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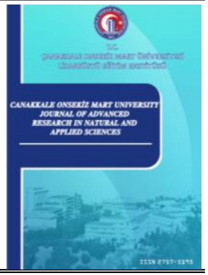

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Assessing Drainage Performance of Turfgrass Rootzone in Sports Fields

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Abstract − Sports fields are used by many national and international organizations worldwide. For this reason, carefully studying the hydraulic and mechanical properties of sports field surfaces is a major engineering concern. This study aimed to increase sports turf's resilience and determine the mixing ratios and fertilizer doses in the rootzone in order to enable effective water drainage. In the field test, the mixture of 3 different soils (100% sand; 10% mixture + 90% sand; 20% mixture + 80% sand) was used for the mix of 70% ryegrass (Lolium perenne L.) and 30% bluegrass (Poa pratensis L.) in baskets with a size of 1.3 x 0.5 x 0.20 m. Moreover, the turfgrasses were grown through the application of two different doses (2.5 ml (A) and 3.0 ml (B)) of liquid humic acid named Run/Black Jak in addition to basic fertilization of 18-22-0 (slow-release fertilizer) + Nu Film spreader-sticker + 26-05-11 (slow-release fertilizer) + 9-9-9 (slow-release fertilizer containing +9% Fe). It was observed that 2 cm layer was formed under the turfgrass in rootzones with 80% sand + 20% sitl+clay mixture by slowing water drainage and negatively affecting infiltration, making it unsuitable for sports fields. Penetration, infiltration, and vane shear tests were performed, and it was determined that the best rootzone in terms of hydraulic and mechanical surface properties was the rootzone treatment formed with 10% silt-clay-organic mixture + 90% sand mixture.

Keywords − *Sports field, rootzone, turfgrass, fertilizer, drainage*

1. Introduction

Football is one of the sports branches that interests people of all ages, which is very important in health, economy, and prestige. Contact of the turf with air causes them to be significantly affected by environmental conditions such as precipitation, temperature, and humidity [1]. The surfaces of the pitches must be sufficiently smooth and durable to maintain the enjoyment of the game, prevent injuries to players, and maintain the quality of the game at its highest level. Moreover, the fields meet in the design phase the conditions such as homogeneity and vividness of turfgrass, in addition to technical conditions for the bouncing and rolling the ball [2]. Therefore, lack of clear arrangements in the design of field surfaces, abrasion of turfgrass due to unsuccessful design and building processes, surface imbalance, and drainage problems are frequently encountered.

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There are various layered sections developed for sports fields, such as pipe drains, suspended water table drainage, sand grooving, and sand slit drainage [3]. Despite different designs, these systems generally consist of gravel, sand, rootzone (sand + silt-clay-organic substance), and turfgrass from bottom to top (Figure 1). The evaluation of the turfgrass species and rootzone mixture to be employed, as well as the precipitation characteristics of the relevant region, are essential factors in preventing accumulations on field surfaces and creating continuous playgrounds [4]. In the case of short-term severe precipitation, draining water amount and turfgrass abrasion increase, and surface resistance decreases. On behalf of to prevent this situation, it is aimed to prevent the formation of accumulation on the field surfaces and to protect the mechanical properties of the grass and rootzone by developing sand channeling and sand slit drainage systems. In addition, the use of fast-growing turfgrass resistant to stepping by means of high sand content should be considered in the design phase for the regions characterized by severe precipitation.

Turfgrass covers the soil surface, grows in a thick manner, forms a dense pattern with intense rooting, has a homogeneous appearance, and requires low nutrition and water by being kept short. It is the name given to green field surfaces that do not hinder the movement on them [5]. The turfgrass, which is in direct contact with factors such as precipitation and temperature due to its positioning on top of the field, is critical in meeting the game's requirements and enabling the exhibition of sportspersons' skills at their maximum level. It is necessary to perform optimal turfgrass selection by considering parameters such as climatic conditions, intensity and duration of rainfall in the area where the field will be built, and frequency of field usage [6]. High temperatures slow turfgrass growth and cause downsizing, wear, and curling of leaf blades [7]. Moreover, darkening and a reduction in the development of leaves are observed. It is impossible to eliminate such effects of temperature, but growing species resistant to temperature, keeping the soil moisture at an optimum level, and performing irrigation, especially during midday at high temperatures, are among the preventive measures. Turfgrass obtains the water that it requires to be healthy and to grow via the roots in the rootzone (sand + silt-clay-organic substance) present in the lower layer. Rootzone is the section that is present right under the surface of turfgrass, which generally has a height of 15-30 cm and consists of a mixture of sand (~90%) and a slight silt-clay-organic substance (~10%) [8]. During the preparation of the sand and silt-clay-organic substance mixture, it should be considered to have sufficient water content for both effective and rapid drainage and the wellness of turfgrass. Considering these two parameters, the preparation requirement of 90% sand and 10% silt-clay-organic substance mixture may be stated [9]. The interaction of rootzone and turfgrass and the obtainment of water from the rootzone through root growth for the turfgrass's wellness are essential regarding surface hardness and color, tolerance against abrasion, and slip resistance [10].

