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RESEARCH ARTICLE

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Influence of Crushed Limestone, Sand Mix, and Bulk Density on Soil Physical Properties Cultivated with Turfgrass in Sulaimani Governorate, Iraq

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ABSTRACT

This study examined the impact of crushed limestone and sand mixtures on soil properties affecting turf performance in a football field at the University of Sulaimani. Using a factorial design, three mixtures (Z_1, Z_2, and Z_3) and three bulk density levels (D_1 (1.45), D_2 (1.55), and D_3 (1.65) Mg m^{-3}) were tested. Key findings revealed a strong inverse relationship between bulk density and infiltration rate, demonstrating that increased compaction decreases soil permeability. The crushed limestone mixtures display superior hydraulic performance and technical strength compared to sand mixtures. The limestone-reinforced Z_2 layer produced the highest dry matter yield (7.667%) at D_1 (1.45 Mg m^{-3}), whereas the sand-predominate Z_1 mixture retained the highest infiltration rates. The dry matter and infiltration reduced significantly at the maximum 1.65 Mg m^{-3}), reaching 2.333% at Z3 × D1. Shear strength increased from 1.9–2.2 kpa to 2.5–3.1 kpa with compression, indicating that soil bulk density possesses higher mechanical strength. Hydraulic conductivity decreased similarly with increasing bulk density (R2 = 0.998). Crushed limestone compositions generally performed better than natural ones.

***Keywords*:** crushed limestone and sand mixtures, bulk density, infiltration rate, dry matter and turfgrass sport field.

INTRODUCTION

Sports fields require root zone materials that not only sustain the growth of thick turfgrass but also possess the necessary physical and hydraulic properties. Turfgrass health and playability are directly impacted by water infiltration, aeration, mechanical stability, and root growth, all of which are influenced by the physical state of the root zone [1]; [2]. The root zone's structure must be perfect for optimal drainage, aeration, and surface stability. These things all have an effect on how well turfgrass grows and how well it works for sports fields. Natural soils, on the other hand, usually include too much clay and silt, which makes them hard, lets water in poorly, stops roots from sprouting, and makes the surface unstable [3]. These poor soil conditions not only weaken the grass, but they also make it less safe for players. Many sports fields have sand-based root zones because they can hold a lot of water, don't become compacted, and keep the soil aerated [4]. Crushed limestone aggregate is one of the greatest options for these replacements since it is the proper size, sturdy, and stable in terms of chemistry. It could make the soil's structure, drainage, and ability to manage traffic better when mixed with root zone mixtures [5].

The bulk density (ρb) of root zone materials is one of the most critical things that impacts how well they operate mechanically and hydraulically. If the bulk density is low, things can become unstable and the surface can become less hard. The soil becomes denser and less porous when the bulk density is high. This means that water doesn't flow through it as quickly [6]. When creating sports fields, you need to determine the correct range of bulk density so that the grass grows well, the field can hold a lot of weight, and water drains quickly. The long-term effectiveness of natural turf systems depends a lot on the density of the soil, how effectively it holds water, and how much organic matter it has. When pushed down, water can flow through the sand faster, hold it better, and be stronger [7]. Peat can assist nutrients in getting to plants and make the soil hold more water, especially in dry places [8]. It modifies how the soil is built and how roots grow when you wet it. If you water the surface too regularly and not deeply enough, it may become hard, which makes it harder for water to soak in. On the other hand, deep, infrequent soaking helps turfgrass grow deeper roots and more of it [9].

Previous studies have shown that changing the amounts of sand and organic matter can help turfgrass grow better and the root zone perform better. [10] It is proposed that incorporating sand particles with a thickness ranging from 0.05 to 1 mm into peat results in a drier substrate and facilitates enhanced water infiltration (6.20 cm $hour^{-1}$). The results show that fine sand is the optimal choice for heavily used sports fields, as it allows for aeration and retains water well. [5] The study found that crushed limestone mixtures with bulk densities ranging from 1.417 to 1.510 Mg/m^3 exhibited strength, effective drainage, and stability during use.

Research Objectives

The goal of this study is to evaluate whether crushed limestone sand can serve as an effective substitute for natural sand in the root zones of sports fields, to determine the optimal range of bulk density that maintains a balanced combination of physical, hydraulic, and mechanical properties essential for healthy turfgrass growth and stability, and to assess the capacity of the modified root-zone system to withstand various environmental and traffic-related stresses.

Materials And Method

1. Laboratory Experiments

1. Experiments in the Laboratory

1.1 Collecting Soil Data and Identifying the Site.

It obtained topsoil samples (0–20 cm) in order to find out fundamental chemical and physical characteristics. The research was carried out at the Soil Physics Laboratory as well as the testing location of the College of Agricultural Engineering Sciences, University of Sulaimani (Table1).

1.2. Chemical and Physical Testing of Soil Particle Size Distribution:

Soil particle size distribution was determined using the International Pipette Method, which separates sand, silt, and clay fractions based on sedimentation principles [11]. Bulk density was measured using the core sampling method [12]. Subsequently, employing a pH meter, the soil pH content of the saturation point extract was determined using the technique provided in [12]. Organic matter content was determined by [13] and expressed in g kg^{-1}. Soluble Ca^{2+} and Mg^{2+} were measured by EDTA titration, and Cl^{-} concentration was determined using the argentometric (Mohr) method following [14]. Total ($CaCO_3$) was measured titrimetrically following the procedure of [13]. The Basic Infiltration Rate (BIR) was measured using a field double-ring infiltrometer to estimate the soil's steady water absorption capacity, complementing texture and bulk density data [15].

Table (1): Some physical and chemical properties of the studied

Soil Physical Properties									
Soil Sample	Sand (g kg^{-1})	Silt (g kg^{-1})	Clay (g kg^{-1})	Textural class	Bulk density (Mg m^{-3})	Basic Infiltration Rate (mm h^{-1})			
	75.1	523.39	401.51	Silty Clay	1.4	8.2			
	Soil chemical properties								
Soil Sample	ECe (dS m^{-1})	pH	O.M. g kg^{-1}	$CaCO_3$ g kg^{-1}	Ca^{2+} mmol L^{-1}	Mg^{2+} mmol L^{-1}	Na^{+} mmol L^{-1}	Cl^{-1} mmol L^{-1}	HCO_3^{-1} mmol L^{-1}
	0.44	7.8	19.59	215.6	.51	0.44	1.1	0.44	4.4

1.3. Particle Size Distribution of Sand and Crushed Limestone: A standard ASTM sieve series (4.75, 2.00, 1.00, 0.50, 0.25, 0.125, and 0.075 mm) was used for dry sieve examination of the fractions of sand and crushed limestone [15]. The weight retained on each sieve was noted after the mechanical shaker was run for fifteen minutes. The following formula was used to determine the coefficient of curvature (Cc) and uniformity coefficient (Cu):

$Cu = \frac{D^{60}}{D^{10}} \ldots\ldots\ldots.(1)$ $Cc = (D^{30})^2 / (D^{10} \times D^{60}) \ldots\ldots\ldots\ldots\ldots\ldots (2)$

Where D_{10}, D_{30}, and D_{60} represent the particle diameters corresponding to the finer fractions of 10%, 30%, and 60%, respectively.

