



Retention and Water Needs of Natural Grass Turf of Football Fields

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Abstract: The paper contains a detailed assessment of three full-size football fields constructed in 2019-2022 to meet the basic conditions for proper operation and maintenance. As a result of field and laboratory tests on permeability and retention capacity of the fields' base and drainage layers, they were found to meet the requirements set out in the standard DIN 18035. It ensures that rainwater and snowmelt are quickly drained from the turf's surface. The grass turfs of the football fields under study meet the conditions for properly performing one of the basic care treatments – irrigation. The base layer can retain an average of 10.3 mm of water in comfortable water availability conditions, depending on the football field. It is the value of a single dose net, which should be used for sprinkler irrigation of grass turf of football fields. However, considering the drainage layer, this dose could be increased to 12.5 mm. Considering the percentage content of generally available water and assuming less comfortable water availability conditions, the appropriate doses net are 12.5 mm on average. In comparison, for both layers together, they are 15.4 mm on average.

Keywords: grass turf of football fields, retention, water needs, water potential, irrigation dose

1. Introduction

Football is a trendy sport all over the world. This discipline requires properly maintained grass football fields with low and compact sod, resistant to intensive use, which will provide optimal conditions for bouncing, rolling, and driving the ball regardless of the weather. Natural grass surfaces on sports grounds are unceasingly highly esteemed by players. They continue to be a measure of functionality and usability of sports fields (Ekstraklasa S.A. Guidelines Regarding preparation and proper maintenance Stadium turf. Version 2017/2018, Version 1.0). However, for grass turf to meet the expectations of being a flexible, player-friendly, and regenerable playing surface, not only its sod but particularly its underlying base layer must meet the highest quality requirements. This layer faces the highest expectations in terms of dynamics: shear strength, flexibility, force reduction and ball rebound elasticity. The basis for creating a football turf of high visual and functional quality is the use of mixtures composed of appropriate grass species (Płaskowska et al. 2006). The most useful species for installing grass sports surfaces include perennial ryegrass (*Lolium perenne* L.) and Kentucky bluegrass (*Poa pratensis* L.). These grasses successfully tolerate low and frequent mowing and intensive trampling and abrasion (Piotrowski et al. 2006). Sports fields are part of the sports infrastructure of urban and housing estate areas. Apart from their dimensions (120 m x 90 m), their most important element is their grassy surface, which should be characterised by good water permeability and retention capacity (Żegocińska-Tyżuk 1988). However, newly built or remodelled sports fields often fail to meet these requirements due to inappropriate materials or technology (Adams 1996). The turf of sports fields installed on sandy soils with a low water capacity (retention) requires expensive irrigation in periods without precipitation; otherwise, it dries up. On compact soils, on the other hand, the upper layer of sports fields usually has high water capacity; however, it is not very permeable to water, and in periods of excessive rainfall or during irrigation, ponds are formed, causing the turf to become wet. In both cases, it is not advantageous to use sports fields, as it deteriorates their aesthetic values and hinders functional efficiency. Sports field surfaces should also be characterised by good sorption and abundance of nutrients (James 2007, Rajda et al. 2006, Rajda et al. 2011) while meeting the water permeability requirement according to DIN 18 035 (Deutsche Norm 1991). Additionally, they should be properly compacted to obtain flexibility and resistance to dynamic loads, which affects water permeability and retention capacity (Gołąb & Gondek 2013). One of the conditions for having a good football field is the efficient drainage of excess rainwater to the drainage layer and drains. Therefore, sports fields should consist of layers (Adams 1996, Kowalik & Rajda 2013, Rajda et al. 2011, Żegocińska-Tyżuk 1988), and the base layer on its surface, several centimetres thick, should be characterised by good water permeability. On compact soils, the construction of football fields should use composites with grain size distribution guaranteeing the fulfilment of this condition (James et al. 2007, Pereira 2007, Milivojević 2011, Policht-Latawiec 2008). According to the guidelines of the German standard (Deutsche Norm 1991), such a field, apart from meeting the requirements for



dimensional parameters (Wirszyla 1966, Rzegocińska-Tyżuk 1988), should be made of a base layer covered with turf, a drainage layer lying underneath, and a substrate of native soil, which contains drains with filtering backfill (Fig. 1). The base layer and the drainage layer should be connected by a few-centimeter interlocking element. The base layer should be a composite of sand (as its fundamental material) and fertile soil from the humus layer of local origin. Its task is to provide retention and sorption capacities to meet the water and nutritional needs of the grassy sward of the field. On the other hand, this layer should conduct water well because water excess during precipitation and immediately after it should easily seep through the drainage layer to drains and, partly, to the native substrate. The base layer and drainage layer thickness should be several centimetres each. In rainless periods, the field should be irrigated, most often by sprinkling, to ensure optimal moisture in the base layer and maintain the proper condition of the sward. Therefore, it is necessary to specify an irrigation dose that ensures the full use of the retention capacity of the base and drainage layers. The drainage layer, due to its function and the type of material it is composed of (sand), is characterised by relatively low water retention capacity. At the same time, with low capillary infiltration capacity, it is a significant barrier against the water-feeding of grasses rooted in the base layer. A properly selected dose of irrigation reduces water losses due to this infiltration. Also, it entails costs since sprinkler irrigation usually uses treated tap water. One of the conditions for having a good football field is the efficient drainage of excess rainwater to the drainage layer and drains.

