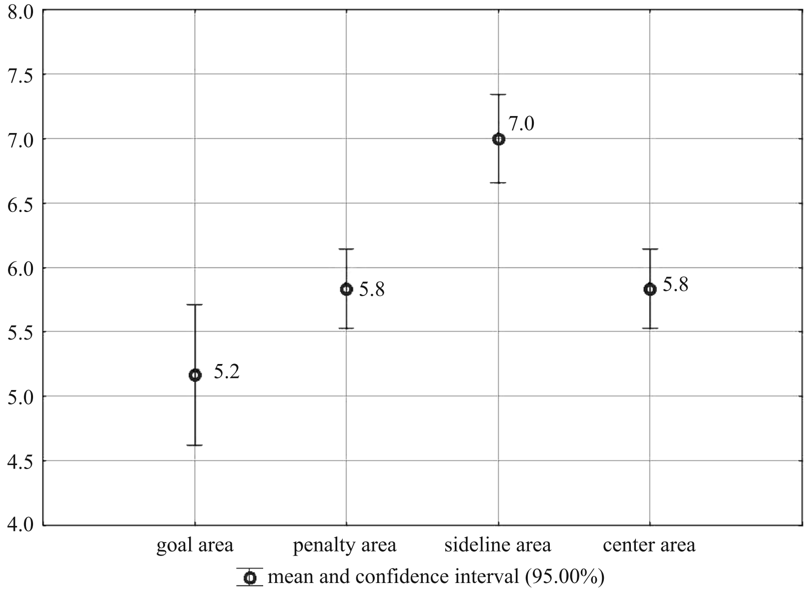

Fig. 4. Visual merit of football turf (9-point scale)

(2004), the visual merit of sports lawns is determined by sward density in 70%, followed by color – 20% and leaf fineness – 10%, which are regarded as less important parameters. FORD and TWOMEY (2016) reported that natural grass cover decreases surface hardness in sports fields, even during drought. The cited authors concluded that sports fields should be sown with grass species that ensure uniform cover over the entire surface throughout the growing season, in particular the species and varieties of lawn grasses forming resilient and dense swards, i.e. *Poa pratensis* L., *Lolium perenne* L. and *Festuca rubra* L. STRAW et al. (2019) found that natural turf creates a softer and safer surface for running in all sports disciplines.

The color of the analyzed football turf was natural green (5.4 points on the 9-point scale) in the sideline area and greyish-green, much less desirable (3.7 points on the 9-point scale, a significant difference) in the goal area. The remaining areas (penalty area and center circle) were characterized by a similar, fresh green color (Figure 2). WOLSKI et al. (2015) observed that in sports fields, a dark green (emerald) color is more visually appealing than a light green color which decreases the overall visual quality of turf. However, according to the literature, color stability during the growing season and the resistance of lawn grass species (varieties) to changes in color caused by environmental stressors are more important determinants of visual merit (DOMAŃSKI 1998, LAUDAŃSKI et al. 2004, RUSSI et al. 2004, WOLSKI et al. 2015). TURGEON (2005) demonstrated that turf color is affected primarily by the selection of grass species and varieties, mowing frequency, high fertilizer doses and irrigation as well as pest and disease control.

The health status of the analyzed football turf was evaluated based on the prevalence of plant diseases. A phytopathological analysis revealed that the rates of infections caused by plant pathogens were very low (6.9-7.5 points on the 9-point scale) in all field areas.

In the first year of use, the sideline area of the evaluated football pitch was characterized by the significantly highest esthetic value (turf assessed as "pleasing the eye"). The appearance of turf in the penalty area and the center circle was satisfactory to good (5.8 points on average on the 9-point scale). The appearance of turf in the goal area was evaluated as average (5.2 points on average on the 9-point scale) – Figure 4. The visual merit of sports turf is determined by numerous factors, including grass species and varieties, substrate type, fertility, granulometric composition and physicochemical properties, intensity of use, maintenance treatments (irrigation, fertilization, pest and disease control), and weather conditions (Domański 1998, Laudański et al. 2004, Russi et al. 2004, Turgeon 2005, Huang et al. 2014, Grabowski et al. 2020). According to Domański (1998), visual merit is a synthetic measure that accounts for interactions between grass genotype and environmental factors, and reflects the overall visual quality of turf. In a study by Russi et al. (2004), turf quality improved during continual use. In contrast, Brede (2008) reported that the esthetic value of turfgrass deteriorated in successive seasons and years of use. According to Diesburg et al. (1997), esthetics is not a critical parameter in intensively used sports fields. The above authors demonstrated that the functional characteristics of turfgrass pitches are determined by the persistence of sward which should uniformly cover the entire field surface, stabilize the substrate, reduce dust and mud, and contribute to weed elimination. Sward density, color and visual merit reflect the health status of plants and the esthetic value of turf (Wolski et al. 2015).