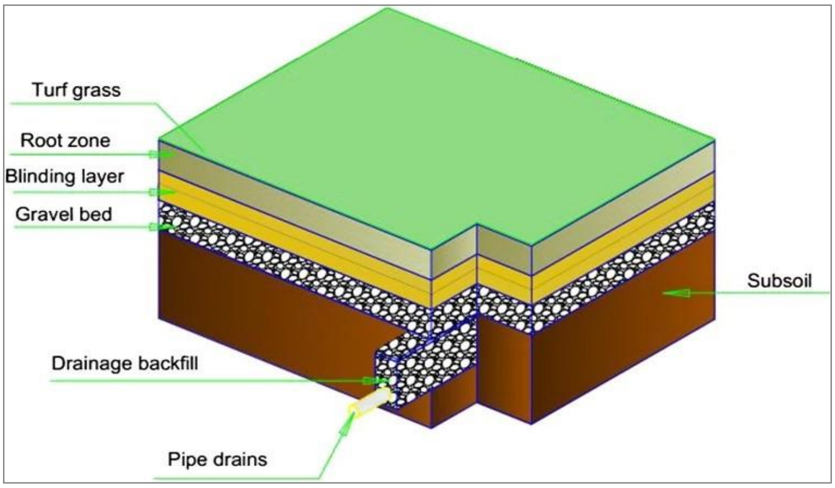


Figure 1. General systematic of three-layered drainage systems [6]

Studies are performed in the literature on different turfgrass species used at sports fields and the rootzone, the most significant drainage layer. However, the studies conducted to determine the interaction between these two layers and of optimum design are very limited. In the scope of the study, it was intended to select the turfgrass species to be used at sports fields that attract large audiences and have international economic importance, and to determine the soil and turfgrass mixture and fertilizer dose that will ensure the optimum conditions. To examine the interaction of turfgrass with rootzone, penetration, infiltration, and Vane shear tests were performed, and the infiltration and hardness conditions of the ground and the resistance of turfgrass were tested. Moreover, it was intended to determine the turfgrass and rootzone mixture and its design, which will decrease the injury risks that arise due to field surface conditions and which will prevent infiltration and drainage problems in terms of maximization of game quality (bouncing and rolling of ball) and exhibition of players' skills (sprint, spin, and shoot).

2. Materials and Methods

2.1. Turfgrass and Rootzone

The natural turfgrass surfaces of sports fields consist of plants that grow in the soil's rootzone, and they are selected considering their abrasion, resistance, and temperature tolerance [11]. The turfgrass species are frequently used at sports fields and their characteristics are given in Table 1.

Table 1. Turfgrass species frequently used at sports fields, and their characteristics [12]

Species	Growth Rate	Fertilizer Requirement	Germination Period (days)
Lolium Perenne	Fast	Medium	4 - 10
Festuca Rubra	Medium	Low	7 - 15
Festuca Arundinacea	Medium	Medium	7-15
Poa Pratensis	Slow	High	12 - 21
Agrostis Tenuis	Medium	High	12 - 18

The height of turfgrass for the quality fields where high-level competitions are performed varies between 18 and 50 mm depending on the maintenance and type of sports [13]. For the growth of natural turfgrass, it is required to adjust to various conditions, such as sunlight, rainwater, and slight wind, in a proper and balanced manner. Negative weather conditions and extreme climates significantly affect the football fields. Therefore, nearly all the companies dealing with this business intend to be able to tackle hard conditions through various methods such as various mixtures of soil types, different fertilizer preferences, and integration of artificial turfgrass and natural turfgrass through new technologies. For this reason, the characteristics of turfgrass to be used on fields, their mixture, and their mutual effects should be analyzed in detail. [14] performed with the use of seven Randall grass (Festuca arundinacea) species and one ryegrass (Lolium perenne L.) species, emphasized that Lolium perenne L. was more successful in terms of growth rate, cold winter conditions, and textural characteristics and that Festuca arundinacea species were more effective under high temperature and drought conditions. Lolium perenne L. is a plant whose fairly big seeds germinate easily, are erected easily, and which tillers highly [15]. Lolium perenne L. (ryegrass) is used at a high level, either in pure form or in mixtures, due to its characteristics of fast growth, plentitude of leaves, and resistance to being stepped on and trampled. But based on the number of seeds, it is required for the seeds of Lolium perenne L. not to exceed 20-25% in seed mixture. When it is at a higher rate in the seed mixture, it causes a stressing and suffocating effect on thin turfgrass such as Festuca, Poa, and Agrostis due to its fast germination and growth characteristics [16].

Poa pratensis is a plant that forms a dense, fine-textured, dark green, and quality turfgrass cover. Despite its slow germination and growth rate, its rhizomes spread rapidly following erection. Its resistance to cold is very good, but its resistance to drought and shading is weak. It is highly resistant to being stepped on and trampled [17]. Poa pratensis is deemed as a species complementing Lolium perenne L. especially at football fields [16]. Success in the constitution of turfgrass fields depends on the selection of species conforming to the purpose of constitution and the conditions of growth, on the use of quality seed, and continuous maintenance. A good turfgrass field is assessed in terms of color, fast growth in the initial period and then slow growth, resistance against drought, being stepped on and frequent mowing, longevity, spread on the ground, rooting in the soil and on the soil, strong root development, and resistance against diseases. Lolium perenne is frequently highlighted in the literature for its widespread use, primarily due to its leaf tissue characteristics, resilience to damage from usage, and rapid growth traits [18]. Moreover, several studies have indicated that a mixture of Lolium perenne and Poa pratensis effectively maintains a high percentage of grass cover [16, 19]. For these reasons, a mixture of 70% perennial ryegrass (Lolium perenne L.) and 30% Kentucky bluegrass (Poa pratensis L.) was chosen as the turfgrass blend, taking into account the climate data of the study area, Istanbul. These grass species were explicitly selected due to their classification as cool-season plants, making them well-suited for the region's climate.

