Journal homepage www.jzs.univsul.edu.iq
Journal of Zankoy Sulaimani
Part-A- (Pure and Applied Sciences)

Using Crushed Limestone Rocks in Sports Field Rootzones at Different Levels of Bulk Density

Mohammed Abdulrazzaq Fattah
Faculty of Agricultural Sciences-Sulaimani University, Bakrajo Street, Sulaimaniyah-Iraq
muhammad.fattah@univsul.edu.iq

Article info

Original: 23.07.2015
Revised: 19.10.2015
Accepted:12.11.2015
Published online: 20.06.2016

Key Words:
Crushed limestone, Bulk density, Sability, Hydraulic conductivity, Penetration resistance, Water holding capacity.

Abstract

Most parks and sports fields are built using native type soils that generally contain excess clay and silt contents. Problems associated with these soil types include: easily compacted, poor drainage, low water infiltration, low nutrient availability, and reduced root growth. Various methods have been used to modify these soils by mixing it with sand and other amendments, due to shortage of natural sand in many parts of the world and conserving natural resources, it is necessary to find alternative materials; crushed limestone sand can be identified as an alternative natural sand in making good quality sport field mixture.

To assess the possibility of using crushed limestone rocks and to establish a successful sports field mixture, (700, 270 and 30 g kg^{-1}) of crushed limestone sand, native soil, and peatmoss, respectively on mass basis were mixed. Some parameters that are related to soil mixture of sport field were studied: stability, saturated hydraulic conductivity (K_{sat}), maximum water holding capacity (M_{WHC}), and each of water holding capacity (W_{HC}) against the gravity and penetration resistance (P_{RE}) of mixture over time were measured at different bulk densities (1.2, 1.3, 1.4, 1.5 and 1.6 Mg m^{-3}). To select the best bulk density (ρ_b) at constructed sports field rootzones, the coefficient of determination (R^2) between ρ_b and each of the studied parameters were determined which were strong relation among them. This finding suggests that ρ_b may control problems during making soil mixture. In this research the best ρ_b of mixture are ranged from 1.417 to 1.510 Mg m^{-3} at which sports field soil provided good stability, good drain, and the quality of the playing surface well recognized in unfavorable weather conditions.

Introduction

One of the important factors influencing the construction of a successful sports field is the selection of a good quality soil mixture for the root zone. Sports fields with the right soil mixture will resist compaction, drain properly, hold moisture and nutrients and will require less fertilizer, pesticides and herbicides [1]. Taha (2013) [2] reported that the soil mixture of sports field grass is not studied in Kurdistan condition, since Kurdistan region is considered as a semiarid region that is specified with hot, dry summer and cold winter, additionally, many of the existing native soils in Kurdistan region have clay, silty clay, silty clay loam textures, are very susceptible to compaction and are very slow to drain. Unmanageable soil mixture may happen due to two of these conditions or more being estabilished. These problems obligate the constructer to think about improving existing native soil conditions on sports fields that do not live up to expectations.

Various methods have been used to modify the soil, these methods usually involve modifying the soil by mixing it with sand and other amendments such as peat, calcites clay, sawdust and other, to maintain proper soil condition for healthy grass plants even after a high degree of compaction. Li (2001) [3] summarized that the stability of sand and soil aggregates has been the concern when they are subjected to weathering actions. The chemical, physical and freezing and thawing actions involved in the weathering process have a great impact on the physical properties after construction. The blending of organic matter with high clay content soils during construction along with a good aerification program will provide increased control of soil compaction problems. Sand is the most commonly used because it is cheap and more available, besides, it does not change its structure when exposed to the impact of frequent foot traffic [4]. Since if the amount of added sand to the soil is not enough, or the selected sand is not right, then the quality of these soils could become unwanted for use in sports field construction. Entering the 1990s, peat became an irreplaceable component in sand-based golf greens to hold more water and nutrients. In studying the physical properties of organic materials in sand-based root zones, [5] reported that no more than 3.5% organic matter by weight should be included in the final mixtures in order to obtain ρ_b < 1.45 Mg m^{-3}, and available water content > 0.2 m^3 m^{-3}. Bulk density is affected by the contents of organic matter in soils, their texture, mineral constituents and total porosity. Knowledge of soil ρ_b is essential for soil management, and information about it is important in soil compaction as well as in the planning of modern farming techniques [6].

Due to shortage of natural sand in many parts of the world and conserving natural resources, there is a need to find alternative materials; crushed limestone sand has been identified as a potential substitute material for natural sand in making good quality sport field mixture, just like how it is used in other engineering fields, it is better to use it in this field also. The objective of this research is to assess the possibility of using crushed limestone sand by studied parameters that are related to soil mixture of sport field, particularly the physical properties, such as M_{WHC},W_{HC}, P_{RE}, K_{sat} and stability of rootzones mixtures over time.