The functional quality (FQ) of football turf can be determined based on the mean values of three main qualitative traits: visual merit, sward density and color. The value of FQ was highest (6.7) in the sideline area, and significantly lower in the penalty area, in the center circle and in the goal area (Figure 5).

In the evaluated football pitch, compaction in the vegetation layer exceeded the norm (DIN 18035-4. 2016) 1.8-fold to 2.2-fold (2.0-fold on average). The highest compaction of the substrate was noted in the goal area and in the penalty area, and it was significantly lower in the sideline area (Figure 6). According to many authors (Cannaway 1990, Gibbs et al. 1993, Kosmala 2004, Turgeon 2005, Kowalik, Rajda 2013), high compaction of the top layer not only decreases water permeability but also suppresses healthy root development and penetration into deeper layers, disrupts gas exchange and nutrient uptake. Therefore, maintaining high-quality sports turf poses a considerable challenge for managers of football facilities.

High-quality sports fields are established on a layer of sand to minimize substrate compaction (Huang et al. 2014). According to Dixon et al. (2015)

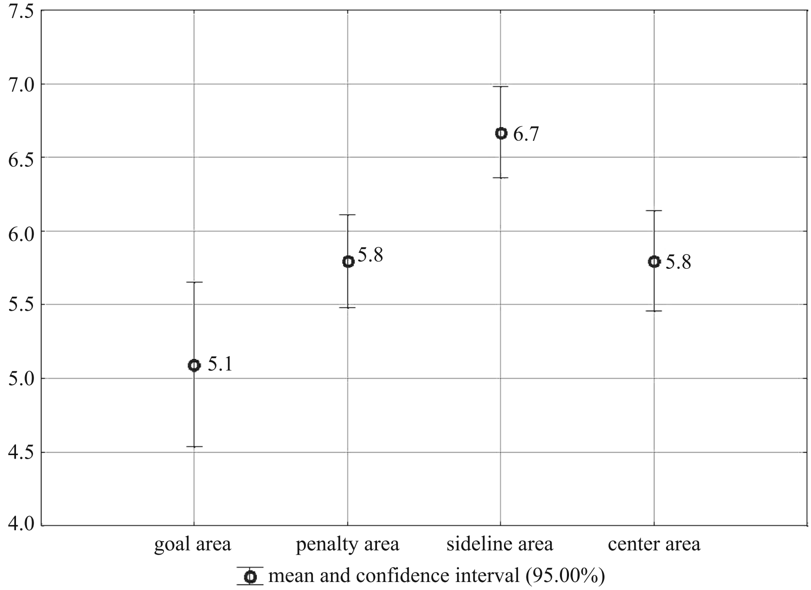

Fig. 5. Functional quality of football turf (9-point scale)