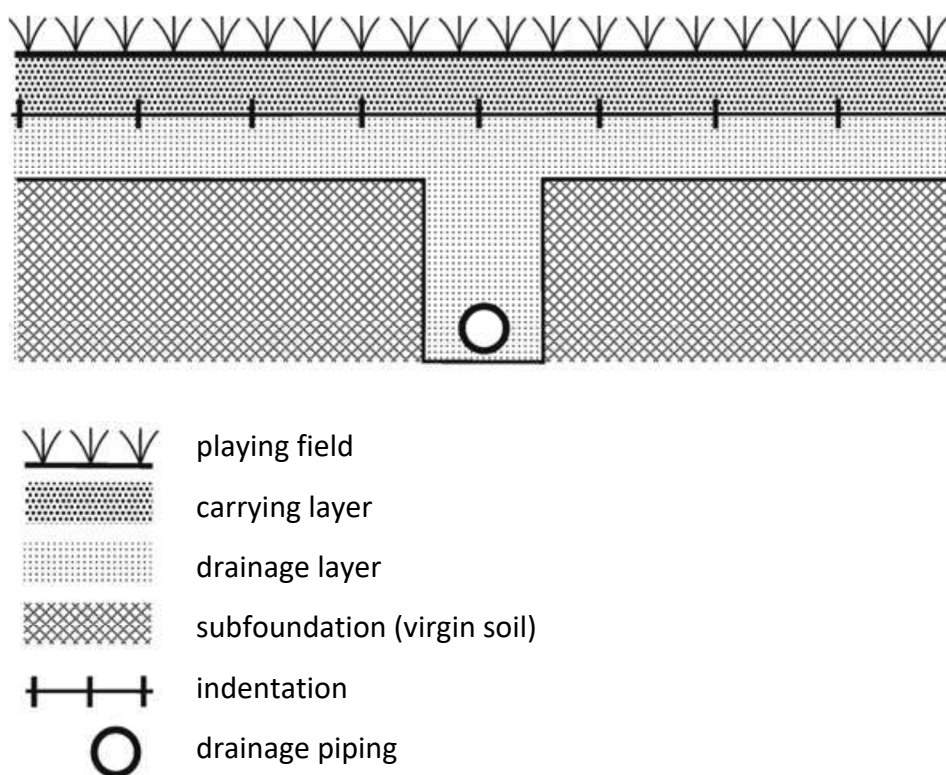


Fig. 1. Cross section of the plate of a professional football playing field (acc. to DIN 18035)

The paper evaluates laboratory results and field tests of the base and drainage layers of 3 football fields commissioned between 2019 and 2022. The soil material from which they were built was analysed, particularly it terms of physical and water properties, water permeability and retention capacity. The results were compared with the German standard DIN 18 035 requirements.

2. Material and methods

The paper presents the results of field and laboratory tests of three football fields' top layers of grass turf. Two are located in the Lubuskie Voivodeship, in Szprotawa, the Żagań powiat, and Rusinów, approx. 7 km north of Świebodzin, the Świebodzin powiat. The third of the football fields is located in Kłecko, the Gniezno powiat in the Wielkopolska Voivodeship. All these natural grass turf football fields are full-size (105 m x 68 m – Fig. 2a), adapted to football games at the national level, under the guidelines of PZPN (Guidelines). The research results should be a guideline for constructing new or modernising football fields in urban and rural areas. The methodology of field and laboratory work was modelled on the works of Rajda & Kanownik (2006),

Rajda et al. (2011), Kowalik & Rajda (2013). The study was carried out during the hydrological year 2021-2022 (November-October). The soil material used to build the football fields was analysed, and the permeability of their surfaces was measured. Each of the football fields was divided into 3 cross-sections. In each of them, approximately symmetrically, there were 3 points where samples of soil material were taken (Polish Standard 1998) from the 15-centimeter base layer and the drainage layer lying underneath it. Cross-sections I and III were located along the lines of penalty fields, whereas cross-sections II were located along the midline of the football fields (Fig. 1). Laboratory tests included the determination of soil grain size distribution using the aerometric method as well as volumetric and specific densities using the dryer-weighing and pycnometric methods, respectively (Zawadzki 2002). The organic matter was determined by calcining samples at 550°C, previously dried at 105°C. When collecting and preparing the samples and making determinations, the following standards were followed: PN-R-04031, PN-R-04032, PN-R-04033 and PN-ISO-11464. The granulometric composition of materials forming the base and drainage layers was determined in the samples taken at points 3, 5 and 7 by the Casagrande sedimentation method, modified by Prószyński (Fig. 2b and 3). (Kowalik & Rajda 2013, Oleszczuk & Truba 2013, Polska Norma (Polish Standard) 1998a). The results are presented in Table 1. Volumetric and specific densities, the percentage of humus content and water potential pF were determined based on the samples taken from eight points of the base layer and nine points of the drainage layer. The samples were taken using an Ejikelkamp sampler from the centre of the tested layers to cylinders with a capacity of 100 cm³ (Drozd et al. 1998). To determine the retention capacity of soils forming the football field layers and their water reserves, suction force tests were performed and retention curves (pF water potential curves) were prepared. Water potential was determined using a 5 and 15 bar pressure extractor. The maximum hygroscopic water capacity was determined using the Mokołajew method. On its basis, water content corresponding to $pF = 4.2$ was determined. Following Ostromecki (1964) and Świącicki (1981), the values of pressure determining moisture values were determined at the state corresponding to field water capacity (W_{PPW} , for $pF = 2.5$), drought water capacity (W_{PS} , for $pF = 3.7$) and for the permanent wilting point (W_{TW} , for $pF = 4.2$). The percentage content of water with different availability for the grass was calculated: generally available (W_{OD}), easily available (W_{LD}) and hardly available (W_{TD}). Considering the thickness of the base and drainage layers, there were calculated the reserves of generally available, easily available, and hardly available water (Z_{od} , Z_{ld} and Z_{td} in mm) and the corresponding irrigation doses net for standard and comfortable conditions for soil water uptake by grass turf (Z_{od}) and (Z_{ld}). The permeability was measured using Kopecki rings with a cross-section of 78.5 cm².