Materials and Methods

Representative soil samples were taken from the field of the Faculty of Agricultural Sciences-Bakrajo at layer (0-30) cm, then air dried and sieved at 2mm sieve to prepare a construction of sport field media by mixing with sand and peatmoss; and subsamples were taken for measuring physical and chemical properties such as content of sand, (silt+clay), ρ_b, organic matter, pH, and some soluble [Ca^{2+}, Mg^{2+}, Na^+, Cl^-, HCO_3^-, CO_3^{2-}] were determined according to the procedure outlined by [7] which were tabulated in (Table, 1). After the preparation of mixture the maximum compactability was determined by using the standard proctor method [8].

Table-1: Some physical and chemical properties of the studied soil.

Si+C	Sa	O.M	ρ_b	EC	Ca^{2+}	Mg^{2+}	Na^+	Cl^-	HCO_3^-	CO_3^{2-}	pH
	g kg^{-1}		Mg m^{-3}	dS m^{-1}			Meq L^{-1}				
900	100	20	1.39	0.46	3.4	0.9	0.7	0.4	3.6	0	7.6

Preparation of mixture (sport field media)

The mixture was prepared from sand, native soil, and peatmoss on mass basis as (700, 270 and 30 g kg^{-1}) respectively [2]; and table (1) shows the soil's contain 90% silt+clay, 10% sand and 2% organic matter, therefore the mixture was made after correction from sand, silt+clay, and organic matter (726, 237.6 and 35.4 g kg^{-1}), respectively (Table, 2). Size distribution of sand produced from crushed limestone was determined by sieving method as shown in figure (1) according to the method described by [9] while, figure (2) shows the particle size distribution of the mixture.

Sand with D_{85}-D_{15} consisted of particles within the range (0.53-0.14) mm in diameter. These values can be read off a summation graph where D_{85} represents the particle diameter D at 85% of the cumulative total, and D_{15} is the same at 15% of the cumulative total, that might lead to a maximum of 15% of particles larger than 0.53mm and a further 15% smaller than 0.14mm (Figure, 1). These values near to the values of topsoil sands in Stewart zones which ranges (0.6–0.14) mm [10]. While, mixture with D_{85}-D_{25} consisted of particles within the range (0.47-0.05)mm in diameter, this would allow for a maximum of 15% of particles larger than 0.47mm and a further 25% smaller than 0.05mm (Figure, 2). Specification of this mixture was near to the mixtures specification of each [11, 12 and 13].

Table-2: Some physical and chemical properties of soil mixture.

Si+C	Sa	O.M	EC	Ca^{2+}	Mg^{2+}	Na^{+}	Cl^{-}	HCO_3^{-}	CO_3^{2-}	pH
	g kg^{-1}		dS m^{-1}			Meq L^{-1}				
726	237.6	35.4	1.34	7.2	3.4	2.1	1.8	6.9	0	7.8

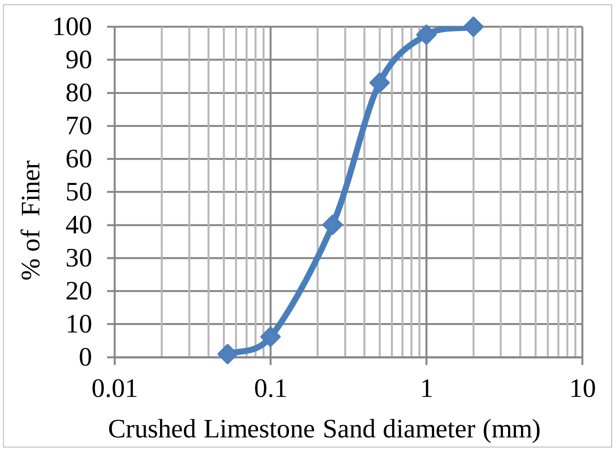


Figure-1: Particle size distribution curve for the crushed limestone sand.

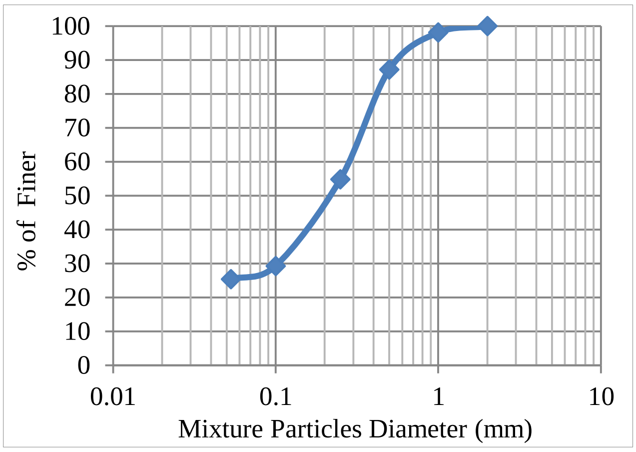


Figure-2: Particle size distribution curve for the mixture.