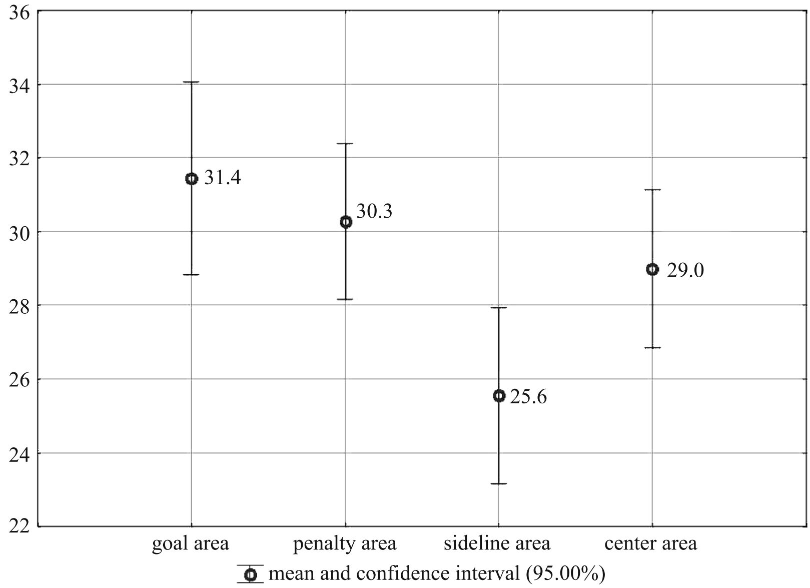

Fig. 6. Substrate compaction in the analyzed football pitch (bar)

and ANDERSON et al. (2018), sand improves drainage but it does not have cohesive properties, and the stability of substrates exposed to load depends on the frictional forces between particles. DOUGLASS and CRAWFORD (1993) found that grass-covered surfaces were more resistant to compaction than bare land due to the activity of soil fauna and the shock-absorbing effects of grass roots.

In the turf installed in the fall (Table 6), the thickness of the sand layer ranged from 0.70 to 2.50 cm (1.56 cm on average), and the felt thickness ranged from 0.30 to 0.50 cm (0.36 cm on average), not exceeding the recommended value (0.50 cm). The intensive use of the football pitch in 2019 contributed to changes in the depth of main root mass (from 4.50 to 6.50 cm, 5.60 cm on average) and the length of individual roots (from 7.0 to 11.50 cm, 8.50 cm on average), which is consistent with the findings of Wolski et al. (2015). According to Turgeon (2005), intensive and low mowing in sports fields decreases the growth rate and depth of grass roots. Reduced nutrient availability also significantly suppresses the development of underground plant parts.

CONCLUSIONS

1. The substrate in the analyzed football pitch was composed of loose sand, and could be classified as light soil. The substrate was characterized by high bulk density and relatively low total porosity, pointing to high compaction.

2. The vegetation layer was characterized by alkaline pH that exceeded the optimal range for grasses, high to very high phosphorus content, a high content of calcium, magnesium, copper and zinc, a moderate content of manganese and iron, low to moderate potassium content and low sodium content.

3. In the first year of use, football turf was characterized by satisfactory to high density, a grayish-green, fresh green or green color, very low disease prevalence, and satisfactory or good visual merit.

4. Poa pratensis L. predominated in the sward, and the proportion of *Lolium perenne* L. (the second component of the mixture) decreased insignificantly. The spontaneous emergence of monocotyledonous and dicotyledonous weeds, resistant to trampling, testifies to intensive football pitch use, excessive compaction in the vegetation layer and deterioration in the physical properties of the substrate.

5. Compaction in the vegetation layer exceeded the norm (two-fold on average). Main root mass was found at a depth of 5.6 cm, and the length of individual roots reached 8.5 cm on average.

6. A fibrous root system that could stabilize the top layer did not develop in the first year after transplanting in the analyzed football turf.

REFERENCES

Adams W.A., Saxon C. 1979. *The occurrence and control of thatch in sports turf*. Rasen, Turf, Gazon, 3: 76-83.

Andersson H., Ekblom B., Krustrup P. 2007. *Elite football on artificial turf versus natural grass: Movement patterns, technical standards, and player impressions*. J Sports Sci, 26(2): 113-122.

Anderson F.D., Fleming P.R., Sherratt P.I., Severn K. 2018. *Novel field equipment for assessing the stability of natural and hybrid turf*. Sports Engin, 21(4): 321-331.

Beard JB., Rieke P.E., Turgeon A.J., Vargas J.M. 1978. *Annual bluegrass (Poa annua* L.*) description, adaptation, culture and control*. Michigan State University Agr. Exp. Res. Rept. 352.

Brede A. D. 2008. *Multi-way Kentucky bluegrass blends and their effect on turfgrass quality*. Acta Horticult, 783: 19-27.

Canaway P.M. 1990. *A comparison of different methods of establishment using seed and sod on the cover and playing quality of turf for football*. J Sports Turf Res Inst, 66: 9-28.