The rootzone is one of the most significant components due to its functions, such as drainage right under the turfgrass surface, soil resistance, surface hardness, and water supply required by turfgrass [20]. The fields hosting elite-level competitions should have optimum surface hardness, be flexible against impacts, and resist tears. In addition, the formation of water accumulation on the field's surface should be prevented with good drainage [21, 22]. The most significant point in meeting these is the selection of rootzone [9]. Soils with high clay and silt content cause compaction and poor drainage, and it is required to use a high rate of sand in the rootzone to prevent these two negative states. However, soil with 100% sand content will be unable to meet the water required to ensure turfgrass wellness due to its inability to retain water due to extremely high infiltration rates. The rootzone consists of about 90% sand and 10% silt, clay, and organic substances in order to prevent the accumulation of water on the field surface, increase the infiltration rates, prevent the air and water balance, and ensure the stability of the surface [8, 23]. The rootzone determines the mechanical of the field surface’s characteristics, such as the surface's hardness, infiltration state, and shear strength [10]. Surface hardness, apart from the interaction of sportspersons and field surface, is critical regarding game quality and sportspersons' health as it closely concerns game characteristics, such as bouncing and rolling the ball.

Quartz sand (0.4-0.7 mm), commonly used in the drainage of football fields, was selected for the experiments. Sieve analysis tests were conducted to determine the characteristics of the material, including its particle size distribution. Additionally, separate tests were performed to assess the sand's bulk density, porosity, field capacity, and water content, summarized in Table 2.

Table 2. Characteristic properties of quartz sand used in the experiments

Characteristic feature	Value	Characteristic feature	Value
D_{10} (mm)	0.28	Coefficient of Curvature (C_c)	1.38
D_{30} (mm)	0.43	Water content (%)	0.02
D_{50} (mm)	0.48	Bulk density (g/cm^3)	2.65
D_{60} (mm)	0.50	Porosity	0.45
Coefficient of Uniformity (C_u)	1.79	Field capacity (%)	27.95

Clegg hammer test and penetrometers are frequently used in the evaluation of the penetration resistance and hardness of the field. [24], by the use of penetration equipment, found high penetration resistance of the sand-based rootzone compared to different systems such as amended topsoil, undrained section, pipe underdrain, and slit drainage. [25], in his study, he examined the frequency of injuries due to ground hardness, found by the readings with a penetrometer that depths of 3.5 cm and 6 cm were the limit values for hard and soft ground, respectively. [26] emphasized that applying the natural turfgrass surface slip resistance is required for sportspersons wearing crampons, but that high resistance may cause injuries. Both mechanical and bio-mechanical tests indicated that the sand-based sports fields' grounds have higher dynamic rigidity and slip resistance than clay-based grounds [27]. Materials such as silt and clay cause lower slip resistance and higher plastic deformation due to their high-water retention capacities compared to sand-based grounds [11]. Slip resistance and lower water retention capacities of sand-based grounds have caused their usage at high rates (90%) in the rootzone of sports fields. Some technical properties of the mixtures used in the study are given in Table 3.

Table 3. Some technical properties of the experimental materials

Material	pH	Organic content (%)	Silt-Clay (%)	Sand (%)	Class
%100 sand	7.87	0	0	100	Sandy
%90 sand+%10 silt-clay	7.51	0.21	10	90	Sandy loam
%80 sand+%20 silt-clay	2.43	0.36	20	80	Sandy loam

2.2. FIFA Quality Parameters

FIFA (Fédération Internationale de Football Association) has created the FIFA Quality Programme for Football Turf with the goal of creating durable, long-lasting football fields that do not increase the risk of injury to players on both natural and artificial fields. There are three main categories defining the general performance of a surface suitable for football games here are three main categories defining the general performance of a surface suitable for football games. (i) Ground's abrasion resistance and wear (resistance), (ii) Ground's reaction to the game being played on it (ball-surface interaction), (iii) Relationship between the ground and the football player (player-surface interaction).

For a football field to get approval following the determination of its conformity to the above three categories, it is primarily subjected to laboratory tests. The second stage consists of field tests, and the fields successfully passing these two stages get usage approval. FIFA follows the diagram below to obtain usage approval for turfgrass fields to be designed (Figure 2). The fields passing the required standard tests are defined by the FIFA quality (1 star) and FIFA high quality (2 star) marks.

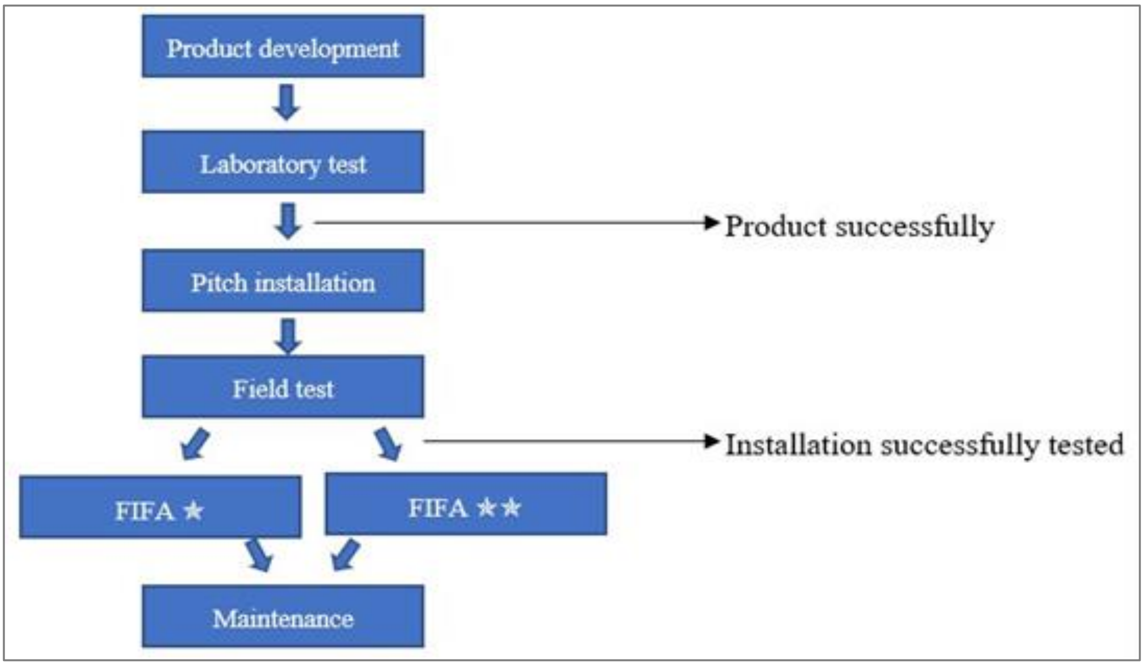


Figure 2. The certification process for football turf pitches [28]