Preparation of samples

A special apparatus was manufactured to prepare the compacted mixture samples; the apparatus consisted of a small mold 5.6 cm in diameter by 5 cm length, a metal base and a piston. The prepared sample was splitted into 2 kg portions, then proper amount of water was added to each portion by sprinkling to bring the soil water content to optimum level, then a predetermined weight of moist mixture at optimum water content was placed inside the mold which mentioned before to achieve these bulk densities (1.2, 1.3, 1.4, 1.5 and 1.6 Mg m^{-3}), since compaction was proceeded by forcing the piston and the disk inside the mold and continued until the upper plate of the piston touched the upper sides of the mold then some parameters which are related to soil mixture of sport field were studied: stability (particles spacing) was estimated in saturated mixture at non-stressed and stressed by tapping in two levels 25 and 50 times from a height of 25 mm; K_{sat} and the ambient temperature was maintained at 30 ± 3°C during measurements using constant head of 50 mm, which was equivalent to a constant hydraulic gradient of 2; M_{WHC}, and each of W_{HC} against the gravity and P_{RE} of the mixture overtime were measured at each bulk density as mentioned previously.

Results and Discussion

Moisture-density relationship of sports field mixture

Moisture-density relationships for the sport field mixture is shown in figure (3), it can be noticed that the resulted curve is bell shaped and it was noticed that the part of the curve after optimum water content parallelled the zero air voids, from linear equation of zero air voids the approximate saturation point can be predicted at any ρ_b, for example if you like to construct a sport field media with 1.5 Mg m^{-3} the saturation point become 30.58%, this helps the constructer to know the amount of water which can be held at sport field media and consequently getting information about stability of media, surface wear, performance and players stress.

Also figure (3) revealed that the optimum water content was ranged between 16 and 18 g g^{-1}, likewise, it was observed that the maximum dry ρ_b was 1.7 Mg m^{-3},on the base of maximum dry ρ_b, the mixture parameters were studied. There was an evidence of an increase in maximum dry ρ_b with an increase in sand content and vice versa for organic matter content, since the values of sand and organic matter are mentioned in the preparation of the mixture.

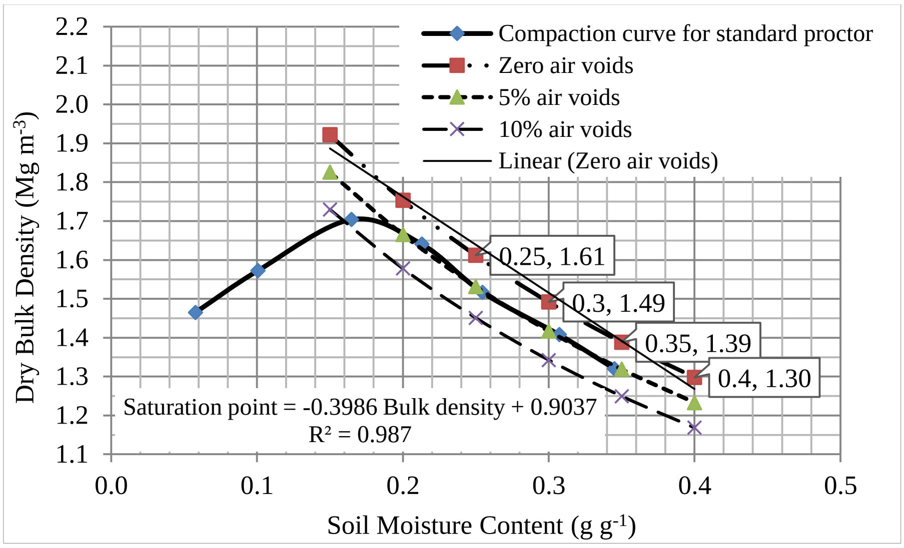
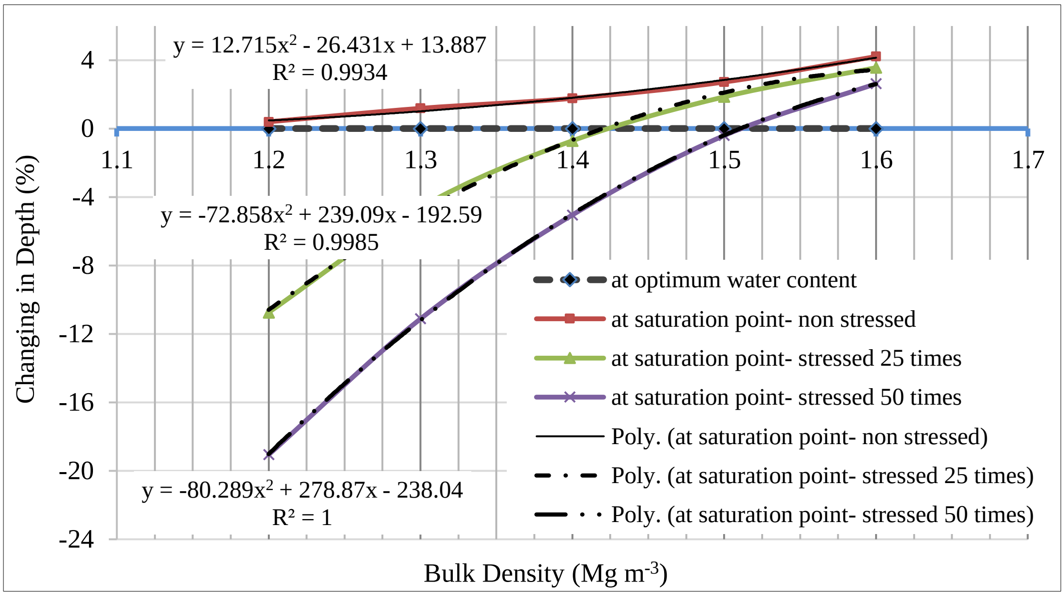


Figure-3: Moisture-Density relationship for the mixture.