Canaway P.M., Baker S.W. 1993. *Soil and turf properties governing playing quality*. Int Turfgrass Soc Res J, 7: 192-200.

Carrow R.N. 2004 *Surface organic matter in creeping bentgrass greens*. Golf Course Mgmt, 75(5): 96-101.

Chen Y., Pettersen T., Kvalbein A., Aamlid T. S. 2018. *Playing quality, growth rate. thatch accumulation and tolerance to moss and annual bluegrass invasion as influenced by irrigation strategies on red fescue putting greens*. J. Agro Crop Sci, 204: 185-195. https://doi.org/10. 1111/jae. 12246

Dernoeden P.H., Caroll M.J., Krouse M.I. 1994. *Mowing of three fescue species for low maintenance turf sites*. Crop Sci, 34(6): 1645-1649.

Diesburg K.L., Christians N.E., Moore R., Branham B., Danneberger T.K., Reicher Z.J., Voigt T., Minner D.D., Newman R. 1997. *Species for low-input sustainable turf in the U.S.* Upper Midwest. Agron. J., 89(4): 690-694.

DIN 18035-4. 2016. Sportplätze. Rasenflächen. Deutsches Institut für Normung, Pforzheim.

Dixon S., Fleming P., James I., Carré M. (Eds.) 2015. *The science and engineering of sport surfaces*. Routledge, Abingdon.

Domański P. 1998. *Methods of studying economical value of cultivars of field crops. Agricultural plants. Turf (lawn) grasses*. COBORU, Słupia Wielka. (in Polish)

Douglass I.T., Crawford C. E. 1993. *The responce of reygrass sward to wheel traffic and applied nitrogen*. Grass Forage Sci, 48: 91-100.

Fertilizing recommendations. 1990. Part 1. *Limits for the valuation of macro-and microelements in soils*. Wyd. 2, ser. P(44), IUNG Puławy, 26 pp. (in Polish)

Follis C.C., Anderson S.H., Fresenburg B.S., Ervin E. H. 2008. *Evaluation of sand-soil-compost root zones developed for athletic fields*. Acta Horticult, 783:97-104.

Ford P.G., Twomey D.M. 2016. *Moderating surface hardness and rotational traction of natural turf community-level football fields in drought*. Acta Horticult, 1122: 111-120.

Gibbs R.J., Adams W.A., Baker S.W. 1993. *Changes in soil physical properties of different construction methods for soccer pitches under intensive use*. Int Turfgrass Soc Res J, 7: 413-421.

Grabowski K., Grzegorczyk S., Kwietniewski H. 2006. *Usefulness of 10 grass mixtures for sowing on sport playing fields*. Zesz. Nauk. UP Wrocław, 545: 95-102.

Grabowski K., Grzegorczyk S., Łachacz A., Olszewska M. 2020. *Functional characteristics of a grass sward as per an athletic field at the University of Warmia and Mazury in Olsztyn*. Pol. J. Environ. Stud., 29(5): 3589-3596. DOI: 10.15244/pjoes/117691

HUANG B., DACOSTA M., JIANG Y. 2014. *Research advances in mechanisms of turfgrass tolerance to abiotic stresses. From physiology to molecular biology*. Crit. Rev. Plant Sci., 33(2-3): 141-189.

IRABA A., CASTONGUAY Y., BERTRAND A., FLOYD D. J., CLOUTIER J., BELZILE F. 2013. *Characterization of populations of turf-type perennial ryegrass recurrently selected of superior freezing tolerance.* Crop Sci, 53: 2225-2238. DOI: 10.2135/cropci 2013.02.0100

KIM K.N. 2014. *Effect of organic soil amendments on establishment vigor, seedling emergence and top growth in Kentucky bluegrass.* Kor. J. Hort. Sci. Technol., 32(2): 133-141.

KOH S.G., TAE H.S., RYN C.H. 2006. *Effect of animal organic soil amendment on growth of Korean lawngrass and Kentucky bluegrass.* Kor. J. Turfgrass Sci., 20: 33-40.