1.4. Soil Hydraulic Conductivity:

The constant head approach was used to calculate the saturated hydraulic conductivity (K_s) [5]. With three replications (27 samples), three combinations of sand (Z_1), crushed limestone (Z_2), and sand–limestone mixture (Z_3) were compacted at bulk densities of 1.45, 1.55, and 1.65 Mg m^{-3}. Darcy's Law was used to compute hydraulic conductivity:

$$Q = K * A * \frac{dh}{dL} \dots \dots \dots (3)$$

(Q) is the discharge (cm³ s⁻¹), (A) is the cross-sectional area (cm²), (dh) is the hydraulic head difference, and (dL) is the flow length.

Figure 1: Constant Head Permeameter Apparatus used for measuring hydraulic conductivity (K_s)

2. Field Experiments

2.1. Root Zone Mixture Preparation:

Three root zone media were created to assess their feasibility for building sports fields in Sulaimani conditions: Z_1: 80% sand + 17% soil + 3% peat moss; Z_2: 80% crushed limestone + 17% soil + 3% peat moss; and Z_3: 40% sand + 40% crushed limestone + 17% soil + 3% peat moss. As suggested by [2], each combination was modified to three bulk density levels (1.45, 1.55, and 1.65 Mg m^{-3}) to imitate different field compaction levels.

2.2. Experimental Design and Plot Preparation:

Nine treatment combinations (three mixtures × three bulk densities) and three replications were used in this factorial randomized complete block design (RCBD). The experimental units were wooden frames measuring 1 m by 1 m by 0.45 m (Figure 2).

The mixtures were compacted using a 68 kg mechanical hand tamper, and bulk density was verified using the core method [16].

Figure 2. Experimental layout of the factorial randomized complete block design (RCBD)

2.3. Design of Irrigation Systems:

To ensure uniform water distribution, a sprinkler irrigation system was put in place. Six sprinklers with a discharge rate of 2.8 L min^{-1} each were run at 2.5 bar of pressure. A Christiansen uniformity coefficient (CU) greater than 85% was attained by the system. FAO Penman-Monteith evapotranspiration served as the basis for irrigation scheduling [17]. To keep soil moisture levels close to field capacity, irrigation depths of 18 mm (April–May), 20 mm (May–June), and 26 mm (June–July) were applied per event (Figure 3).

Figure 3: Visual Effects of Soil Treatments (Crushed Limestone, Sand Mixture, and Bulk Density Levels) on Turfgrass Growth

2.4. Establishing and Maintaining Turfgrass

Because of its ability to adapt and withstand the climate of Sulaimani, Bermuda grass (*Cynodon dactylon* (L.) Pers.) was chosen. On April 20, 2025, seeds were manually seeded at 35 g m^{-2} after being mixed with a base fertilizer (N: P: K 18:18:18) at 60 g m^{-2}. Every week, the turf was mowed.

2.5. Measurement of Soil Physical Properties

A double-ring infiltrometer with an inner diameter of 10.16 cm was used to measure the infiltration rate, and the duration of 10 cm of water infiltration was noted. A pocket penetrometer (S088.M01.EN.01) was used to measure penetration resistance. The shaft was inserted 6.4 mm into the soil, and the highest resistance was recorded. A vane shear apparatus (S057.AB.0083) was used to measure soil shear strength in order to calculate untrained shear strength in accordance with [18].

2.6. Growth Parameters of Turfgrass

Turf height, root zone depth, root branching, and dry matter production were measured to assess the growth performance of turfgrass. To calculate the dry matter yield, turf samples were oven-dried at 65°C for a full day before being weighed. In accordance with [19], root properties were evaluated. Measurements were made using the methods described in [20]. Analysis of variance (ANOVA) was performed on all gathered data, and the Least Significant Difference (LSD) test at $P < 0.05$ was used to compare treatment means.

Results

Laboratory Experiments

1. Distribution of Sand and Crushed Limestone Particle Sizes:

The curves for the size distribution of crushed limestone and sand particles are shown in Figure 4. Both materials have well-graded profiles, which indicates that the amount of particles that are maintained gets smaller as the particles get smaller. Sand has many different particle sizes, which makes it easy to pack tightly and lets some water through. Most of the particles are coarse (>1 mm), while just a few are tiny (<0.1 mm). Crushed limestone has a steady range of particle sizes, with a rapid decline from 1 mm to 0.1 mm and then a flat section that demonstrates a low fine amount. This distribution makes the structure more stable, packs it better, and makes it simpler for particles to touch each other. All of these things are vital for using soil in engineering and farming. These results are consistent with those of [21], which indicated that well-graded sands had better stability and lower void ratios, and with [22], which indicated that well-graded crushed limestone has better compaction and shear strength. When you look at the fractions of crushed limestone and sand, you can see that both materials have high gradation qualities. However, they may operate differently in the field.

Sand is excellent for aerating and moving water through soil since it has bigger particles and less fine stuff. Crushed limestone, on the other hand, has better interlocking potential and more angularity. This technique the soil firmer and more compact, but it also makes it a little less permeable. Adding both portions to soil mixes could help water flow through and make the soil more stable. This conclusion is in line with what [23] found, which showed that the shape and size of particles had a combined effect on soil compaction, porosity, and hydraulic conductivity.

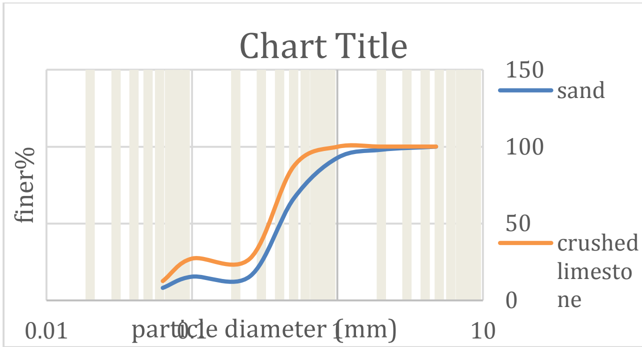

Figure 4. Particle Size Distribution of Sand and Crushed Limestone Fractions

2. Test for saturated hydraulic conductivity (K□)

Bulk density and hydraulic conductivity

As bulk density increased, hydraulic conductivity (K□) decreased, as shown in Figure 5. The result shows that compacting the soil makes it harder for water to flow and for pores to stay open. This means that 90% of the changes in H.C. are due to bulk density. According to [7] and [24], compressed native soils (Z_3) let less water through, while blends with more sand (Z_1) kept their permeability better.