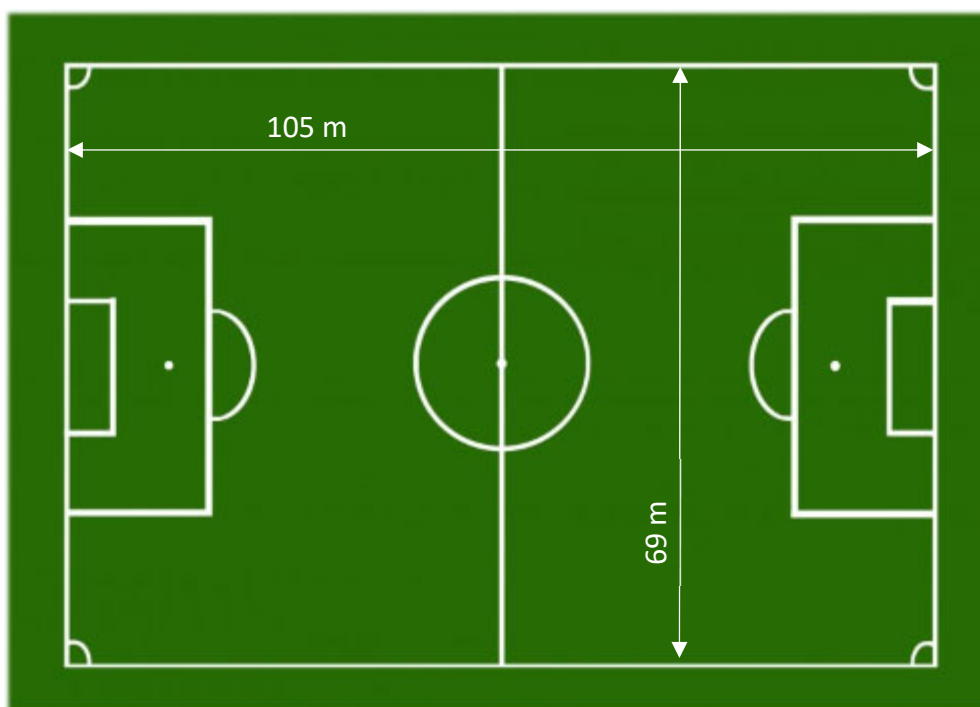


Fig. 2a. Dimensions of the studied football fields

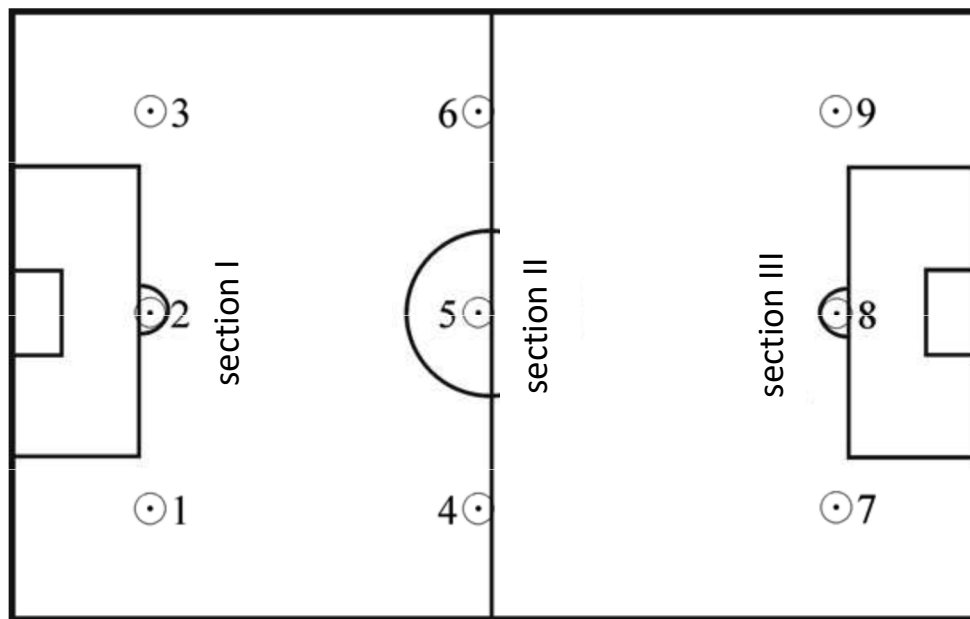


Fig. 2b. Distribution of sampling points

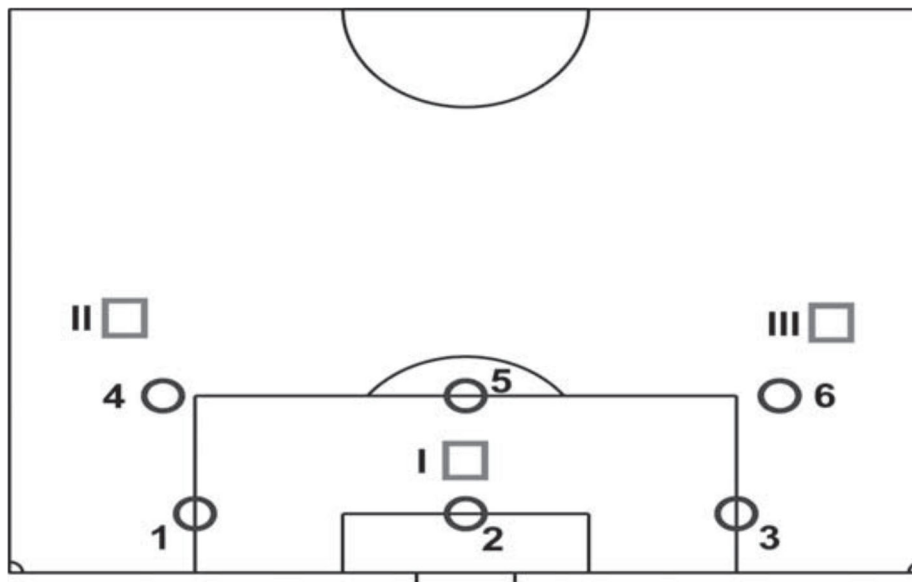


Fig. 3. Location permeability measurement points (I, II, III) and samples carrying layer and drainage layer

Samples with an intact structure of up to 18 rings with a diameter of 53 mm and a capacity of 100 cm³ for physical and water determinations were taken in 3 repetitions. The infiltration course was determined from the relationship by (Ostromęcki 1964). The properties of soil material were determined under the methodology recommended by Pisarczyk (2001), Myślińska (1998), Ostrowska et al. (1991), Bednarek et al. (2004) and following the operating instructions (09.02 laboratory permeameters), Operating instructions for 5 and 15 bar). Porosity was calculated based on volumetric density determined by the gravimetric method and specific density determined by the pycnometric method. The filtration coefficient K_f was determined in an Eijkelkamp laboratory permeability meter (Operating instructions 09.02 laboratories permeameters). Before measuring the filtration coefficient, the samples were saturated to full water capacity by gradually increasing the water level in the main tank.