All the football turfgrass fields that desire to host international games are obliged to conform to FIFA's official rules. The fields are classified as 2 starred and 1 starred, respectively, depending on the usage requirements of professionals and the public. The characteristics of materials to be used in the field are extensively tested under laboratory conditions, and after succeeding in the tests, the field is built, and field tests are performed. These tests reflect the technical requirements (vertical deformation, spin resistance, bouncing of the ball, etc.) and material characteristics. Football fields receive the status of conforming to FIFA criteria following successful laboratory and field tests, and they provide long-term usage facilities due to regular resistance [28]. Table 4 indicates some test methods, field characteristics, and suitable value ranges regarding the quality class determined by FIFA for football fields.

Table 4. FIFA test method and requirements [28]

Characteristics	Test Method	Requirements	
		FIFA PRO Quality (★★)	FIFA Quality (★)
Vertical ball bounce	FIFA 01	60cm-85cm	60cm-100cm
Shock absorption	FIFA04A	60%-70%	55%-70%
Vertical deformation	FIFA05A	4mm-10mm	4mm-11mm
Spin resistance	FIFA 06	30Nm-45Nm	25Nm-50Nm
Game surface's surface regularity	FIFA 12	<10mm	<10mm

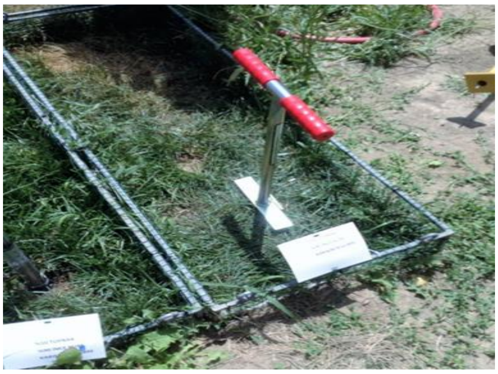
2.3. Experimental Methodology

Determining a suitable soil and turfgrass mixture and fertilizer dose, which will increase the resistance of turfgrass and enable fast and effective drainage in the rootzone, constitutes the basis of the study. For that reason, initially, sampling was made from the systems formed using different root layer mixtures and fertilizers, and the development and length of roots were examined. Next, penetration and infiltration tests were performed on the layers. Finally, Vane shear tests were performed on the samples, the slip resistance of turfgrasses was calculated, and their resistance characteristics were compared. For the performance of rootzone tests, baskets with a length of 1.3 m, a width of 0.5 m, and a depth of 0.2 m were used. Each mixture was manually mixed until full homogeneity was achieved. After mixing, the mixtures were evenly placed into experimental baskets through leveling and compaction. After placing the rootzones along with the turfgrass, they were regularly maintained daily and fertilized at specific intervals. Six baskets were formed using three rootzones and two fertilization doses (Figure 3). Three different mixtures, 100% sand, 90% sand + 10% silt-clay-organic mixture, and 80% sand + 20% silt-clay-organic mixture were formed for the rootzones. As for fertilizer application, basic fertilization of 18-22-0 (slow-release fertilizer) + 26-05-11 (slow-release fertilizer) + 9-9-9 (slow-release fertilizer containing +9% Fe) was applied to all the baskets, and the turfgrasses were grown through the application of two different doses (2.5 ml (A) and 3.0 ml (B)) of liquid humic acid named Run/Black Jak. In agricultural activities, in order to be able to avoid problems such as low fertilizer retention, high porosity, and excessive irrigation, materials that will be able to absorb large amounts of water and which have the ability to release nutrients for a long period have been developed [29]. The SRF (slow-release fertilizer) used within the scope of the study prevents the nitrification process, thus minimizing the nitrogen loss and increasing the lifetime and success.

Figure 3. Basket with a size of 1.3m x 0.5m x 0.2m in which rootzones were placed

After about 30 days, it was considered that the turfgrass had enrooted sufficiently, and the tests were performed on the rootzones. This study used Lolium perenne and Poa pratensis, with 60% Lolium perenne and 40% Poa pratensis. Samples were taken from each rootzone using the tool in Figure 4a for sampling. The fertilizer type and rootzone mixture to be used were agreed upon considering the samples' root lengths and densities, and the infiltration tests performed on the rootzones. Then, penetration tests, determining the ground hardness, were performed on different rootzones. Penetration test equipment is provided in Figure 4b. The test was performed with the help of a thin needle, and the ground hardness was determined according to the penetration of the needle tip into the ground. The permeability of rootzones regarding drainage is also a significant parameter. Therefore, infiltration tests were performed to determine the unsaturated hydraulic conductivities in the rootzones (Figure 4c).