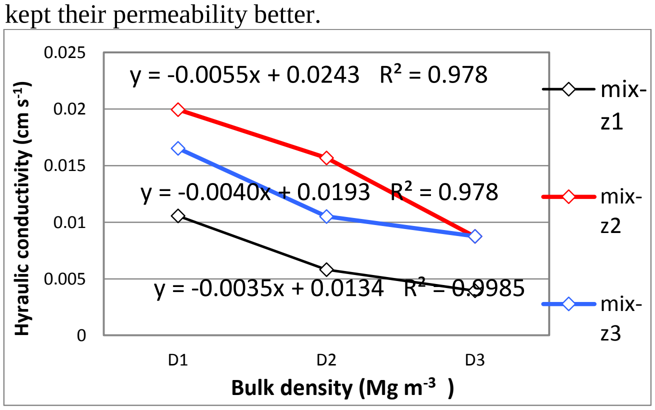

Figure 5. Effect of soil mix and (pb) on H.C

Field Tests: 1. Bulk density (pb) and Infiltration Rate

The correlation between bulk density (Pb) and infiltration rate for the three soil combinations (Z_1, Z_2, and Z_3) is shown in Figure 6. The observation of a strong negative linear relationship ($R^2 > 0.93$) confirmed that infiltration reduces with increasing bulk density. At all density levels, Mix Z had the maximum infiltration, indicating better drainage and porosity. The lowest infiltration results were maintained by Mix Z_2, indicating increased compaction and decreased permeability. The inverse relationship between infiltration and bulk density is supported by linear regression models, indicating that soil compaction considerably limits water access into the root zone.

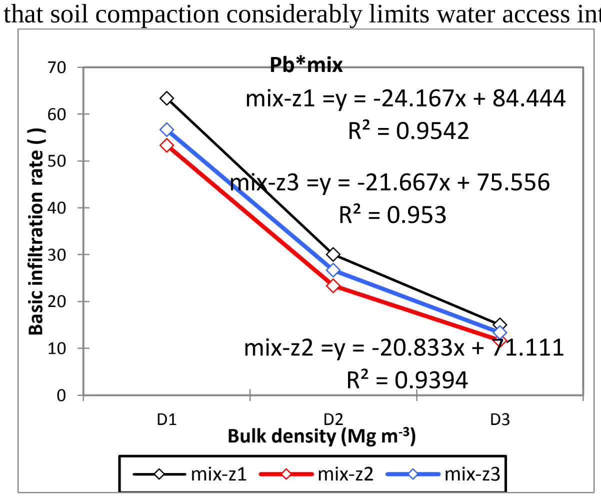

Figure 6: Effect of soil mix composition and bulk density on infiltration rate

2. Bulk density and penetration resistance

Figure 7 shows the link between penetrating resistance and bulk density. R^2 values over 0.92 shows that bulk density and penetration resistance are a good fit. Because of their high bulk density, all of the combinations were harder to go through. The slope of mix Z_2 was the steepest, which suggested it was more vulnerable to compaction. These results are in line with [6] and [25] because they reveal that roots have a harder time getting into soil that is more compacted and that the soil is less stable.

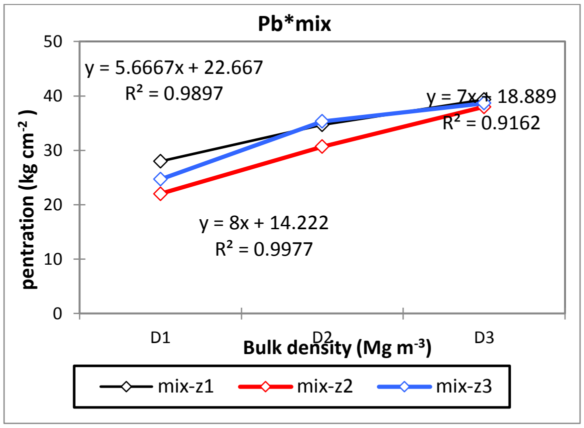

Figure 7: Effect of soil mix composition and (pb) on penetration resistance.

3. Root Zone Depth and Bulk Density: There was a strong negative relationship between root zone depth and bulk density (R^2 = 0.91, Figure 8). Z_1D_3, the deepest layer, had the lowest depth (5.67), while Z_1D_1, the higher layer (bulk density = 11.33 Mg m^{-3}), had the highest root depth. The middle layers' (Z_2 and Z_3) root depth eventually got shallower as the layers were increasingly packed together. These results imply that deeper zones possess a more robust structure and are less permeable to roots; yet, the effects of compaction are most pronounced in the surface layers.

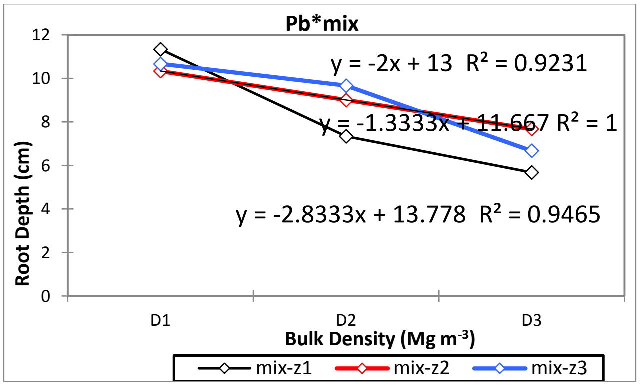

Figure 8: Effect of soil mix composition and bulk density on root zone depth

4. Bulk Density and Dry Matter Content

There was a strong negative correlation (R = 0.907, Figure 9) between dry matter content and bulk density. Across the mixtures, Z_2 (5.7%) was greater than Z_3 (4.3%) and Z_1 (3.3%). Z_2D_1 has the most dry matter (7.7%) and the least (2.3%). This data shows that compaction makes it harder for roots to breathe and messes up the air-water balance, which slows down the growth of biomass. Therefore, bulk density is one of the most important things that affect how productive plants are [25]; [1].