3. Results and Discussion

Levelling measurements showed the correct shape of the football fields under study. They had a slight gradient towards side-lines, and there were no surface irregularities greater than ± 20 mm, which is within the standard (DIN 18035). The gradient of grass turf of all the football fields allowed water to move from the turf surface into the depth of its profile. The gradient was approx. 0.5%. Regarding granulometric composition, materials building the base and drainage layers did not differ much (Table 1). The composite forming the base

layer showed (Polish Standard 1998a) the granulometric composition of light loamy sand (pgl) light clay (gl), and medium clay (gs) with the content of 65% to 91% of the 2.00 – 0.5 mm fraction, while sand content in the drainage layer was slightly higher and ranged from 62% to 98% of this fraction. Dust content in the base layer ranged from 2% (profile no. 1) up to 8% (profile no. 3). In the drainage layer up to 8% (profile no. 2 and 3), colloidal clay content was 2% to 17% and 0% to 17%, respectively (profile no. 3). The key to the proper functioning of the vegetation layer (base layer) is its proper grain-size distribution. It determines permeability, stability, and other physical parameters, i.e., water capacity. The German standard indicates soil that allows the share of clay and dusty fractions in the range of 5 to 16%. The base layer of grass turf (vegetation layer, also called root zone) should be mineral soil with specific parameters. Poland does not have recommendations regarding the soil that should be used for the vegetation layer, so we use German recommendations and guidelines specified in DIN 18035-4.

The German standard quite precisely indicates the key root zone parameters, including soil grain size distribution, i.e., the content of individual fractions – clay, dust, sand, gravel and stone, water capacity and water permeability i.e., water velocity, organic matter content, pH (soil), the recommended thickness of the vegetation layer. Differentiating the granulometric composition and, consequently, other properties of both layers should be intentional. It is conditioned by its different functions: the base layer provides retention and filtration; the drainage layer is limited to conduction only. These functions were fulfilled by adding an appropriate amount of finer-grained native humic soil to sand – the basic building material of the base layer. The base layer of all the examined football fields was made of grass seeds in the amount of 25 g·m⁻², a sports mixture dedicated to intensive use, composed of 60% meadow grass and 40% perennial ryegrass. The mixture contained at least 4 varieties of bluegrass and min. 3 varieties of perennial ryegrass. It was characterised by 6.0-7.2 pH, measured in H₂O. The grain size curve was consistent with DIN 18035-4 recommendations, and the organic matter content should be 1-3%. As seen from the above, all the football fields under study have properly selected composites and the right proportions between the base and drainage layers are maintained. In the created layers, the humus content was at the level of the standard limit (Deutsche Norm 1991), which, as can be seen from the detailed soil research, was used in the construction of the base layer. It was still higher than in the drainage layer (Table 1).

A high content of the finest fractions means that water can be retained at the humus level. As the permeability measurements showed, due to the good permeability of the substrate level (Table 2), water can seep into the underlying layers. It is not favourable to the local accumulation of water on the football fields. The marked averages for 3 measuring points for measuring the infiltration value in the base layer (football field no. 1) were 0.23 mm·min⁻¹ and were lower than the normative value for this layer (0.3 mm·min⁻¹ according to DIN 18035). Similarly, it was over 4 times lower than recommended for moisture, corresponding to 60% of the maximum capillary saturation of the mixture (composite) (1.0 mm·min⁻¹) (DIN 18 035).

The filtration coefficient K_{10} at the humus level was 41 mm·min⁻¹ on average and 123 mm·min⁻¹ at the drainage level (sub-arable level) (Table 2). Meanwhile, the permissible normative value of this indicator for a base layer of the football field, at full saturation, should not be less than 0.3 mm·min⁻¹, and for a drainage layer, it should range from 3.0 to 30 mm·min⁻¹ (Deutsche Norm 1991). According to the guidelines of DIN 18035, a base layer of the football field covered with grass not only takes the dynamic load during the game and stays durable and consistent but also ensures adequate permeability, limiting the stagnation of water on the surface during irrigation of the football field or, more importantly, after heavy rainfall (Rajda et al. 2011). Water absorption into the football field surface should result from the intensity of heavy rain calculated for a given region with the assumed duration and probability of occurrence. Calculated by the Lambor formula (Byczkowski 1996), the intensity of torrential rain, with probability $p = 10\%$ and duration $t = 15$ minutes, for Lubuskie and Wielkopolskie voivodships between 1971-2022, with average annual precipitation from 500 to 550 mm, is 98 mm·h⁻¹ (0.098 m³·m⁻²·h⁻¹) on average. Within 15 minutes, this gives a volume of 0.0246 m³·m⁻² and corresponds to precipitation of 24.6 mm (The Polish Atlas of Rains Intensities – PANDA)). Assuming that for the infiltration starting at the onset of such rain, it will permeate twice as long as it lasts, the required average infiltration rate would be 0.0246 m³·m⁻²: 30 = 0.00082 m³·m⁻² min⁻¹ (0.82 mm·min⁻¹). It would be 0.00041 m³·m⁻²·min⁻¹ (0.41 mm·min⁻¹) for one hour. It is almost twice the infiltration rate measured in the base layer of the football field no. 1 (Table 2). The average infiltration time of this precipitation at this infiltration rate would be 2 hours.

These small differences in physical properties also resulted in small differences in the retention capacity of the two layers. The base layer's desirable, greater retention capacity in relation to the drainage layer favours the accumulation of water reserves provided from precipitation or supplied during irrigation.

