Tikrit Journal for Agricultural Sciences
ISSN:1813-1646 (Print); 2664-0597 (Online)
Journal Homepage: http://www.tjas.org
E-mail: tjas@tu.edu.iq
DOI: https://doi.org/10.25130/tjas.25.4.6

TJAS
Tikrit Journal for Agricultural Sciences

A study on the impact Soil degree of Compactness on Soil Physical Quality index for Soils with varying gypsum content

Ruwaida Kh. Sabber
Soil Science & Water Resources Department, College of Agriculture, Tikrit University, Iraq
***Correspondence: Rowyda.khaild1@tu.edu.iq**

KEY WORDS:
critical bulk density, Soil water retention curve, Gypsiferous soils, Soil compaction

Received:	26/01/2025
Revision:	14/07/2025
Proofreading:	15/10/2025
Accepted:	26/07/2025
Available online:	31/12/2025

ABSTRACT

Laboratory experiments were conducted to study the impact of soil compaction degree (DC%) defined as the ratio between natural bulk density ($BD_{natural}$) and critical bulk density ($BD_{critical}$) on Soil Physical Quality index (S-index) for seven soil samples with different gypsum content 61.1(G1), 104 (G2), 151 (G3), 214 (G4), 279 (G5), 363 (G6), and 414 g kg^{-1}(G7). The water retention curve for each soil sample was determined at matric suctions of 0, 3, 8, 33, 200, 500, 700, 1000, and 1500 kPa after compacting the soil samples to bulk densities of 1.3, 1.5, and 1.7 Mg m^{-3}. The physical soil quality index (S-index) was calculated using the van Genuchten-Mualem equation implemented in the RETC program.The results revealed that the critical bulk density (Proctor density) decreased with increasing soil gypsum content. A positive exponential relationship was observed between the S-index and soil gypsum content, indicating that higher gypsum content improved the physical soil quality index. A negative polynomial relationship was found between soil gypsum content and compaction degree (DC%). Furthermore, the S-index was negatively correlated with both bulk density and compaction degree (DC%).

دراسة تأثير درجة رص التربة في مؤشر نوعية التربة الفيزيائية لترب مختلفة بمحتواها من الجبس

رويده خالد صابر
قسم علوم التربة والموارد المائية ، كلية الزراعة ، جامعة تكريت ، العراق

الخلاصة
نفذت تجارب مختبرية لدراسة تأثير درجة رص التربة (DC%) التي تمثل النسبة بين كثافة التربة الظاهرية ($BD_{natural}$) والكثافة الظاهرية الحرجة للتربة ($BD_{Critical.}$) في مؤشر نوعية التربة الفيزيائية(S-index) لسبع نماذج من التربة ذات محتوى مختلف من الجبس (G_1) 61.1 و (G_2) 104 و (G_3) 151 و (G_4) 214 و (G_5) 279 و (G_6) 363 و (G_7) 414 غم كغم$^{-1}$. قدر منحنى الوصف الرطوبي لكل نموذج من نماذج التربة عند الشدود 0 و3 و 8 و33 و 200 و 500 و 700 و 1000 و 1500 كيلوباسكال بعد رص نماذج التربة الجبسية الى الكثافات 1.3 و 1.5 و1.7 ميكاغرام م$^{-3}$ حسب مؤشر نوعية التربة الفيزيائية (S-index) باستعمال معادلة van Genuchten-Mualem وبتطبيق برنامج RETC. بينت النتائج انخفاض الكثافة الظاهرية الحرجة (كثافة بروكتر) بأرتفاع نسبة الجبس في التربة، ارتباط مؤشر نوعية التربة الفيزيائية (S-index) مع محتوى التربة من الجبس بعلاقة اسية موجبة إذ ادت زيادة نسبة الجبس في التربة الى ازدياد قيم مؤشر نوعية التربة الفيزيائية، وتم الحصول على علاقة سالبة متعددة الحدود بين محتوى التربة من الجبس ودرجة الرص(DC%)، ارتبط مؤشر نوعية التربة الفيزيائية بعلاقة سالبة مع الكثافة الظاهرية ودرجة الرص (DC%).
الكلمات المفتاحية: الكثافة الظاهرية الحرجة ، منحنى الوصف الرطوبي ، الترب الجبسية ، رص التربة.