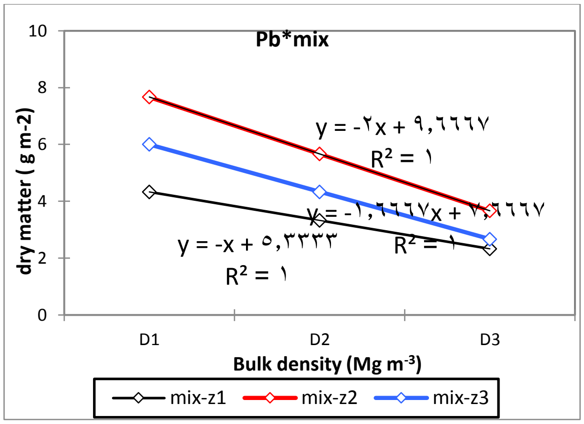

Figure (9): Effect of Soil Mix Composition and (pb) on Turfgrass Dry Matter Weight

5. Soil Treatment and Shear Strength

As the bulk density rose, the vane shear strength also rose, showing that the soil became more cohesive as it was compacted (Figure 10). Z_2 always had the highest shear strength at all density levels. Even though the R^2 values are low (<0.11), the trend shows that compaction makes mechanical resistance better, which supports [23].

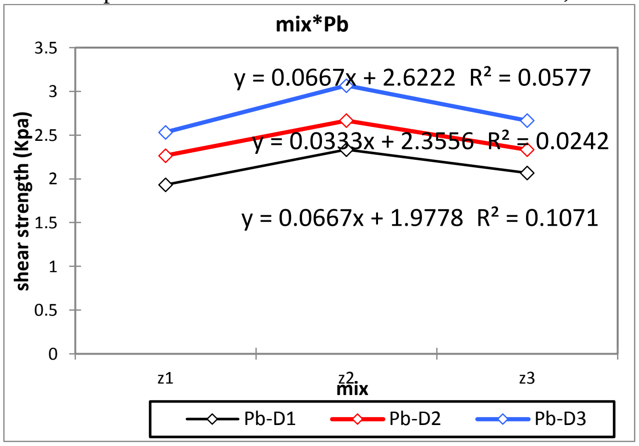

Figure 10. Effect of soil mix composition and bulk density on vane shear strength

6. The impact of soil bulk density and soil mix type on turfgrass height The statistical analysis revealed that the interaction between bulk density and soil mix composition significantly influenced turfgrass height ($P < 0.05$, figure 11). The mean height of the turfgrass was highest for treatment Z_2D_1 (crushed limestone mixed with bulk density 1.45 Mg m^{-3}) at 19.3 cm. The mean height was lowest for treatment Z_2D_3 (crushed limestone mixed with bulk density 1.55 Mg m^{-3}) at 4.3 cm. The bulk densities of D_1, D_2, and D_3 are 1.45, 1.55, and 1.65 Mg m^{-3}, respectively. The area has sand, crushed limestone, and dirt in Z_1, Z_2, and Z_3. The Least Significant Difference says that mean values that are followed by different letters show big disparities.

Changes in the structure and compaction of soil have a huge effect on how well it holds water, let's air through, and helps roots grow through it, according to [3]. All of these things help grass grow and stay healthy. Their research showed that roots flourish and absorb nutrients most effectively at the lowest bulk density (D_1) and with the crushed limestone mixture (Z_2), this made the plants grow taller. The same mixture, however, hindered growth by lowering root activity at the highest bulk density (D_3). These data highlight the critical importance of monitoring the bulk density and composition of the soil to ensure the development, health, and productivity of turfgrass in the field over time.

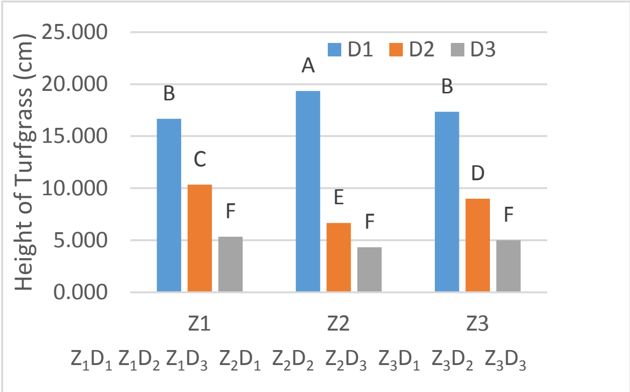

Figure (11) shows the Effect of soil mix composition (Z) and soil bulk density (D) on turfgrass height.

7. Impact of Soil Bulk Density and Soil Mix Composition on Turfgrass Dry Matter Weight

The statistical study indicated that the interaction between the soil mix and the soil bulk density had a large effect ($P < 0.05$) on the turfgrass's dry matter weight. Figure 12, the Z_1D_2 treatment, which was a mix of sand with a bulk density of 1.55 Mg m^{-3}, produced the highest dry matter (7.833 g m^{-2}). The Z_3D_1 treatment, which was a mix of soil with a bulk density of 1.45 Mg m^{-3}, had the lowest value (2.333 g m^{-2}). Treatments D1, D2, and D3 (1.45, 1.55, and 1.65 Mg m^{-3}) show that the soil's bulk density is always going up. The soil mixes for treatments Z_1, Z_2, and Z_3 are not the same. Z_1 has sand, Z_2 has crushed limestone, and Z_3 has a blend of the two. The letters above the bars show the average values, which the Least Significant Difference (LSD) test says are very different from each other.

The quantity of biomass that turfgrass grew depended a lot on the soil chemistry and bulk density. In general, intermediate bulk density (D_2) made more dry matter, especially when the mix comprised sand (Z_1). This suggests that moderate compaction can help roots absorb nutrients and interact with the soil. Conversely, suboptimal soil mixing conditions (Z_3) or excessive compaction (D_3) inhibited root development and restricted biomass output.

These results align with previous research indicating that optimal soil physical conditions are crucial for turfgrass development and physiological performance. [3] People have said that too much soil compaction stops water from moving around and roots from getting in, which slows down the formation of dry matter. Similarly, [25] emphasized that maintaining soil structure within an optimal density range enhances plant productivity and soil health. Furthermore, [1] said that too much bulk density weakens plants, slows down root growth, and stops shoot growth. On the other hand, moderate bulk density speeds up photosynthesis and makes nutrient intake more efficient.