The tested topsoil layers forming the base and drainage levels of the football fields are characterised by good retention capacity (Table 3). At the base levels (with 15 cm thickness), approx. 13 mm of generally

available water can be retained, and at the filtration level, it can be approx. $3 \text{ cm}^3 \cdot \text{cm}^{-3}$ (30 mm) on average. The hardly available water reserve was only $0.22 \text{ cm}^3 \cdot \text{cm}^{-3}$ (2.2 mm) and $0.10 \text{ cm}^3 \cdot \text{cm}^{-3}$ (1.0 mm).

Calculations show that moisture content in the base layer, at field water capacity, ranged from 14.0% (football field no. 1) to 16.2% (football field no. 3) on average, and its analogous values for the drainage layer averaged from 4.7% (football field no. 1) to 5.9% (football field no. 2). Moisture content in the drought period averaged from 8.4% (football field no. 2) to 9.7% (football field no. 1) for the base layer and averaged from 2.9% (football field no. 1) to 4.6% (football field no. 2) for the drainage layer (Table 3). The moisture content of permanent wilt for the base layer ranged on average from 6.8% (football field no. 1) to 7.4% (football field no. 2 and 3), and for the drainage layer, on average from 2% (football field no. 1) to 4.7% (football field no. 3).

Table 1. Granulometric composition of the 3 football fields: carrying layer 0-15 cm and drainage layer 15-30 cm

No of sampling point	Layer (cm)	Percentage fraction content (mm)					Density dry bulk ($\text{g} \cdot \text{cm}^{-2}$)	Humus (%)	Quality soil	
		sand		dust	silt	clay			PTG	USDA
		2.0-0.05	0.05-0.02	0.02-0.01	0.005-0.002	< 0.002				
typical soil profile of pitch No. 1										
3	0-15	91	2	2	3	2	1.99	0.53	<i>pgl</i>	<i>ls</i>
	15-30	97	0	0	2	1	1.93	0.61	<i>pglp</i>	<i>ls</i>
5	0-15	89	3	3	2	3	1.85	0.79	<i>ps</i>	<i>ls</i>
	15-30	98	0	0	2	0	1.95	0.55	<i>pgl</i>	<i>ls</i>
7	0-15	92	0	4	2	2	1.85	0.69	<i>pglp</i>	<i>sl</i>
	15-30	96	1	2	1	0	1.84	0.73	<i>ps</i>	<i>ls</i>
typical soil profile of pitch No. 2										
3	0-15	74	7	6	3	10	1.87	0.85	<i>gl</i>	<i>sl</i>
	15-30	77	5	6	3	9	1.79	0.76	<i>gl</i>	<i>sl</i>
5	0-15	71	7	7	5	10	1.7	0.8	<i>gl</i>	<i>sl</i>
	15-30	72	9	5	4	10	1.59	0.93	<i>gl</i>	<i>sl</i>
7	0-15	80	4	4	3	9	1.83	0.71	<i>pgm</i>	<i>sl</i>
	15-30	62	7	8	6	17	1.59	1.59	<i>gs</i>	<i>scl</i>
typical soil profile of pitch No. 3										
3	0-15	65	5	8	5	17	1.98	2.09	<i>gs</i>	<i>scl</i>
	15-30	81	3	5	4	7	1.84	0.79	<i>pgm</i>	<i>sl</i>
5	0-15	71	7	7	5	10	1.87	0.82	<i>gl</i>	<i>sl</i>
	15-30	72	9	5	4	10	1.69	0.7	<i>gl</i>	<i>sl</i>
7	0-15	80	4	4	3	9	1.74	0.84	<i>pgm</i>	<i>sl</i>
	15-30	62	7	8	6	17	1.88	1.28	<i>gs</i>	<i>scl</i>

Table 2. Mean for 3 replications average speed in the field of infiltration (in time 0-t) and coefficients of permeability K_{10}

No of sampling point	Level [cm]	Average infiltration speed [$\text{mm} \cdot \text{min}^{-1}$]	Permeability coefficient K_{10} [$\text{mm} \cdot \text{min}^{-1}$]
3	0-15	0.223	49.5
	15-30	0.134	132.5
5	0-15	0.197	24.5
	15-30	0.125	116.6
7	0-15	0.268	47.7
	15-30	0.167	118.9
Average infiltration for the point: I-III	0-15	0.230	41.0
	15-30	0.142	123.0

Table 3. Characteristic states of humidity, humidity reserves and irrigation doses (netto)