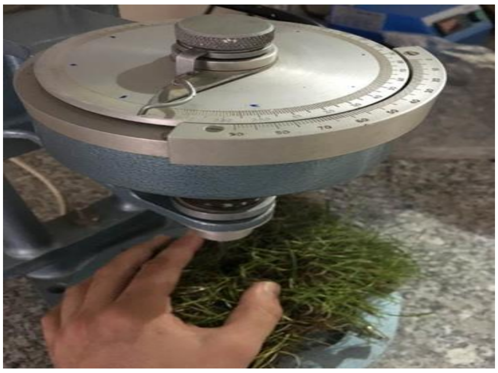
Moreover, saturated hydraulic conductivity coefficients of rootzone mixtures were determined. With the help of a mini disc infiltrometer, unsaturated hydraulic conductivity values were calculated according to the water content in the rootzones. In total, 30 tests, 5 for each rootzone, were performed. The 5 tests, performed on each of the rootzones, were conducted continuously at the same point and consecutively. It was deemed that the water content of the following test would be higher than the previous test, and all the tests were performed accordingly. Finally, Vane shear tests were performed on turfgrasses left for radication in the baskets prepared for rootzones and subjected to fertilizer doses A and B, and the slip resistances of the turfgrasses were calculated. As observed in Figure 4d, the tests were performed with the Vane shear apparatus, and angles of rupture were determined with the help of the goniometer, which is located on the top of the testing equipment and which indicates the angle of rupture and slip resistance values were calculated according to the angles of rupture.



(a)

(b)

(c)



(d)

Figure 4. Testing apparatuses used within the scope of the study. a) Sampling equipment, b) Penetration test equipment, c) Mini Disc Infiltrometer, d) Vane shear apparatus

3. Results and Discussion

Regarding the turfgrass and rootzone mixtures used at sports fields, the fertilizer type and rootzone mixture to be used were agreed upon considering the samples' root lengths and densities and the infiltration tests performed on the rootzones. Moreover, by the penetration tests and Vane shear tests, the fields' hardness statuses and resistances were compared, and an extensive evaluation of turfgrass and rootzone mixtures was performed. Figure 5a and Figure 5b indicate the samples taken from rootzones formed with 100% sand content and to which fertilizer doses A and B were applied. When these rootzones were examined, it was observed that high turfgrass rooting was not present and that thin roots of 2-3 cm in length were growing. Even if just a bit, more rooting was observed in the 100% sand-based rootzone on which the fertilizer dose B was applied.

Consequently, it was observed that rooting was not much in rootzones completely formed of sand and that the turfgrass didn't completely integrate with the underlying rootzone. As this circumstance directly affects turfgrass's surface stability, quality, and lifetime, using such rootzones at sports fields is considered inappropriate. Figures 5c and 5d show the samples from rootzones formed with a 10% clay-silt-organic material mixture and 90% sand content, on which fertilizer doses A and B were applied. When compared with the 100% sand-based rootzone, it was observed that the roots were longer and denser. Moreover, it can be stated that the sample from the rootzone with 10% clay and silt mixture on which fertilizer dose B was applied had more root density than the sample on which fertilizer dose A was applied. Figure 5e and Figure 5f indicate the samples taken from rootzones formed with a 20% clay and silt mixture to which fertilizer doses A and B were applied. When the rootzones with a 20% clay and silt mixture were compared with other samples, it was observed that they had higher root length and density. However, due to the 20% clay and silt mixture, it was observed that about a 2 cm layer had formed under the turfgrass. As this state causes slower drainage of water to lower layers by negatively affecting the infiltration of the rootzone, opting for it at sports fields is improper. The root growth rates obtained for all the tests are given in Table 5.

Figure 5. Root depths of different rootzone and fertilizer mixtures: a) 100% sand – fertilizer A, b) 100% sand – fertilizer B, c) 10% silt and clay, and 90% sand – fertilizer A, d) 10% silt and clay, and 90% sand – fertilizer B, e) 20% silt and clay, and 80% sand – fertilizer A, f) 20% silt and clay, and 80% sand fertilizer B.

Table 5. Root depths of different rootzones and fertilizer mixtures

Rootzone	Fertilizer Type	Approximate Root Depth (cm)
100% sand	A	3.1
	B	3.3
90% sand+10% silt+clay	A	7.0
	B	7.8
80% sand+20% silt+clay	A	8.3
	B	8.7

[30] has defined quality indicators for natural grass surfaces based on various mechanical and hydraulic characteristics, primarily focusing on ball roll, shock absorption, surface hardness, ground coverage, and root depth. In FIFA's 2022 guidelines [30], a root length of less than 5 cm is unacceptable. In our study, the root depths in the sample with 100% sand content were determined to be 3.1 and 3.3 cm, which falls within the "unacceptable" category. Additionally, the mixture containing 90% sand and 10% silt-clay-organic material was classified under FIFA's "satisfactory quality" category (7-8.49 cm). Finally, the soil with 80% sand and 20% silt-clay-organic material meets FIFA's criteria for "good quality" (8.5-9.99 cm). However, considering the potential drainage and infiltration issues posed by a 2 cm layer formed by the 20% silt-clay-organic material, the most suitable choice would be the soil containing 90% sand and 10% silt-clay-organic material.

Penetration tests, which would determine the ground hardness, were performed on different rootzones. With the test performed with the help of a thin needle, the ground hardness was determined according to the penetration of the needle tip into the ground (Figure 4b). At sports fields, it is required for the penetration needle to penetrate the ground in the range of 5-7 mm. The results of penetration tests are given in Figure 6 as fertilizer A and B at different rootzones. Random measurements were taken from frames representing the top view of the baskets (1.5m x 0.5m), and contour graphs were drawn. Measurements were taken at many points regarding representing real values on the basket. The measurements taken from different points of the baskets were interpolated using the Kriging method through the Surfer program. When the results of penetration tests were compared, it was observed that the values were generally ranging between 5 mm and 8 mm. It was observed that the ground was softer at some points in the rootzones with a 20% clay and silt mixture and that the values generally ranged between 7 mm and 8 mm. [31] conducted field experiments to assess surface characteristics over time and space by evaluating various parameters such as surface hardness, soil moisture content, ground surface grass cover percentage, and normalized difference vegetation index (NDVI). They reported a negative correlation between soil moisture and surface hardness, observing higher soil moisture in areas with softer surfaces.