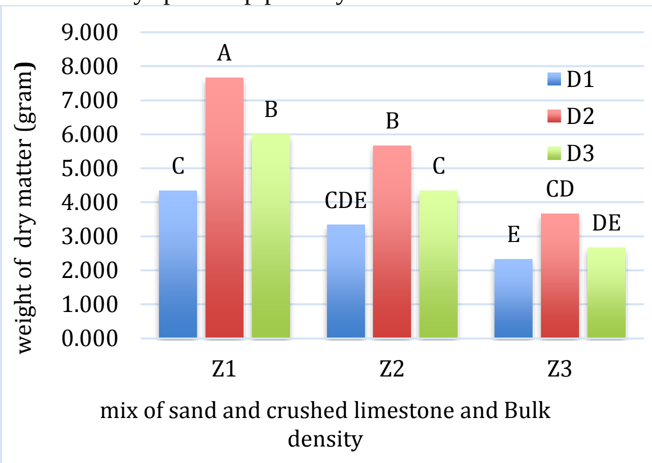

Figure 12: Soil Bulk Density and Soil Mix Composition on Turfgrass dry matter weight

8. Impact of Bulk Density and Soil Mix Composition on Turfgrass Root Depth

(As shown in Figure 13), the results indicated that the interaction between soil bulk density and soil mix composition significantly ($P < 0.05$) influenced turfgrass root depth. The treatment that produced the greatest average root depth (11.667 cm) was Z_1D_1 (sand mix at bulk density 1.45 Mg m^{-3}), whereas the lowest root depth (5.667 cm) was observed in Z_1D_3 (sand mix at bulk density 1.65 Mg m^{-3}). D_1, D_2, and D_3 represent increasing bulk density levels (1.45, 1.55, and 1.65 Mg m^{-3}, respectively), while Z_1, Z_2, and Z_3 correspond to sand mix, crushed limestone, and soil mix compositions. Mean comparisons were performed using the LSD test at $P < 0.05$, and values followed by different letters in Figure 13 differ significantly. The results clearly show that root depth decreased progressively with increasing bulk density. This indicates that greater soil compaction restricts root elongation and penetration. The Z_1D_1 treatment provided favorable aeration and lower mechanical resistance, promoting deeper root growth. In contrast, higher bulk density levels (D_3) across all soil mixtures significantly reduced rooting depth, limiting water and nutrient uptake. These findings agree with [3], who reported that severe soil compaction reduces infiltration and oxygen diffusion, thereby restricting root development. Similarly, [1] indicated that deeper root systems improve turfgrass tolerance and overall performance under suitable soil conditions. Furthermore, [25] reported that optimal soil density enhances root growth, while excessive compaction inhibits it.

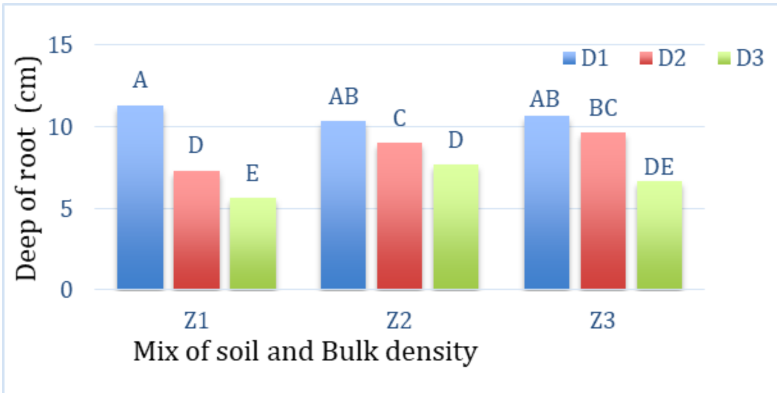

Figure 13: Effect of Soil Mix Composition and Bulk Density on Turfgrass Root Depth

9. Impact of Bulk Density and Soil Mix Composition on Soil Penetration Resistance (kg cm^{-2})

As illustrated in Figure 14, soil penetration resistance significantly increased with rising bulk density levels across all soil mix treatments ($P < 0.05$). The highest penetration resistance (38.667 kg cm^{-2}) was recorded under treatment Z_1D_3, while the lowest value (22.000 kg cm^{-2}) was observed in Z_2D_1. Statistical analysis (LSD test, $P < 0.05$) confirmed significant differences among treatments.

The increase in penetration resistance with higher bulk density indicates reduced pore space and increased soil compaction. All soil mixes followed the same trend, where D_3 treatments exhibited significantly higher resistance compared with D_1 and D_2. These results are consistent with [25], who reported that increased bulk density enhances soil compaction and reduces root penetration capacity. Likewise, [6] demonstrated that increasing soil density strengthens soil structure but limits root elongation.

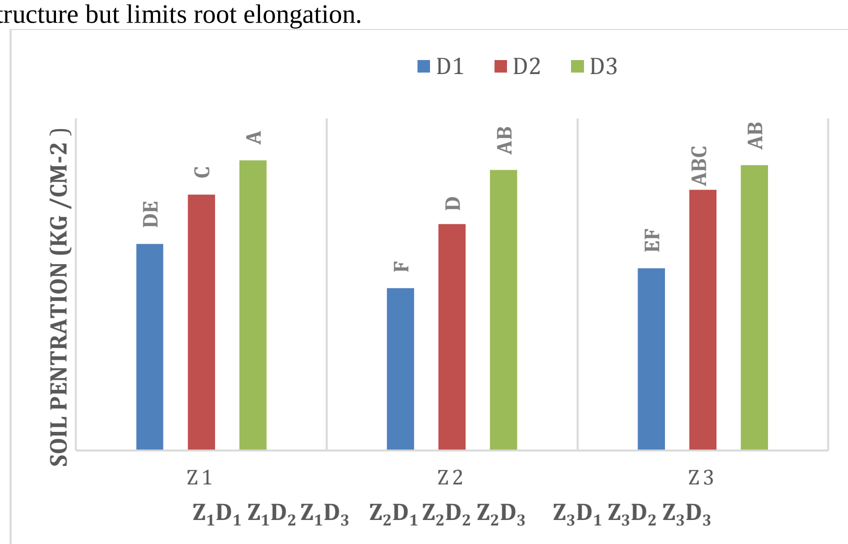

Figure 14. Shows the impacts of bulk density and soil mix composition on soil penetration.

10. Impact of Bulk Density (pb) and Soil Mix Composition on Turfgrass Root Zone Vane Shear Strength

According to Figure 15, both bulk density and soil mix composition significantly affected vane shear strength ($P < 0.05$). The highest shear strength value was recorded in treatment Z_2D_3, where bulk density was highest. Conversely, treatment Z_1D_1 exhibited the lowest shear strength value.

Duncan's Multiple Range Test at $P < 0.05$ indicated that treatments sharing the same letter were not significantly different.

The results demonstrate a direct relationship between bulk density and soil mechanical stability. As soil packing increased, particle cohesion increased and pore space decreased, leading to higher shear strength values. Treatment Z_2 showed superior mechanical stability compared to Z_1 and Z_3, likely due to improved particle interlocking and balanced texture. These findings agree with [25], who reported that bulk density strongly influences soil penetration resistance and structural stability. Similarly, [26] found that increasing bulk density enhances vane shear strength up to a critical compaction level beyond which soil function declines. Moreover, [27] observed similar trends in sandy soil mixtures, where higher density improved shear resistance due to closer particle arrangement.