Profile number	Layer (cm)	percentage water content at			percentage content of accessible water			accessible water reserve and doses (mm)					
		W_{PPW}	W_{PS}	W_{TW}	general W_{OD}	easy W_{LD}	hardly W_{TW}	general Z_{OD} (mm)		easy Z_{LD} (mm)		hardly Z_{DT} (mm)	
		field water capacity pF = 2,5	drought period humidity pF = 3,7	drought of lasting wilting pF = 4,2	$W_{PPW}-W_{TW}$	$W_{PPW}-W_{PS}$	$W_{PS}-W_{TW}$		0-30 cm		0-30 cm		0-30 cm
profile Number No. 1													
1	0-15	11.4	7.6	7.2	4.2	3.8	0.4	6.3		5.7		0.6	
	15-30	4.8	3.2	2.0	2.8	1.6	1.2	4.2	11	2.4	8	1.8	2
2	0-15	12.8	9.0	6.9	5.9	3.8	2.1	8.9		5.7		3.2	
	15-30	4.2	3.0	2.3	1.9	1.2	0.7	2.9	12	1.8	8	1.1	4
3	0-15	13.7	8.2	6.8	6.9	5.5	1.4	10.4		8.3		2.1	
	15-30	4.3	3.3	2.2	2.1	1.0	1.1	3.2	14	1.5	10	1.7	4
4	0-15	17.0	10.0	7.0	10.0	7.0	3.0	15		11		4.5	
	15-30	5.8	3.0	2.0	3.8	2.8	1.0	5.7	16	4.2	15	1.5	6
5	0-15	13.7	8.8	6.8	6.9	4.9	2.0	10.4		7.4		3	
	15-30	5.3	3.2	2.2	3.1	2.1	1.0	4.7	15	3.2	11	1.5	5
6	0-15	13.5	8.8	6.3	7.2	4.7	2.5	10.8		7.1		3.8	
	15-30	4.8	3.0	2.2	2.6	1.8	0.8	3.9	15	2.7	10	1.2	5
7	0-15	14.7	8.5	7.2	7.5	6.2	1.3	11.3		9.3		2	
	15-30	5.1	2.5	2.1	3.0	2.6	0.4	4.5	16	3.9	13	0.6	3
8	0-15	15.0	9.0	6.7	8.3	6.0	2.3	12.5		9		3.5	
	15-30	4.3	2.8	1.9	2.4	1.5	0.9	3.6	16	2.3	11	1.4	5
9	0-15	14.9	8.8	6.5	8.4	6.1	2.3	12.6		9.2		3.5	
	15-30	4.0	2.0	1.2	2.8	2.0	0.8	4.2	17	3	12	1.2	5
mean	0-15	14.0	9.7	7.0	7.3	5.3	2.0	10.9		8		2.9	
	15-30	4.7	2.9	2.0	2.7	1.8	1.0	4.1	15	2.8	11	1.3	4
profile Number No. 2													
1	0-15	14.5	8.8	6.8	7.7	5.7	2	11.6		8.6		3	
	15-30	5.7	3.5	2.9	2.8	2.2	0.6	4.2	16	3.3	12	0.9	4
2	0-15	15.3	7.8	7.2	8.1	7.5	0.6	12.2		11		0.9	
	15-30	5.9	4.3	3.8	2.1	1.6	0.5	3.2	15	2.4	14	0.8	2
3	0-15	15.9	7.7	7.8	8.1	8.2	0	12.2		12		0	
	15-30	6.1	4.9	5.2	0.9	1.2	0	1.4	14	1.8	14	0	0
4	0-15	16	8.5	7.2	8.8	7.5	1.3	13.2		11		2	
	15-30	5.5	4	3.8	1.7	1.5	0.2	2.6	16	2.3	14	0.3	2
5	0-15	16.3	8.1	7	9.3	8.2	1.1	14		12		1.7	
	15-30	5.8	4.9	5.8	0	0.9	0	0	14	1.4	14	0	2
6	0-15	16.8	8.9	7.9	8.9	7.9	1	13.4		12		1.5	
	15-30	6.6	5	4.8	1.8	1.6	0.2	2.7	16	2.4	14	0.3	2
7	0-15	16.9	8.2	6.8	10.1	8.7	1.4	15.2		13		2.1	
	15-30	6.2	5.6	5.9	0.3	0.6	0	0.5	16	0.9	14	0	2
8	0-15	17.2	8.5	7.6	9.6	8.7	0.9	14.4		13		1.4	
	15-30	5.6	5	4.9	0.7	0.6	0.1	1.1	16	0.9	14	0.2	2
9	0-15	17	9.1	7.9	9.1	7.9	1.2	13.7		12		1.8	
	15-30	6	4.1	5.9	0.1	1.9	0	0.2	14	2.9	15	0	2
mean	0-15	16.1	8.4	7.4	8.9	7.8	1	13.3		12		1.6	
	15-30	5.9	4.6	4.7	1.2	1.3	0.2	1.3	15	2	14	0.3	2
profile Number No. 3													
1	0-15	15.7	9.5	8.1	7.6	6.2	1.4	11.4		9.3		2.1	
	15-30	5.1	2.5	2.1	3	2.6	0.4	4.5	16	3.9	13	0.6	3
2	0-15	15.5	10	7.7	7.8	5.5	2.3	11.7		8.3		3.5	
	15-30	6	3.7	2.8	3.2	2.3	0.9	4.8	17	3.5	12	1.4	5
3	0-15	16	8.8	7.9	8.1	7.2	0.9	12.2		11		1.4	
	15-30	5.5	3.7	3.5	2	1.8	0.2	3	15	2.7	14	0.3	2
4	0-15	16.7	8.5	7.3	9.4	8.2	1.2	14.1		12		1.8	
	15-30	6	5.5	3.4	2.6	0.5	2.1	3.9	18	0.8	13	3.2	5
5	0-15	16.8	9.1	7.7	9.1	7.7	1.4	13.7		12		1.7	
	15-30	5.8	5	4.2	1.6	0.8	0.8	2.4	16	1.2	13	1.2	3
6	0-15	15.8	7.9	6.9	8.9	7.9	1	13.4		12		1.5	
	15-30	4.8	4.6	3.5	1.3	0.2	1.1	2	15	0.3	12	1.7	3
7	0-15	16	8.3	7.9	8.1	7.7	0.4	12.2		12		0.6	
	15-30	5.1	4.2	3.4	1.7	0.9	0.8	2.6	15	1.4	13	1.2	2
8	0-15	16.7	8.5	6.6	10.1	8.2	1.9	15.2		12		2.9	
	15-30	6	5.3	3.8	2.2	0.7	1.5	3.3	19	1.1	13	2.3	5
9	0-15	16.9	8.3	6.2	10.7	8.6	2.1	16.1		13		3.2	
	15-30	5.9	4.9	3.7	2.2	1	1.2	3.3	19	1.5	14	1.8	5
mean	0-15	16.2	8.8	7.4	8.9	7.5	1.4	13.3		11		2.1	
	15-30	5.6	5.6	3.4	2.1	1.2	1	3.3	17	1.8	13	1.5	4

The average percentages of generally available, easily available, and hardly available water calculated on this basis were: for W_{OD} from 7.3% to 8.9%, for W_{LD} from 5.3% to 7.8% and for W_{TD} from 1% to 2% of the volume for the base layer and from 1.2% to 2.7% of the volume (W_{OD}) for the drainage layer (Table 3). Hence, the calculated water reserves in the base layer (0-15 cm) were on average (depending on the water availability) for three football fields for moisture content corresponding to W_{OD} 12.5 mm, W_{LD} 10.3 mm on average and W_{TD} approx. 2.2 mm. Considering the drainage layer, which similarly can retain an average 3.0 mm (W_{AD}), 2.2 mm (W_{LD}) and 1.0 mm (W_{TD}), the grass turf of three football fields potentially has, in a decreasing system of availability, the water reserve in the 0-30 cm layer (base and drainage) on average: 15.4 mm (W_{OD}), 12.5 mm (W_{LD}) and 3.2 mm (W_{TD}).