Stability of the mixture

Percentage of changing in mixture depth was studied as an index of reduction particles spacing or stability of sport field mixture, more % of changing in mixture depth means more reduction particles spacing of sport field mixture. Figure (4) indicates that there was a decrease % of changing in mixture depth with increasing mixture ρ_b from 1.2 to 1.6 Mg m^{-3}, since with increasing ρ_b, stiffness surface and surface shear strength increased and vice versa, low stiffness surfaces will yield to the player, reducing physiological stress but increasing the energy consumption of the player and so fatigue due to a greater compressibility of the surface. Likewise, low surface shear strength will cause player instability due to the lack of traction, with the consequent risk of injury for the players. A low strength surface will be more susceptible to wear and degradation. At the same time, compliant or low stiffness surfaces will present a higher risk of compaction and unevenness, creating an undesirable low oxygen condition for the grass plant. While with increasing ρ_b as shown in figure (4) that means stiff surface, in turn, may increase physiological stress to the player but will result in more efficient energy balance due to a limited surface deformation. At the same time, greater stiffness implies less surface compaction and so a more homogenous and even surface. Likewise, excessive shear strength will imply little deformation of the surface and will cause too much traction with the subsequent higher risk of injury for the player. Whereas, at optimum state that exist between these two mentioned conditions where injury risk and surface wear would be kept at a minimum level, while allowing for a reasonable level of sports performance.

From the strong and significant polynomial regression (R^2 = 0.9934, 0.9985 and 1.00) ($P \leq 0.01$), for non-stressed and stressed 25 and 50 times tapping, respectively; could be confirmed that is more than 99% of the variation in mixture stability due to variation in mixture ρ_b. These findings suggest that ρ_b may control problems during making incapable mixture to be stable in depth and volume. Lowery and Schuler (1994) [14] revealed that when soil becomes compacted, it will break down, most aggregated, changed pore size distribution and reduced total porosity particularly macro pores that cause the soil to be more stable as a result of increasing soil ρ_b. Therefore selecting the best ρ_b at the construction sport field mixture is a worthy goal to reduce % of changing in mixture depth to minimum level which is equal to zero, by using equations of stressed mixture with 25 and 50 times and the results of bulk densities are 1.417 and 1.510 Mg m^{-3} respectively, so the target ρ_b of sport field mixture in this research is ranged from 1.417 to 1.510 Mg m^{-3} to be more stable in volume, consequently injury risk and surface wear would be kept at a minimum level while allowing for a reasonable level of sport performance.



Figurer-4: Effect of bulk density on depth changing of sports field mixture.

Effect of bulk density on maximum water holding capacity

Simple regression of ρ_b with W_{HC} was performed as shown in figure (5) and the results revealed that maximum W_{HC} was significantly ($P \leq 0.01$) and negatively related ($R^2 = 0.9949$) with the ρ_b, this agrees with [14] they reported that with increasing ρ_b in the same soil it will break down most aggregated then reduced macro pores consequently decreasing in total porosity and maximum W_{HC}. This reflects the importance of ρ_b in predicting maximum W_{HC}. This study supports the earlier findings of [2] who found that ρ_b was a significant discriminator of sports field mixture maximum W_{HC}. The maximum water holding capacities were 31.68% and 26.97% when bulk densities were 1.417 and 1.510 Mg m^{-3}, respectively. Since the volume of sports field soil does not change at 1.417 and 1.510 Mg m^{-3} for stressed mixture by tapping with 25 and 50 times as mentioned previously, the value of ρ_b at zero changing in depth can be predicted from the relationship between ρ_b and percentage of depth changing. Also at that point, sports field soil will provide good stability, good drain, and the quality of the playing surface well recognized in unfavorable weather conditions.