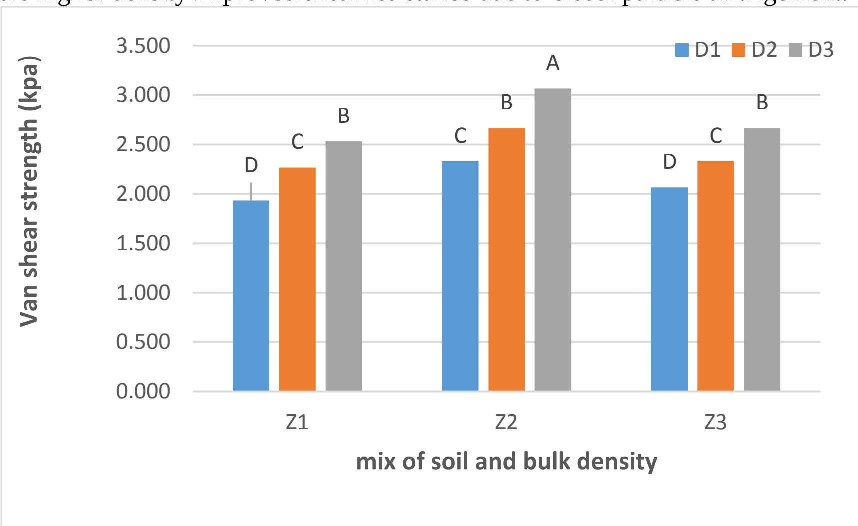

Figure 15. Impact of bulk density levels and soil mix type on vane shear strength

11. Influence of Bulk Density Levels and Soil Mix Composition on Infiltration Rate (cm hr⁻¹)

Figure (16) illustrates the impact of varying bulk density levels ($D_1 = 1.45$, $D_2 = 1.55$, $D_3 = 1.65$ Mg m^{-3}) and distinct soil mixture types (Z_1, Z_2, Z_3) on the rate of water movement through soil. The results indicated that infiltration dropped down a lot in all of the root zone combinations when bulk density increased higher. Z_1D_1 was a mix of sand and other things that weren't very tightly packed. It let water through the fastest, at a rate of roughly 66 cm hr^{-1}. The lowest rate, about 15 cm hr^{-1}, was for Z_2D_3, which was a highly tightly packed mix of components.

For all the different types of soil, the infiltration rate slowly dropped from D_1 to D_3. This indicates that compaction stops macrospores from moving and makes it harder for water to travel through the soil. The Z_2 (sand-dominant) and Z_3 combinations let the most water through. Z_2 (limestone-enriched) let in slightly less water, but it stayed in shape better after being crushed a lot. The density levels in groups A, B, C, and D differed significantly from each other ($p < 0.05$), with D_1 and D_3 being the most distinct.

The results confirm the conclusions of [28], which indicated that high bulk density makes it harder for water to move and roots to grow in turfgrass systems by lowering macro porosity, infiltration, and hydraulic conductivity. [4] Also discovered that sandy mixes permit greater water permeability compared to soils that are densely compacted or possess fine textures. Adding crushed limestone to the soil and keeping it at a density of about 1.45 Mg m^{-3} strengthened it. This made it easier for water and air to get through. This action keeps the grass healthy and helps the roots get stronger. The density levels in groups A, B, C, and D differed significantly from each other ($p < 0.05$), with D_1 and D_3 being the most distinct.

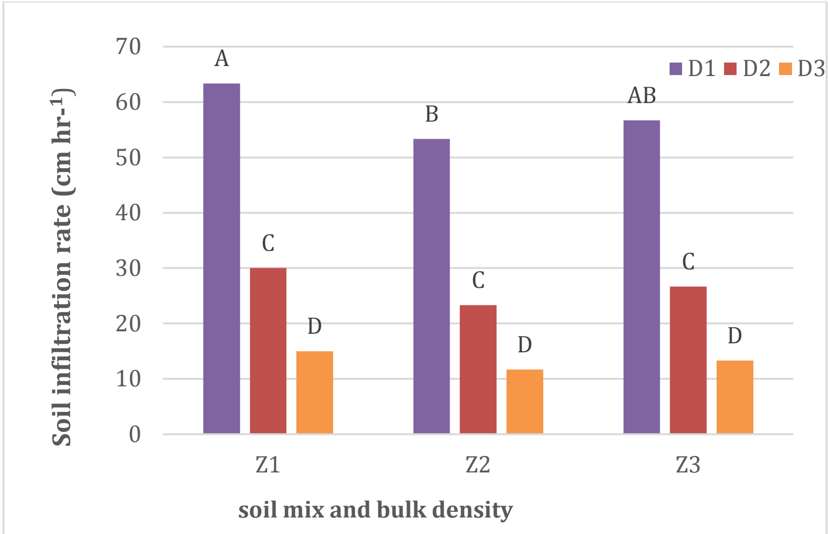

Figure 16: Impact of (Pb) Levels and Soil Mix Composition on Infiltration Rate (cm hr^{-1})

Discussion

The results of this study indicate that both bulk density and soil composition significantly affect the physical, mechanical, and biological properties of root zones in sports pitches, supporting the idea that turfgrass growth, root development, and field performance depend heavily on soil texture, density, and structure. [19]. Turfgrass height, dry matter yield, root depth, and branching were strongly influenced by the type of root zone material. Among the tested materials, the crushed limestone mixture (Z_2) showed the best performance compared to native soil and sand-based mixes. This superiority is attributed to its well-graded particle size distribution, which provides adequate aeration, drainage, and moisture retention [29]. In contrast, native soil (Z_3), with its high fine particle content, exhibited compaction and poor drainage, restricting root elongation and oxygen diffusion. [30]. The efficacy of crushed limestone corresponds with prior research indicating that mixes with bulk densities ranging from 1.417 to 1.510 Mg m^{-3} attain an ideal equilibrium between infiltration and compaction resistance [5].

It was proven that bulk density (Pb) has a big effect on the porosity, infiltration, and mechanical resistance of soil. The research demonstrated an inverse correlation between bulk density and turfgrass growth indices. When bulk density raised, the height, root depth, and branching of the turfgrass all went down. Lower densities (1.45 Mg m^{-3}) kept the pores large and linked, which made it easy for water and oxygen to go through. Higher densities (1.55 Mg m^{-3}), on the other hand, made the soil firmer and left less pore space, which made it harder for roots to grow and water to soak in [25].

The makeup of the soil also had a big effect on its bulk density. This indicated that the impacts of density depend on what the material is made of. Crushed limestone worked effectively even when it was only mildly compressed (1.50 Mg m^{-3}) because its particles were angular and its aggregates were stable Huang, [7]. Only when the density was low did sand-based mixes function successfully. Native soils with a fine texture do not work well at any density; therefore, they are unsuitable for turf unless mixed with coarser materials [4]. The mechanical properties of the soil, such as vane shear strength and penetration resistance, increased markedly with bulk density, reflecting stronger cohesion and particle interaction [31]. But if there is too much resistance, roots have a harder time growing and water has a harder time getting in. The optimal bulk density range of 1.45–1.50 Mg m^{-3} was established as best for maintaining stability and promoting root growth, aligning with the principle of “functional compaction”, which posits that soil strength should be sufficient for load-bearing without hindering plant development [30].