Calculations presented in Table 3 show that under comfortable conditions of water availability (W_{LD}), the base layer can retain, depending on the football field, from 8.0 mm (football field no. 1) to 11.8 mm (football field no. 2), 10.3 mm of water averagely. Therefore, this is the average value of a single irrigation dose net that should be used for sprinkler irrigation of grass turf of the analysed sports fields. However, considering the drainage layer, this dose under the same conditions (W_{LD}) can be increased by 2.2 mm to 12.5 mm. While specifying the retention capacity of both layers of the football fields, it was found that the effective usable retention of soil (ERU) ranged from 10.3 mm (football field no. 1) to 13.8 mm (football field no. 2) – 12.5 mm on average. On the other hand, the value of potential usable retention (PRU) ranged from 14.6 mm (football field no. 2) to 16.6 mm (football field no. 3), 15.4 mm on average.

Considering the percentage of generally available water (W_{OD}) and assuming less comfortable conditions of water availability, the appropriate irrigation doses net would average 12.5 mm during the irrigation of the base layer. On the other hand, for both layers, the average value would be 15.4 mm. Considering the surface of each football field within its playing area (120 m x 90 m) equal to 10800 m², the volume of water needed for one single irrigation of the base layers, determining the cost of single irrigation, would be 111 m³ in comfortable conditions (Z_{LD}), and in less comfortable conditions (Z_{OD}) 135 m³. Regarding the retention capacity of the filtration layer (drainage), the corresponding volumes of water for one-time sprinkling of each football field would be 135 m³ and 166 m³, respectively. The irrigation system in the form of sprinkling allows for economical and effective irrigation of grass turf. The calculated irrigation doses will affect grass vegetation, directly providing water necessary for its growing and indirectly influencing the good development of root systems. In addition to irrigation doses, the main factors affecting the amount and frequency of irrigation are temperature and climate. Water consumption should be considered depending on the temperature during the growing season, which ranges from 2 mm to 5 mm, at air temperature from 20°C to 30°C. Intervals between watering should also be maintained from 14 days (at 20°C) to 7 days (at 30°C). The total irrigation dose also depends on the climatic conditions, where for a zone with moderate amounts of precipitation, it should range from 75 to 150 mm·year⁻¹.

4. Conclusions

The paper presents a detailed analysis of physical and water properties, including water potential, determining the availability of soil water and retention capacity of artificially shaped soil formations to build the top layers of football fields. Another equally important parameter for facilities of this type determining their proper use and maintenance is the permeability of the base layer. Permeability – with sufficiently large water capacity is important for irrigation – should guarantee the conduction of excess rainwater from the surface of the football field to the drainage layer. All the football fields tested met the condition that after excessive rainfall, they would be ready for use quickly. As a result of the research, a single irrigation dose net was determined, the proper use of which ensures the maintenance of grass turf in proper condition. At the same time, the layers that build the football fields are characterised by good retention capacity.

It was found that the base layer 15 cm thick can – in comfortable water availability conditions for grass – maintains an irrigation dose net of 10.3 mm. The football field area for direct play gives a volume of 111 m³. Lower water comfort availability can increase an irrigation dose net to 12.5 mm and 135 m³, respectively. In rainless periods, in conditions conducive to evaporation, grass turf would require irrigation every 3-4 days, depending on its assumed water comfort.

To ensure high requirements related to sports functions (i.e., strength, durability, traction, playing experience and appearance), the natural grass surfaces of football fields should meet the German standard DIN 18 035-5 requirements. The problem is that this standard does not have the status of a European norm (EN) and does not constitute a legal interpretation in the territory of the Republic of Poland. However, it is successfully widely used here. The study confirmed that DIN 18035 should be observed and applied when building new or renovating existing football fields. It applies in particular to constructing their base layers so that the grain size distribution is close to the standard one. Water permeability should always be verified and confronted with the permissible infiltration rate resulting from the intensity of torrential rain in a given region so that the assumed infiltration time of precipitation or meltwater is as short as possible.