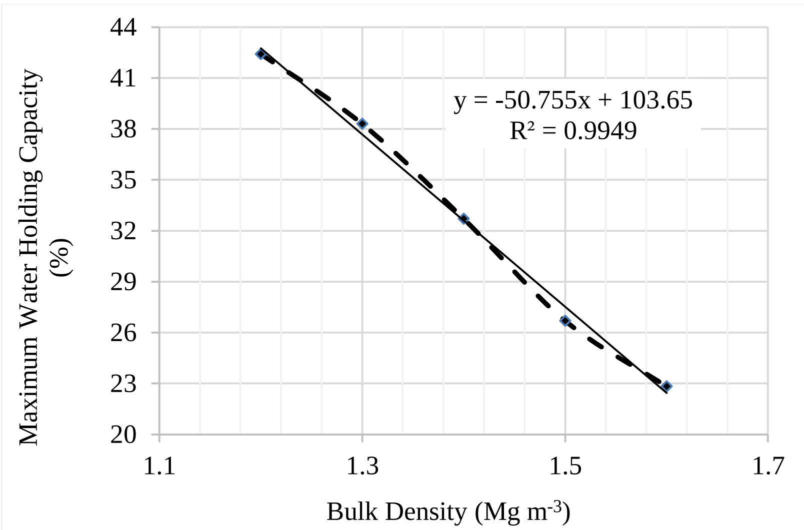


Figure-5: Effect of bulk density on maximum water holding capacity of the mixture.

Effect of bulk density on water holding against the gravity over time

At the beginning time, all water that might presented will include gravitational, available and unavailable water, while after a period, gravitational water will allowed to drain freely. Water holding against gravity designates the ability of a soil to hold water. It is useful information for irrigation scheduling, crop selection, groundwater contamination considerations, estimating runoff and determining when plants will become stressed, and it varies by soil texture. Because of these reasons apart of studies on the effects of different ρ_b (1.2, 1.3, 1.4, 1.5 and 1.6 Mg m^{-3}) on W_{HC} against gravity over time (1, 5, 15, 25, 35, 45, 65, 85, 105 and 1440) min was done as shown in figure (6) which shows that the W_{HC} against gravity was decreased with increasing ρ_b over time.The water holding against gravity after (1 and 1440) min in ρ_b of (1.2 Mg m^{-3}) were (0.424 and 0.372 g g^{-1}) which decreased 12.19%, while (1.6 Mg m^{-3}) of ρ_b which were (0.228 and 0.202 g g^{-1}) that decreased 11.47%. Replotted data of figure (7) shows that increasing ρ_b from (1.2 to 1.6 Mg m^{-3}) decreased W_{HC} by (46.2 and 45.7) % for (1 and 1440) min, respectively. This is agreeing with the results obtained by [15] they observed that increasing of available water storage capacity of several Missouri soils with the decreasing in soil ρ_b.

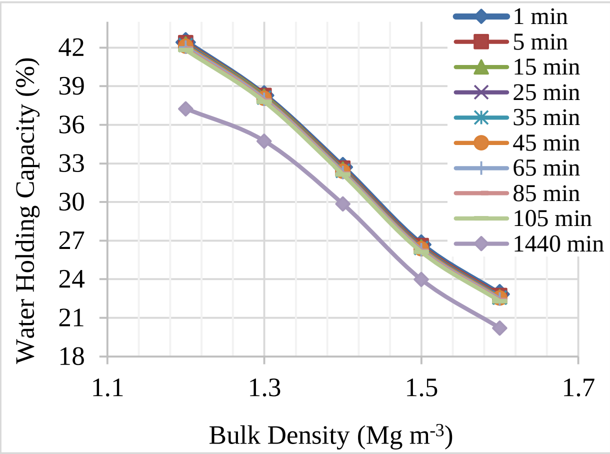


Figure-6: Effect of bulk density on water holding capacity.

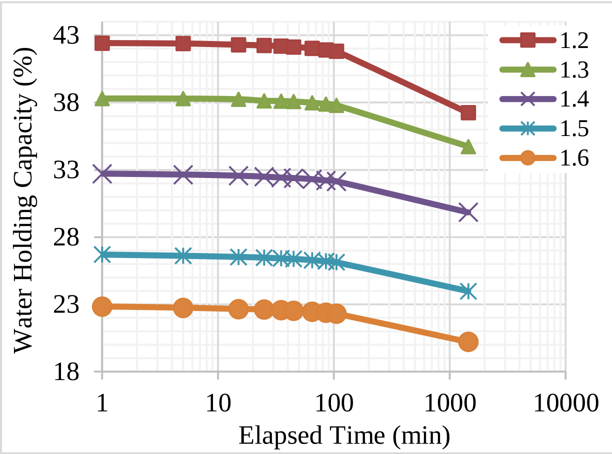


Figure-7: Water holding capacity versus elapsed time in different bulk density.