The research indicates that constructing sports fields using crushed limestone sand rather than natural sand is an excellent idea that will endure for an extended period. The density of this material is between 1.45 and 1.50 Mg m^{-3}. This is the right balance of drainage, stability, and grass performance. Using limestone materials that are close by can assist the environment and save money while still meeting safety and performance standards. Also, good field management is needed to keep the bulk density at a good level and prevent the field from getting excessively compacted while it is being used. Aeration, topdressing, and watering on a timetable are all part of this [9]; [8].

Conclusion

This study examined the feasibility of employing crushed limestone sand as a natural sand alternative, assessing the impact of soil composition and bulk density on the mechanical, biological, and physical characteristics of sports field rootzones. Research undertaken in both controlled and natural environments demonstrates that the bulk density and composition of the root zone are critical factors affecting turfgrass development, soil stability, and water infiltration.

In both physical and mechanical ways, mixes of crushed limestone sand worked better than natural sand and native soil. The crushed limestone particle size helps maintain drainage, aeration, and stability. This balance in the structure made the turfgrass higher, gave it deeper roots, and created more dry matter. These characteristics helped it spread out more evenly. It also has adequate shear strength to stay strong and last through sports. The bulk density made the ground tougher, the grass grew better, and the ground took up water better. When the bulk densities were between 1.45 and 1.50 g cm^{-3}, the lawn looked better, the roots grew stronger, and the water soaked in faster. The gaps between the pores let air through. But when it was excessively thick at 1.55 g cm^{-3}, it was harder for air and water to move about. The grass and roots as a whole were damaged by this.

Researchers discovered that materials with a higher bulk density provide superior mechanical properties, such as shear strength and penetration resistance. Soils that were too compacted had less biological activity and root penetration, but soils that were moderately compacted were firmer and better for playing on. So, to keep your lawn healthy, it's important to find the right balance between mechanical stability and root zone porosity.

There was also a strong inverse linear association ($R^2 > 0.93$) between bulk density and infiltration rate in all soil combinations. The soil's porosity and ability to soak up water decreased considerably as the bulk density went up. This indicates that compaction can hurt how well water flows through soil. Because it was coarser and had greater pore continuity, the sand-dominant mixture (Z_1) let the most water through at all levels of compaction. The fine-textured mixture (Z_3) had the lowest infiltration rates because it had fewer macropore connections. To ensure that water can move freely in the root zone, keep the bulk density below 1.50 Mg m^{-3}. This will help the soil's structure stay the same and make sure that water can move through it.

References

[1]. Huang, B., DaCosta, M., & Jiang, Y. (2014). Research advances in mechanisms of turfgrass tolerance to abiotic stresses: from physiology to molecular biology. Critical Reviews in Plant Sciences, 33(2–3), 141–189. DOI: 10.1080/07352689.2014.870411

[2]. Krum, J. M., & Carrow, R. N. (2020). Turfgrass management and environmental sustainability. Agronomy, 10(9), 1261. https://doi.org/10.3390/agronomy10091261

[3]. Hillel, D. (2004). Effects of soil structure and bulk density on root growth and water uptake. Soil and Tillage Research, 77(2), 171–179. https://doi.org/10.1016/j.still.2003.12.004

[4]. Guertal, E. A., & Howe, J. A. (2021). Soil physical properties and water movement in intensively managed turfgrass systems. Agronomy Journal, 113(5), 3938–3948. https://doi.org/10.1002/agj2.20743

[5]. Fattah, M. A. (2016). Using crushed limestone rocks in sports field rootzones at different levels of bulk density. J. of Agri. Sciences, Univ. of Sulaimani, 48(2), 1–10. DOI:10.17656/jzs.10507

[6]. Hamza, M. A., & Anderson, W. K. (2005). Soil compaction in cropping systems: A review of the nature, causes and possible solutions, Soil & Tillage Research, 82(2), 121–145. https://doi.org/10.1016/j.still.202004.08.0009

[7]. Huang, B., & Xu, Q. (2015). Rootzone characteristics and turfgrass responses to soil texture and amendments. Agricultural Water Management, 152, 99–107. DOI:10.1016/j.agwat.2015.02.009

[8]. Bigelow, C. A., Bowman, D. C., & Cassel, D. K. (2001). Physical properties of three sand size classes amended with inorganic materials or sphagnum peat moss for putting green rootzones. Crop Science, 41(3), 886–892. DOI: 10.2135/cropsei.2001.413886x

[9]. Leinauer, B., & Devitt, D. A. (2013). Irrigation and water management. In Turfgrass: Biology, Use, and Management (pp. 535–582). ASA, CSSA, and SSSA, Madison, WI. DOI: 10.2134/agronmonogr56.c15

[10]. Aziz, S.A., Rasheed, H.M., & Taha, N.A. (2017). Effect of sand fractions and peat mixtures on infiltration rate and turfgrass growth performance in play yards. Journal of Soil and Turfgrass Science, v. 19, i. 2, p.53-60. DOI: 10.17656/jzs.10611

[11]. Day, P.R. (1965). Particle fractionation and particle-size analysis. In C.A. Black (Ed.), Methods of Soil Analysis, Part I: Physical and Mineralogical Properties, Including Statistics of Measurement and Sampling (pp. 545–567). American Society of Agronomy, Madison, Wisconsin, USA. DOI: 10.2134/agronmonogr9.1.c43

[12]. Jackson, M.L. (1958b). Soil Chemical Analysis: Advanced Course. University of Wisconsin, Madison,

Wisconsin, USA.

[13]. Jackson, M.L. (1958a). Soil Chemical Analysis. Prentice-Hall Inc., Englewood Cliffs, New Jersey, USA.