Additionally, [32] highlighted that root layers with high clay, silt, and organic matter exhibit greater water retention capacity. This study observed the softest surface hardness in samples with the highest silt, clay, and organic matter content (20%), which can be attributed to their water retention capacity and soil moisture levels. When the hardness of all the rootzone samples was examined, it was considered that they didn't constitute a negative circumstance in terms of sports organizations. Ground softening, along with the increase in the percentage of silt and clay mixture, needs to be considered in the design of fields, especially in regions with long-term and severe precipitation.

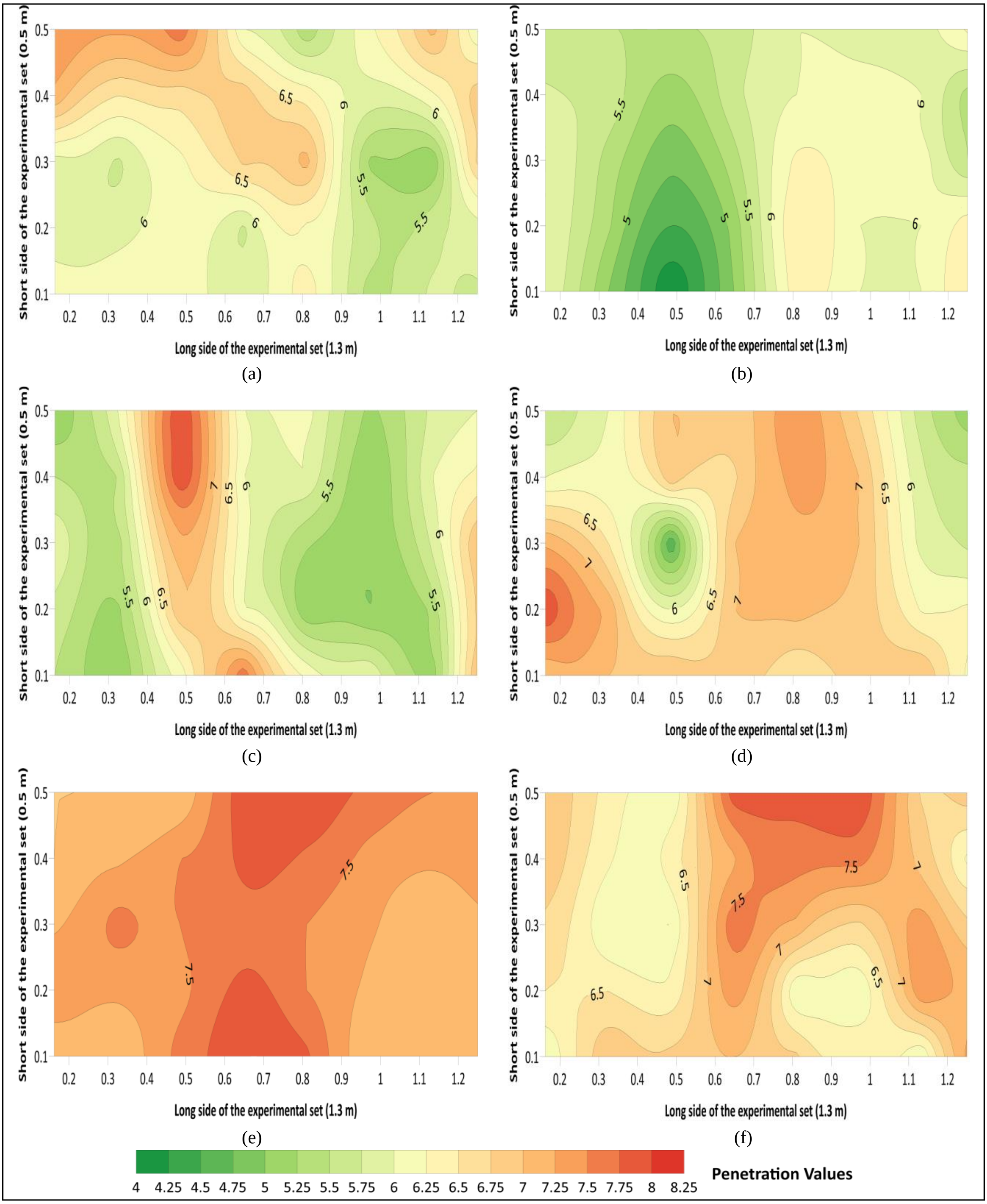


Figure 6. Display of results of penetration tests with contour graphs: a) 100% sand – fertilizer A, b) 100% sand – fertilizer B, c) 10% silt and clay, and 90% sand–fertilizer A, d) 10% silt and clay, and 90% sand – fertilizer B, e) 20% silt and clay, and 80% sand – fertilizer A, f) 20% silt and clay, and 80% sand–fertilizer B

The saturated hydraulic conductivity of rootzones regarding drainage is also a significant parameter measured in the study. The infiltration tests for evaluating the unsaturated hydraulic conductivity were also performed on rootzones. As a result, saturated hydraulic conductivity coefficients of rootzone mixtures are given in Table 6. These values were determined under laboratory conditions in the study of [4].

Table 6. Saturated hydraulic conductivities of rootzone mixtures

Rootzone	Saturated hydraulic conductivity (K_s)
100% Sand	0.0285 cm/s
10% Clay-Silt, 90% Sand	0.0053 cm/s
20% Clay-Silt, 80% Sand	0.0046 cm/s

Moreover, with the help of an infiltrometer, unsaturated hydraulic conductivity values were calculated according to the increasing water content in the rootzones (Table 7). In total, 180 tests, being 30 tests for each rootzone, were performed. The tests performed on each rootzone were conducted continuously at the same point and consecutively. It was deemed that the water content of the following test would be higher than the previous test, and all the tests were performed accordingly. According to the relation between hydraulic conductivity and water content, as the water content of the soil increases, the unsaturated hydraulic conductivity value also increases up to the saturated water content. In the presented experiments, even though the measured unsaturated hydraulic conductivity values increased, and 30 experiments were conducted for each set, they did not go up to the saturated hydraulic conductivity. The results obtained from the tests performed were measured in Table 7 for prepared experimental conditions.