Effect of bulk density on penetration resistance

Penetrability is the quantitative measure of soils resistance to an object as it is physically inserted into the soil. Typically these measurements are collected through the use of a soil penetration and provide measurements of a soils resistance consistency. In general, compaction increases ρ_b and soil strength that increases P_{RE}, this was recorded in a study by [16]. Other factors that affect resistance include soil structure, soil moisture and compressibility. The results in figure (8) illustrate the effect of ρ_b in P_{RE}, confirming strong effect of ρ_b on P_{RE} when ρ_b increased from 1.2 to 1.3 Mg m^{-3} at all time periods (0, 0.25, 0.5, 0.75, 1, 2, 4, 48, 120) hrs having a steep slope (*i.e.*, the effect of ρ_b on P_{RE} is more than increasing ρ_b from 1.3 to 1.4 Mg m^{-3}) and when ρ_b reached 1.4 Mg m^{-3}, the relationship curve between P_{RE} and ρ_b becomes straight line and values of P_{RE} are ranged between (0.180 to 0.303 kg cm^{-2}) for periods of (0 and 120) hrs. This agrees with previous work of [17] they found that the P_{RE} increased with increasing ρ_b to some extent. So, the target ρ_b of sport field mixture in this research based on P_{RE} is more than 1.4 Mg m^{-3} to be more stable, consequently injury risk and surface wear would be kept at a minimum level while allowing for a reasonable level of sport performance, this ρ_b is very closed to which had been discussed earlier in the effect of ρ_b on stability which is more than 1.417Mg m^{-3}. Strong negative relations were noticed between P_{RE} and moisture content and the values of (R^2) are (0.9779 and 0.9835) for ρ_b (1.417 and 1.510 Mg m^{-3}), respectively (Figure, 9). These results are consistent with the results of [18] who found a strong negative relation (R^2 =0.995) between moisture content and P_{RE} in repacked sandy loam soils at different levels of ρ_b (1.35, 1.45, 1.55 and 1.65 Mg m^{-3}). The values of P_{RE} at field capacity (100% available water) are (0.6 and 0.8 kg cm^{-2}) for ρ_b (1.417 and 1.510 Mg m^{-3}), respectively while at 75% available water approximately are (0.8 and 1 kg cm^{-2}). Already, it is known that a 75 kg player wearing studded shoes and if player standing would exert (0.032 to 0.052 kg cm^{-2}) depending on the stud size and pattern, but when walking, this player would exert (0.096 to 0.156 kg cm^{-2}), and while running the compressive strength increases 2 to 3 times, amounting (0.24 to 0.39 kg cm^{-2}), another reference gives a value of up to 0.41 kg cm^{-2} for a running player wearing studded shoes. Added to these values for a running player, planting of one's foot for rapid direction changes will add significantly to these loadings [19]. While in this study, the mixture shear strength will provide sufficient resistance to compaction by player as mentioned previously cases. Also it should not be forgotten that high strength of soil mixture can physically impede root elongation [20], and thereby restrict oxygen, water, and nutrient uptake by grasses, and then reduce biomass production [21]. Moreover, at the high strength creating a stiff surface and may increase physiological stress to the players. For those reasons, selecting optimum state of the P_{RE} is very important as mentioned previously in the section of stability of the mixture, since the optimum state of the P_{RE} ranges (0.6 - 0.8 kg cm^{-2}) and (0.8 - 1 kg cm^{-2}) and they are good for the players where injury risk and surface wear would be kept at a minimum level, while allowing for a reasonable level of sport performance, and it is also positive shoot and root growth responses would be expected for the grass.

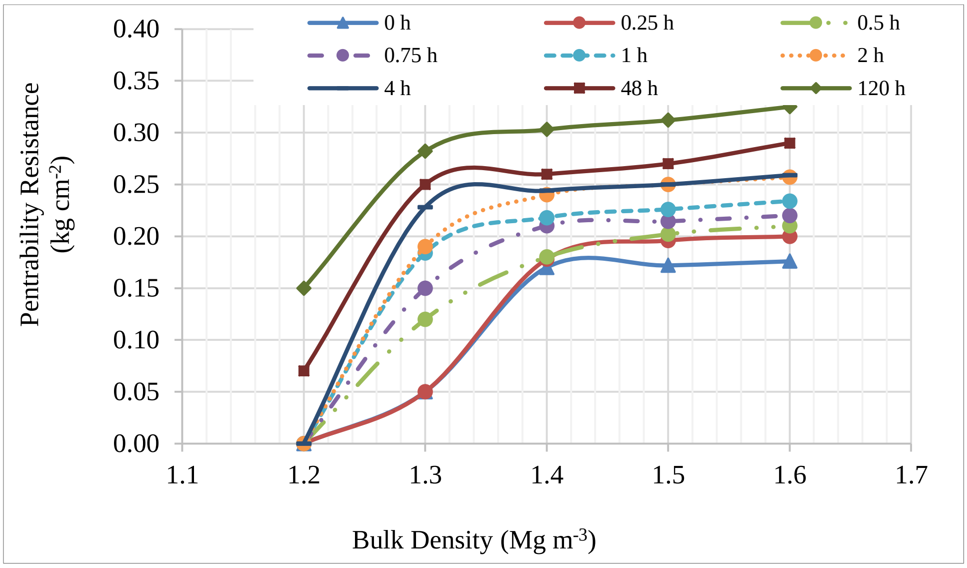


Figure-8: Effect of bulk density on penetration resistance at different times.