KOSMALA M. 2004. *Modern methods of establishment sport field grass.* Prz Komun, 8(155): 43-46. (in Polish)

KOWALIK T., RAJDA W. 2013. *How to construct a turf covered football pitch – part 1. Testing suitability of natural ground for constructing football pitch.* Infrastructure Ecol Rural Areas, 1(IV): 271-283. (in Polish)

LAUDAŃSKI Z., PROŃCZUK S., PROŃCZUK M. 2004. *A proposed synthesis of turf characteristics for assessment of the value of Festuca ssp. cultivars.* Biul. IHAR, 233: 181-194. (in Polish)

MAGANI S., VOLTERANI M., MIELE S. 2004. *Pitches performances as affected by construction method, sand type and turfgrass mixture.* Acta Horticult, 661: 281-285.

MCAULIFFE K. 2005. *Are our playing surfaces up to standard?* NZ Turf Manage J, 20: 26-27.

MCNITT A.S., LANDSCHOOT P.I. 2003. *Effects of soil reinforcing materials on the surface hardness, soil bulk density, and water content of a sand root zone.* Crop Sci, 43(3): 957-966.

ORCHARD J., CHIVERS I., ALDOUS D., BENNELL K., SEWARD H. 2005. *Ryegrass is associated with fewer non-contact anterior cruciate ligament injuries than bermudagrass.* Brit J Sports Med, 39: 704-709.

OSTROWSKA A., GAWLIŃSKI A., SZCZUBIAŁKA Z. 1991. *Methods of analysis and assessment of soil and plant properties*. Inst Environ Protect, Warsaw, 324 pp. (in Polish)

PAKEMAN R.J., SMALL J.L. 2005. *The role of the seed bank, seed rain and the timing of disturbance in gap regeneration.* J Veget Sci, 16(1): 121-130.

Particle size distribution and textural classes of soils and mineral materials – Classification of Polish Society of Soil Science 2008. 2009. Rocz. Glebozn. – Soil Sc. Ann., 60(2): 5-16. (in Polish)

PATTON A.J., BRAUN R.C., SCHORTGEN G.P., WEISENBERGER D.V., BRANHAM B.E., SHARP B., SOUSEK M.D., GAUSSOIN R.E., REICHER Z.J. 2019. *Long-term efficacy of annual bluegrass control strategies on golf course putting greens.* Crop, Forage Turfgrass Manage, 5: 180068-180078. DOI: 10.2134/cftm 2018.09.0068

RAJDA W., ŻARNOWIEC W., STACHURA T. 2011. *Physical properties and water permeability of the football field Wisła Kraków after the renovation.* Acta Sci. Pol., Architektura, 10(1): 31-41. (in Polish)

RUSSI L., ANNICCHIARICO P., MARTINIELLO P., TOMASONI C., PIANO E., VERONESI F. 2004. *Turf quality of cool season grasses at low inputs: Reliability across years, seasons and sites of evaluation.* Acta Horticult, 661: 387-392.

SCHEFFER F., SCHACHTSCHABEL B. (Eds.) 2002. *Lehrbuch der Bodenkunde*. 15. Auflage Springer Verlage, Berlin.

STRAW CH. M., HENRY G.M,. SHANNON J., THOMSON J.J. 2019. *Athletes' perceptions of within-field variability on natural turfgrass sports fields.* Precision Agri, 20: 118-137. https://doi.org/10.1007s11119-018-9585-2

THANHEISER S. Y., GRASHEY-JANSEN S., ARMBRUSTER G. 2018. *Hardness measurement of natural and hybrid turf soccer fields*. Sports Engine, 21: 367-377.

THOROGOOD D. 2003. *Perennial ryegrass (Lolium perenne).* Turfgrass Biol, Genetics and Breeding, 7: 75-105.

TURGEON A.J. 2005. *Turfgrass management*. Pearson Prentice Hall. Phoenix Book Tech., 1-13.

WOLSKI K., TALAR-KRASA M., DRADRACH A., SZYMURA M., BIERNACIK M., ŚWIERSZCZ S. 2015. *The assessment of usuable features of football pitch turf on the example of KS AZS Wrocław*. Łąkarstwo w Polsce (Grassland Science in Poland), 18: 241-254. (in Polish)

ZHU H., LI D. 2018. *Using humus on golf course fairways to alleviate soil salinity problems*. HortTechnol, 28(3): 284-288. DOI: 10.21273/Horttech 03989-18