References

- Adams, W.A. (1996). Recommendations on the construction, upgrading and maintenance of natural turf pitches for winter games. *Natural Turf Pitch Prototypes Advisory Panel Report No. 11*, Sports Council.
- Bednarek, R., Dziadowiec, H., Pokojaska, U., Prusinkiewicz, Z. (2004). *Badania ekologiczno-gleboznawcze*. Wyd. Naukowe PWN, Warszawa. (in Polish)
- Byczkowski, A. (1996). *Hydrologia*. T. II. Wydawnictwo SGGW, Warszawa. (in Polish)
- Deutsche Norm (1991). *DIN 18035*, 4. Sportplätze. Rasenflächen, Teil 4.
- Drozd, J., Licznar, M., Licznar, S.E., Weber, J. (1998). *Gleboznawstwo z elementami mineralogii i petrografii*. Wyd. AR we Wrocławiu, 124-126. (in Polish)
- Głąb, T., Gondek, K. (2013). The Influence of Soil Compaction on Chemical Properties of Mollic Fluvisol Soil under Lucerne (*Medicago sativa* L.). *Polish Journal of Environmental Studies*, 22(1), 107-113.
- Guidelines Regarding preparation and proper maintenance Stadium turf. Version 2017/2018*. Ekstraklasa S.A., Warsaw. (2019). (in Polish)
- James, I.T., Blackburn, D.W.K., Godwin, R.J. (2007b). Mole drainage as an alternative to sand slitting in natural turf sports surfaces on clays. *Soil Use and Management*, 23, 28-35.
- James, I.T., Hann, M.J., Godwin, R.J., James, I.T., Hann, M.J., Penn, A., Godwin, R.J., Dresser, M.L. (2007a). Minimisation of leg-slot expansion in mole-drained sports surfaces. *Biosystems Engineering*, 97, 109-116.
- Kowalik, T., Rajda, W. (2013). Jak zbudować płytę boiska piłkarskiego o trawiastym poroście – Część I: Badanie przydatności gruntu rodzimego do budowy płyty boiska. *Infrastruktura i Ekologia Terenów Wiejskich*, 1/IV, 271-284. (in Polish)
- Licznar, P., Zaleski, J. (2020). *Metodyka opracowania polskiego atlasu natężeń deszczów (Panda)*. Wyd. Instytut Meteorologii i Gospodarki Wodnej, Państwowy Instytut Badawczy Warszawa. 139. 15.08.2023. Available at: <https://atlaspanda.pl>, <https://retencja.pl/aplikacje/panda/>
- Milivojević, J., Nikezić, D., Krstić, D., Jelić, M., Đalović, I. (2011). Influence of Physical-Chemical Characteristics of Soil on Zinc Distribution and Availability for Plants in Vertisols of Serbia. *Polish Journal of Environmental Studies*, 20(4), 993-1000.
- Myślińska, E. (2001). *Laboratoryjne badania gruntów*. Wydanie II, zmienione i rozszerzone. PWN, Warszawa. (in Polish)
- Oleszczuk, R., Truba, M. (2013). *The analysis of some physical properties of drained peat-moorsh soil Layers*. *Annals of Warsaw University of Life Sciences – SGGW, Land Reclamation*, 45(1), 41-48.
- Operating instructions 09.02 laboratorium permeameters (1999). Available at: <http://pkd.eijkelkamp.com/Portals/2/Eijkelkamp/Files/Manuals/M10902e%20Lab-permeameters.pdf> (in Polish)
- Operating instructions of pressure extractors 5 and 15-bar (no. cat. 08.25.07, 08.25.01). Available at: <http://pkd.eijkelkamp.com/Portals/2/Eijkelkamp/Files/P1-81e.pdf>
- Ostromęcki, J. (1964). *Wstęp do melioracji rolnych*. PWRiL, Warszawa, 162-165. (in Polish)
- Ostrowska, A., Gawliński, S., Szczubiałka, Z. (1991). *Metody analizy i oceny właściwości gleb i roślin*. Instytut Ochrony Środowiska, Warszawa. (in Polish)
- Pereira, J.O., Défossez, P., Richard, G. (2007). Soil susceptibility to compaction by wheeling as a function of some properties of a silty soil as affected by the tillage system. *European Journal of Soil Science*, 58(1), 34-44.
- Piotrowski, M., Szyszkowski, P., Wolski, K. (2006). *Ocena składu gatunkowego pokrywy rekultywacyjnej składowiska odpadów komunalnych Żerniki we Wrocławiu*. Zesz. Nauk. UP Wrocław, Rolnictwo LXXXVIII, 545, 211-219. (in Polish)
- Pisarczyk, S. (2001). *Gruntoznawstwo inżynierskie*. PWN, Warszawa. (in Polish)
- Płaskowska, E., Wolski, K., Moszczyńska, E., Zacharkiewicz-Witan, K. (2006). *Ocena zdrowotności intensywnie użytkowanych muraw piłkarskich*. Zesz. Nauk. UP Wrocław, Rolnictwo LXXXVIII, 545, 221-227. (in Polish)
- PN-ISO-11464. (1999). *Wstępne przygotowanie próbek do badań fizyczno-chemicznych*. (in Polish)
- PN-R-04031. (1997). *Analiza chemiczno-rolnicza gleby. Pobieranie próbek*. (in Polish)
- PN-R-04032. (1998a). *Gleby i utwory mineralne. Pobieranie próbek i oznaczanie składu granulometrycznego*. (in Polish)
- PN-R-04033. (1998b). *Gleby i utwory mineralne. Podział na frakcje i grupy granulometryczne*. (in Polish)
- Policht-Latawiec, A. (2008). Badanie wodoprzepuszczalności kompozytów gleby pyłowo-ilastej, piasku i substratu torfowego. *Acta Scientiarum Polonorum, Formatio Circumiectus*, 7(4), 21-30. (in Polish)
- Rajda, W., Kanownik, W. (2006). Retencja użyteczna warstwy nośnej i drenażowej płyty boiska do piłki nożnej. *Acta Sci. Pol., Architektura*, 5(2), 65-74. (in Polish)
- Rajda, W., Stachura, T., Żarnowiec, W. (2011a). Własności fizyczne i przesiąkliwość kompozytu warstwy nośnej i piasku warstwy drenażowej płyty boiska Wisły Kraków S.A. po przebudowie w 2004 r. *Acta Sci. Pol., Architektura*, 10(1), 31-41. (in Polish)
- Rajda, W., Żarnowiec, W., Stachura, T. (2011b). Własności fizyczne i przesiąkliwość płyty boiska TS Wisła Kraków S.A. po renowacji. *Przegląd Naukowy Inżynierii i Kształtowania Środowiska*, 20(2), 153-159. (in Polish)
- Święcicki, Cz. (1981). *Gleboznawstwo melioracyjne*. PWN, Warszawa, 150-157. (in Polish)
- Wirszyla, R. (1966). *Urządzenia sportowe. Projektowanie i budowa*. Arkady, Warszawa. (in Polish)
- Zawadzki, S. (2002). *Podstawy gleboznawstwa*. PWRiL, Warszawa. (in Polish)
- Żegocińska-Tyżuk, B. (1988). *Terenowe urządzenia sportowo-rekreacyjne*. Wyd. Politechnika Krakowska, Kraków. (in Polish)