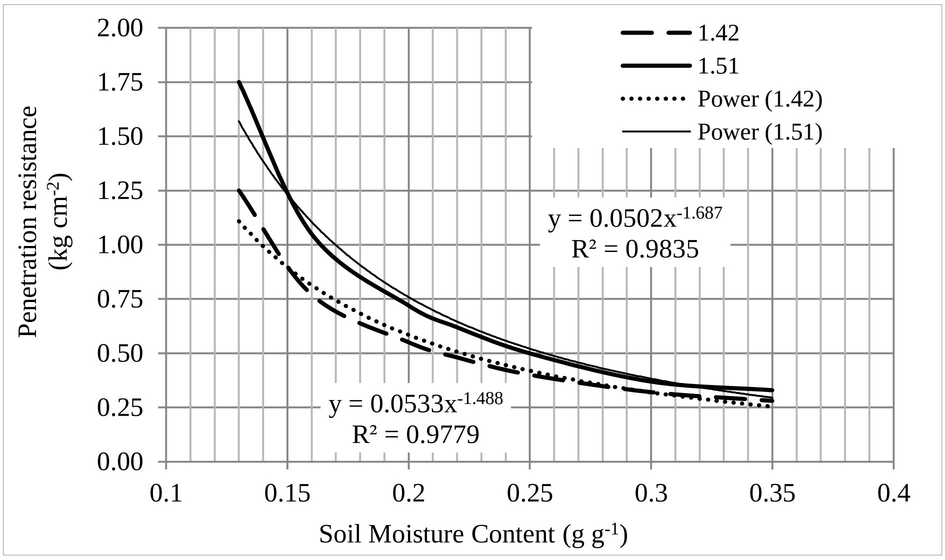


Figure-9: Effect of moisture content on penetration resistance at two levels of bulk density

Effect of bulk density on saturated hydraulic conductivity

Polynomial regression of ρ_b with K_{sat} (Figure, 10) revealed that K_{sat} was significantly ($P \leq 0.01$) and negatively related (R^2= 0.9848) with the ρ_b, this reflects the importance of ρ_b in predicting of K_{sat}. This study supports the earlier findings of [22] who found that the ρ_b had a significant effect on K_{sat}. This would be expected because the K_{sat} is a combined measure of size and continuity of pores and both of them are reduced with increasing soil ρ_b [23]. The predicted values of K_{sat} at ρ_b of 1.417 and 1.510 Mg m^{-3} are ($1.27x10^{-2}$ and 6.05 $x10^{-3}$) cm sec^{-1}. These values are very closed to the values which were recommended by [24] they reported that the best values of K_{sat} are ($1.667x10^{-2}$ and 4.167 $x10^{-3}$) cm sec^{-1}. Since the stability of sport field soil does not change at 1.417 and 1.510 Mg m^{-3} as mentioned previously, this range of the sports field soil provides good stability, good drain and the quality of the playing surface well recognized in unfavorable weather conditions.

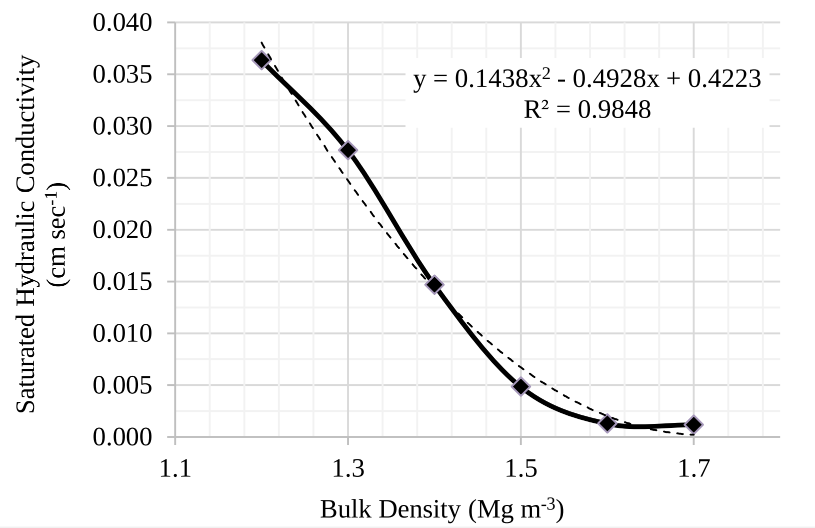


Figure-10: Effect of bulk density on saturated hydraulic conductivity.

Conclusions

- A good topsoil sands for sports field rootzones with reliable properties can be obtained from a mixture made from native soil, peatmoss and crushed limestone sand.
- The depth or volume changing, *PRE*, M_{WHC}, W_{HC} against the gravity of mixture were affected by different levels of ρ_b.
- More than 99% of the variation in depth changing is due to variation in ρ_b in sports field mixture; therefore the ρ_b may control problems through making mixture incapable to be stable in depth or volume.
- The target ρ_b of sport field mixture are ranged from 1.417 to 1.510 Mg m^{-3} which provides good stability, good drain, and the quality of the playing surface well recognized in unfavorable weather conditions, consequently injury risk and surface wear would be kept at a minimum level while allowing for a reasonable level of sport performance.