When Table 7 was analyzed, it was observed that the unsaturated hydraulic conductivity coefficients were decreasing as 100% sand, 10% clay and silt mixture and 90% sand, and 20% clay and silt mixture and 80% sand in descending order, as expected. The increase of silt-clay-organic mixture in sand material reduced the hydraulic conductivity value. Moreover, regarding the mixtures having similar water content in the same rootzone, the hydraulic conductivity values of rootzones prepared with fertilizer dose B were measured higher than those of grounds prepared with fertilizer dose A. In brief, it is a fact that unsaturated hydraulic conductivities (Table 7) became much closer to saturated hydraulic conductivity (Table 6) with an increasing number of experiments.

Table 7. Unsaturated hydraulic conductivities for 30 experiments in this study

Rootzone	Fertilizer Type	Unsaturated Hydraulic Conductivity (cm/s)	
		Minimum	Maximum
100% sand	A	0.002121	0.008258
	B	0.002369	0.009467
90% sand+10% silt-clay- organic mixture	A	0.003732	0.010131
	B	0,004161	0.014522
80% sand+20% silt-clay-organic mixture	A	0.002563	0.009763
	B	0.003476	0.009974

Finally, Vane shear tests were performed on turfgrasses that had been left for radication in the rootzone baskets and had received fertilizer doses A and B, and the slip resistances of the turfgrasses were calculated. As observed in Figure 4d, the tests were performed with the Vane shear apparatus, and angles of rupture were determined with the help of the goniometer, which is located on the top of the testing equipment and indicates the angle of rupture. Slip resistance values were calculated according to the angles of rupture. Slip resistance, being important in abrasion damage, especially at rootzones with high sand content, can cause field surface deformations and player injuries [33]. For the sake of ensuring optimum conditions at turfgrass sports fields, [34] stated that it is required for the slip resistance to change between 10 and 20 kPa. As a result of the tests performed, the slip resistance (cu) was determined as an average of 14.25 kPa for fertilizer dose A and 18.22 kPa for fertilizer dose B (Table 8). Both mechanical and bio-mechanical tests indicated that the sand-based sports fields' grounds have higher dynamic rigidity and slip resistance than clay-based grounds [27]. Materials such as silt and clay cause lower slip resistance and higher plastic deformation due to their high-water retention capacities compared to sand-based grounds [11]. Slip resistance and lower water retention capacities of sand-based grounds have caused their usage at high rates (90%) in the rootzone of sports fields. The values obtained for both conditions meet the optimum conditions. Still, as the slip resistance calculated for fertilizer dose B (basic fertilization + 3.0ml Run/Black Jak addition) was higher, it was considered that it is required to opt for the rootzone on which this fertilizer dose was applied in terms of resistance.

Table 8. Root depths of different rootzones and fertilizer mixtures

Rootzone	Fertilizer	Slip Resistance (kPa)
100% sand	A	16.09
	B	19.53
90% sand+10% silt-clay- organic mixture	A	13.89
	B	18.02
80% sand+20% silt-clay-organic mixture	A	12.77
	B	17.11

This study aimed to improve the durability of sports fields by determining the mix ratios and fertilizer doses in the rootzone to ensure effective water drainage. [19] emphasized that a football field must meet efficient and adequate mechanical properties, such as surface hardness and slip resistance, and hydrological parameters, including infiltration, surface temperature, rootzone soil moisture, and drainage. The numerous and often conflicting parameters and the lack of a standardized specification make achieving optimal conditions for the field surface challenging [22]. Therefore, considering the different requirements of the game, players, and field conditions, it can be stated that the field surface is designed in layers. However, it has been particularly emphasized that the top few centimeters of the surface must consist of sand material to ensure good permeability and effective drainage [6]. In our study, the 2 cm layer formed beneath materials with 20% silt-clay content presents a significant challenge regarding infiltration and drainage conditions. Soils with 100% sand content exhibit high drainage and infiltration capacity and are less prone to compaction. However, they require more frequent irrigation and fertilization to maintain healthy turf growth [35]. Therefore, the mixture of 90% sand and 10% silt-clay-organic matter provides the most optimal conditions for efficient drainage and surface stability while ensuring that grassroots can access the necessary water in the rootzone.

As a result of penetration, infiltration, and vane tests, it was determined that the best rootzone was formed with 10% silt-clay-organic mixture + 90% sand. This finding supported the results of [8, 23, 24]. However, it was observed that the rootzones consisting entirely of sand did not provide sufficient rooting and full integration with the grass. Since this situation has a direct effect on the durability and quality of the surface and the life of the grass, it was considered that it is not suitable for use in sports fields [6]. On the other hand, it was observed that a layer of about 2 cm was formed under the grass in the rootzones with 80% sand + 20% silt-clay-organic mixture. This situation is not suitable for sports fields as it slows down water drainage and negatively affects the infiltration of the rootzone, especially in areas with prolonged and heavy rainfall, this situation can be a significant problem [3].

The importance of the rootzone has been emphasized throughout the study due to its functions such as drainage, soil resistance, surface hardness, and meeting the water requirements of the grass. The correct composition of the rootzone, approximately 90% sand and 10% silt, clay, and organic matter, is vital for preventing water accumulation on the surface, increasing infiltration rates, and stabilizing the surface. Slip resistance, essential regarding abrasion damage and player safety, was within the recommended range of 10-20 kPa for both A and B fertilizer doses [36]. The importance of an effective drainage system to ensure the durability of the pitch surface and minimize water-related problems on the pitch is supported by previous literature [36-38]. Previous studies have also emphasized the need for sports pitches to be constructed with a high sand content for satisfactory infiltration rates and surface aeration.