[14]. Page, A. L., Miller, R. H., & Keeney, D. R. (Eds.). (1982). *Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties* (2nd ed.). American Society of Agronomy and Soil Science Society of America, Madison, Wisconsin, USA. DOI:10.2134/agronmonogr9.2.2ed

[15]. ASTM (2007). Standard Test Method for Particle-Size Analysis of Soils (ASTM D422-63, Reapproved 2007). American Society for Testing and Materials, ASTM International, West Conshohocken, Pennsylvania, USA. DOI: 10.1520/D0422-63R07

[16]. Blake, G.R., & Hartge, K.H. (1986). Bulk density. In A. Klute (Ed.), Methods of Soil Analysis, Part 1: Physical and Mineralogical Methods (2nd ed., pp. 363–375). American Society of Agronomy and Soil Science Society of America, Madison, Wisconsin, USA. DOI: 10.2136/sssabookser5.1.2ed.c13

[17]. Allen, R.G., Pereira, L.S., Raes, D., & Smith, M. (1998). Crop Evapotranspiration Guidelines for Computing Crop Water Requirements (FAO Irrigation and Drainage Paper No. 56). Food and Agriculture Organization of the United Nations (FAO), Rome, Italy. DOI: 10.1061/40499(2000)125

[18]. Abdullahi, M.B., Ajanlekoko, J.O., & Owonubi, S. (2020). Comparison between in-situ vane test and undrained triaxial test for cohesive soils. Civil and Environmental Research, 12(6), 21–30. https://doi.org/10.7176/CER/12-6-03

[19]. Zhang, J. et al. (2019). Effects of soil compaction and irrigation level on turfgrass performance and soil water distribution. Agronomy Journal, 111(5), 2530–2541.

[20]. DOI: 10.2134/agronj.2018.12.0779

[21]. AOAC (2000). Official Methods of Analysis of AOAC International (17th ed.). Association of Official Analytical Chemists, Gaithersburg, Maryland, USA.

[22]. Skempton, A. W., & Brogan, J. M. (1994). Experiments on Piping in Sandy Gravels. Géotechnique,44(3),449–460.DOI:10.1680/geot.1994.44.3.449

[23]. Olofin, E.A., Dada, G.A., & Eze, C.L. (2017). Effect of particle size distribution on the engineering properties of compacted lateritic soils. Nigerian Journal of Technology, 36(2), 387–395. DOI: 10.4314/njt.v36i2.10

[24]. Zhang, H., Li, W., & Wang, X. (2018). Mechanical properties of compacted soils and their effect on root growth. Soil Science Society of America Journal, 82(6), 1456–1465.

[25]. DOI: https://doi.org/10.2136/sssaj2018.03.0124

[26]. Lipiec, J., Horn, R., Pietrusiewicz, J., & Siczek, A. (2012). Effects of soil compaction on root elongation and anatomy of different cereal plant species. Soil and Tillage Research, 121, 74–81. https://doi.org/10.1016/j.still.2012.01.013

[27]. Lal, R. (2015). Soil compaction and soil health in agriculture. Soil & Tillage Research, 146, 121–128.https://doi.org/10.1016/j.still.2014.10.001

[28]. Wang, X., He, J., Bai, M., Liu, L., Gao, S., Chen, K., & Zhuang, H. (2022). The impact of traffic induced compaction on soil bulk density, soil stress distribution and key growth indicators of maize in North China Plain. Agriculture, 12(8), 1220. https://doi.org/10.3390/agriculture12081220

[29]. Lu, N., Godt, J. W., & Wu, D. T. (2010). A closed-form equation for effective stress in unsaturated soil. Water Resources Research, 46(5). DOI: 10.1029/2009WR008646

[30]. Horgan B.P., Hollman A.B. & Watkins E. (2010) “Evaluation of alternative turfgrass species for low□input golf course fairways” Hort. Science 45(1):113□118–https://doi.org/10.1002/csc2.20122

[31]. Carrow, R. N. (1990). Soil compaction effects on turfgrass growth. Agronomy Journal, 82(4), 761–766. https://doi.org/10.2134/agronj1990.00021962008200040022x

[32]. Dexter, A. R. (2004). Soil physical quality: Part I. Theory, effects of soil texture, density, and organic matter, and effects on root growth. Geoderma, 120(3–4), 201–214. DOI: 10.1016/j.geoderma.2003.10.018

[33]. Al-Khafaji, A. N., & Andersland, O. B. (1992). Equations for Compressibility and Consolidation of Soils. Journal of Geotechnical Engineering, 118(1), 148–152. DOI: 10.1061/(ASCE)0733-9410(1992)118:1(148)

تاثير الحجر الجيري المسحوق ، خليط الرمل والكثافة الظاهرية في بعض الخصائص الفيزيائية للتربة المزروعة بالعشب الرياضي في محافظة السليمانية - العراق

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الخلاصة

أُجريت هذه الدراسة في الملعب التجريبي لكرة القدم بكلية علوم الهندسة الزراعية، جامعة السليمانية، بهدف تقييم تأثير الحجر الجيري المسحوق، وخليط الرمل، والكثافة الظاهرية على بعض الخصائص الفيزيائية للتربة ذات العلاقة بأداء العشب الرياضي. استخدم تصميم عاملي تضمّن ثلاثة أعماق لخليط منطقة الجذور (Z_1) ، Z_2، (Z_3وثلاث مستويات من الكثافة الظاهرية(D_1 (1.45) :، D_2 (1.55)، و D_3 (1.65) كغم م$^{-3}$، مما نتج عنه تسع معاملات ($Z \times D$). تم تقييم أربعة مؤشرات رئيسية هي: معدل الترشح، وقوة القص، والإيصالية الهيدروليكية، والمحتوى من المادة الجافة.

أظهرت النتائج علاقة عكسية قوية ($R^2 > 0.93$) بين الكثافة الظاهرية ومعدل الترشح، مما يشير إلى أن زيادة الانضغاط تقلل بشكل واضح من نفاذية التربة. أظهرت خلطات الحجر الجيري المسحوق أداءً هيكلياً وهيدروليكياً أفضل مقارنةً بالخلطات الرملية البحتة، نتيجة لتحسن ترابط الجزيئات وانخفاض المسامات البينية. حافظ الخليط (Z_1الغالب عليه الرمل) على أعلى معدلات ترشح، في حين حقق الخليط Z_2 الغني بالحجر الجيري أعلى إنتاج للمادة الجافة (7.667%) عند الكثافة D_1 (1.45 كغم م$^{-3}$). عند أعلى مستوى انضغاط ($D_3 = 1.65$ كغم م$^{-3}$) انخفض كل من معدل الترشح والمادة الجافة بشكل ملحوظ ليصل إلى 2.333% في المعاملة $Z3 \times D1$. ازدادت قوة القص بزيادة الكثافة، من 1.9–2.2 كيلوباسكال إلى 2.5–3.1 كيلوباسكال، مما يؤكد زيادة المقاومة الميكانيكية في الترب الكثيفة. كما انخفضت الإيصالية الهيدروليكية مع زيادة الكثافة الظاهرية ($R^2 = 0.998$). وبشكل عام، تفوقت خلطات الحجر الجيري المسحوق على الرمل الطبيعي من حيث الاستقرار والبنية المسامية والدعم الحيوي لنمو العشب الرياضي بصورة مستدامة.

الكلمات المفتاحية: خليط الحجر الجيري المكسر والرمل؛ الكثافة الظاهرية للتربة؛ معدل تسرب المياه إلى التربة؛ المادة الجافة؛ ملاعب العشب الرياضي.