References

[1] McAfee, J., "Using Compost for Sports Fields", Texas Cooperative Extension, Dallas, TX, P.1, (2009).

[2] Taha, Z.Y., "Effect of sand fractions size and moisture contents on some physical properties of sport field soil", MSc Thesis, Faculty of Agricultural Sciences, University of Sulaimani, Sulaimani, Iraq, (2013).

[3] Li, D., "Physical properties of golf and sports turf rootzones as affected by amendments, construction methods, and management practices", Ph.D. dissertation. Iowa State University, Ames, Iowa, USA, (2001).

[4] Bingaman, D.E., and Kohnke, H., "Evaluating sand for athletic turf". Agron. J., 62:464–467, (1970).

[5] McCoy, E.D., "Quantitative physical assessment of organic materials used in sports turf rootzone mixes", Agron. J., 84:375-381, (1992).

[6] Chaudhari, P.R., Ahire, D.V., Ahire, V.D., Chkravarty, M., and Maity, S. "Soil Bulk Density as related to Soil Texture, Organic Matter Content and available total Nutrients of Coimbatore Soil". International Journal of Scientific and Research Publications, Volume 3, Issue 2, ISSN 2250-3153, (2013).

[7] Page, A.L., Miller, R.H., and Keeney, D.R., "Methods of soil analysis" Part 2. Amer. Soc. Agric. Pub. Madison, Wisconsin, U.S.A, (1982).

[8] ASTM-D698, "American Society for Testing and Materials, Standard test methods for laboratory compaction characteristics of soil using standard proctor method", (1986)

[9] Klute, A., "Methods of soil analysis", Part 1. 2nd Ed., Agron. Monogr. 9. ASA and SSSA. Madison. WI., (1986).

[10] Stewart, V.I., "Sports Turf Science, construction and maintenance, Soil Science and Sports Turf Consultant, Published in association with the National Playing Fields Association", E & FN SPON, An Chapman An Imprint of Chapman & Hall London-Glasgow, New, York, Tokyo, Melbourne, Madras, (2005).

[11] Wells, W., "Managing Sports Fields in Mississippi", Extension Service of Mississippi State University, cooperating with U.S. Department of Agriculture, Publication 2086, (2000).

[12] Taylor, D.H., and Blake, G.R., "Sand Content of Sand-Soil-Peat Mixtures for Turf grass", Soil Sci. Soc. Am. J., 43: 394-398., (1979).

[13] Swartz, W.E., and Kardos, L.T., "Effects of Compaction on physical properties of Sand-soil-peat mixture at various moisture Contents", Agron. J., 55: 7-10. (1963).

[14] Lowery, B., and Schuler, R.T., "Duration and effects of compaction on soil and plant growth in Wisconsin", Soil and Tillage Res., 29(2-3):205-210, (1994).

[15] Jamison, V.C., and Kroth, E.M., "Available moisture storage in relation to textural composition and organic matter content of several Missouri soils", Soil Sci. Soc. Am. J., 22(3), 189-192, (1958).

[16] Taylor, H.M., Robertsonand, G.M., and Parker, J.J., "Soil strength-root penetration relations for medium to coarse textured soil materials", Soil Sci., 102:18-22. (1966).

[17] Bengough, A.G., and Mullins, C.E., "Mechanical impedance to root growth: A review of experimental techniques and root growth responses", J. Soil Sci. 14:341-358, (1991).

[18] Costantinir, A., "Relationships between cone penetration resistance, bulk density, and moisture content in uncultivated, repacked, and cultivated hardsetting and non hard setting soils from the coastal lowlands of south-east Queensland", New Zealand Journal of Forestry Science, 26(3): 395-412, (1996).

[19] McCoy, E., Sherratt, P.J., and Street, J.R. "Golf course and athletic field soils; Soils in Landscaped Commercial Areas", edited by Joyce Scheyer, Encyclopedia of Life Support Systems (EOLSS), Developed under the Auspices of the UNESCO, Eolss Publishers, Oxford, UK, (2004).

[20] Barley, K.P., and Greacen, E.L., "Mechanical resistance as a soil factor influencing the growth of roots and underground shoots", Advances in Agron. 19(1): 1-43, (1967).

[21] Burdett, A.N., Simpson, D.G., and Thompson, C.F., "Root development and plantation establishment success", Plant and Soil 71:10-103, (1983).

[22] Fattah, M.A., "Some practical tests to reduce seepage from earthen ponds for different texture soils" MSc Thesis, College of Agriculture, University of Salahaddin-Erbil, Iraq, (2004).

[23] Singh, B.D, Chanasyk, S., and McGill, W.B., "Soil hydraulic properties of an Orthic Black Chernozem under long-term tillage and residue management", Can. J. Soil Sci., 75:63-71, (1995).

[24] Green Section Staff, "USGA Recommendations for a method of putting green construction", USGA Green Section Record 31(2):1-3, (1993).