In conclusion, this study provides valuable information on the composition of the rootzone and appropriate fertilizer doses to improve the durability of sports pitches. Using a rootzone composed of 10% silt-clay-organic material and 90% sand is optimal for effective water drainage and turf health. Furthermore, the research emphasizes the importance of an effective drainage system and highlights the necessity of sports pitches with high sand content for proper infiltration rates and player functionality. Regarding fertilizer dosage, the B fertilizer dose proves to be more effective across all soil mixtures, promoting healthier turfgrass by enabling sufficient water uptake from the rootzone due to the longer root lengths observed. Additionally, with its higher hydraulic conductivity, the B fertilizer dose allows rainfall and irrigation water to drain more quickly and efficiently from the field surface. Both fertilizer doses exhibit optimal conditions in terms of slip resistance values. Therefore, fertilizer dose B should be preferred for developing grass cover, promoting better root establishment, effective drainage, and overall resilience. Overall, the findings of this study provide essential contributions to sports field management and offer valuable guidance to turf professionals, sports field designers, and companies engaged in sports field development.

4. Conclusion

In the design phase of the sports fields, it is crucial to know the turfgrass species to be used and the fertilizer applications, as well as the drainage, surface hardness, and slip resistance characteristics of the rootzone, which is the most significant part of the drainage layer. The selection of proper species and mixtures will make the exhibition of players' skills possible and fulfill the game requirements. FIFA evaluates the resistance of the field surfaces, the ball-surface interaction, and the player-surface interaction before approving FIFA Pro Quality or FIFA Quality certificates. According to [30] criteria, less than 5 cm root length values are classified as unacceptable quality. This study measured root depths in the 100% sand sample at 3.1 and 3.3 cm, confirming its categorization as unacceptable. Additionally, a soil composition of 90% sand and 10% silt-clay-organic matter falls within the satisfactory quality range (7-8.49 cm) defined by FIFA. Lastly, according to FIFA criteria, soil containing 80% sand and 20% silt-clay-organic matter is classified as relatively good quality (8.5-9.99 cm). However, considering that the 2 cm layer formed by the 20% silt-clay-organic matter will create drainage and infiltration challenges, it can be concluded that the optimal choice would be soil comprising 90% sand and 10% silt-clay-organic matter.

In terms of infiltration, it can be stated that the saturated hydraulic conductivity (0.0046 cm/s) of the root layer with 20% clay and silt mixture and 80% sand content may cause drainage problems according to providing the FIFA minimum infiltration condition (0.005 cm/s). Although slip resistance and penetration values are within acceptable standards for football fields, there may be issues with injuries and drainage in places with frequent severe precipitations due to the increased silt-clay concentration in the root layer.

The tests (examination of root samples, penetration, infiltration, and Vane test) performed on different rootzones developed for being used at sports fields, indicated that the best rootzone formed with 10% clay and silt mixture and 90% sand. The fertilizer dose B (18-22-0 (slow-release fertilizer) + Nu Film spreader-sticker + 26-05-11 (slow-release fertilizer) + 9-9-9 (slow-release fertilizer containing +9% Fe) + 3.0ml Run/Black Jak addition) application should be preferred in terms of the development of turfgrass layer, better radication and resistance. As much as being good in terms of drainage, the quality and healthy radication of the turfgrass used at sports fields are also significant parameters. The rootzone formed of 100% sand may be considered the best drainage due to having a better hydraulic conductivity coefficient. However, in the previous studies and this study, it was observed that it is required to have a specific rate of clay and silt organic substance mixture, which will increase the root quality and density of turfgrass in the rootzone. The literature emphasizes the necessity for the top few centimeters of the surface layer to consist of sandy material to ensure good permeability and effective drainage. Considering the tests of rootzone in which 20% clay and silt mixture was used, the formation of about 2 cm layer under the turfgrass surface through the examination of root lengths would negatively affect the infiltration. It would cause decreases in the transmission rate of water to lower layers. Therefore, a mixture of 90% sand and 10% silt-clay-organic matter provides the optimal conditions for effective drainage, surface stability, and the ability of grassroots to access the necessary water from the rootzone. Moreover, it may be stated that relatively high values observed in penetration tests, along with the increase of clay and silt mixture, would cause players' injuries by causing an increase in field surface abrasions. Therefore, considering the drainage, slip resistance, and sand and rootzone interaction, the use of rootzone with 10% clay and silt organic substance mixture on which fertilizer dose B (basic fertilization + 3.0ml Run/Black Jak addition) was applied may be considered as the most suitable solution.

In future studies, the hydrological and mechanical characteristics of natural and artificial fields, to be obtained as the result of applying similar methods on artificial turfgrass fields that are increasingly being used in recent years, may be compared and evaluated. Moreover, the study's scope may be extended by applying tests such as bouncing and rolling the ball, spin resistance, and impact absorption.

Author Contributions

The fourth and sixth authors directed the project and supervised this study's findings. The first, second, and third authors devised the main conceptual ideas and developed the theoretical framework. The first, second, and fifth authors performed the experiment and statistical analyses. The first author wrote the manuscript with support from the second and third authors. The fourth and sixth authors reviewed and edited the paper. All authors read and approved the final version of the paper. This paper is derived from the fifth author's master's thesis, supervised by the sixth author. The authors read and approved the final version of the paper.

Conflicts of Interest

All the authors declare no conflict of interest.

Ethical Review and Approval

No approval from the Board of Ethics is required.

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