INTRODUCTION

Gypsiferous soils are widely distributed in arid and semi-arid regions, where gypsum constitutes a significant proportion of their mineral composition, The degree of soil compaction is a critical factor influencing the physical properties of gypsiferous soils, such as aeration, water distribution, surface runoff, and permeability (Al-Kayssi,2021). Soil Physical Quality (SPQ) is closely related to compaction, which is primarily caused by the movement and passage of agricultural machinery and equipment. Soil compaction is one of the key indicators of reduced soil productivity, as it alters pore size distribution, negatively impacts soil properties, and reduces physical soil quality. Most physical, chemical, and biological soil processes are affected by compaction, leading to variations in the value of the S-index with changes in soil bulk density (Dexter, 2004a). Highly compacted soils can result in structural degradation, reduced porosity, and lower water retention capacity. Understanding the relationship between soil compaction degree in gypsiferous soils and physical soil quality requires studying the effects of compaction on factors such as bulk density and the soil water retention curve to achieve optimal soil management, maintain fertility, and ensure sustainable agricultural production.

The concept of Soil Physical Quality has been recently proposed and developed as an indicator for assessing soil degradation or improvement and for determining appropriate management practices to ensure agricultural sustainability and environmental protection for the well-being of plants and animals (Dexter, 2004a; Moncada *et al*., 2014). Although bulk density is a common indicator of Soil Physical Quality, it is not always suitable for comparing soils of different textures (Naderi-Boldaji *et al*., 2016). For instance, high bulk density may indicate compaction in clay soils, while it may suggest friability in sandy soils (Håkansson, 1990). Dexter (2004 a,b) introduced the "S-value" or "S-index" for Soil Physical Quality, which has been linked to various critical soil properties and conditions, including water conductivity, compaction, optimal soil water content for tillage, penetration resistance, available water, root growth, and soil structure stability. The S-index represents the slope of the soil water retention curve (WRC) at the inflection point of log(h), where matric suction is plotted against gravimetric water content (θg). The WRC is commonly described using mathematical relationships, among which the Van Genuchten (1980) equation is the most widely used. Dexter (2004a) employed this equation to develop the theoretical framework for the S-index, which allows deriving specific functions from measurable datasets to estimate the parameters of the Van Genuchten model (Wösten *et al*., 1999). soil moisture content decreased with an increase in gypsum content and water tension (Al-Asafi and Al-Hadeethi,2024) .

Soil compaction caused by machinery traffic is a major indicator of reduced soil productivity, as it alters pore size distribution and negatively impacts soil properties, reducing physical soil quality. The S-index value changes with soil bulk density (Dexter, 2004a). Soil Physical Quality is highly influenced by management practices, including cropping, fertilization, tillage, machinery traffic, and drainage (Ball *et al*., 1997; Bronick & Lal, 2005; Kibblewhite *et al*., 2008; Valipour, 2014). The S-index is significantly affected by soil compaction and bulk density (Naderi-Boldaji & Keller, 2016). This study aims to investigate the effect of soil compaction degree (DC%) on the physical soil quality index (SPQ, S-index) for soil samples with varying gypsum contents.

MATERIAL AND METHODS

Soil samples were collected from a gypsiferous soil profile at the Agricultural Research Station of the College of Agriculture, Tikrit University, located at 43°38'23" E longitude, 34°40'48" N latitude, and an altitude of 250 m above sea level. Samples were taken from the surface horizon (0–0.1 m depth) with a gypsum content of 1.16 g kg^{-1} (G1) and from the gypsiferous horizon (0.6–1 m depth) with a gypsum content of 414 g kg^{-1} (G7). Different soil samples with varying gypsum contents 104 (G2), 151 (G3), 214 (G4), 279 (G5), and 363 g kg^{-1} (G6) were prepared by mixing the surface soil sample (G1) with the gypsiferous horizon sample (G7) in specific proportions.The prepared soil samples were moistened by spraying water to reach two-thirds of their field capacity and incubated in sealed plastic bags. The samples were mixed daily for two months to ensure uniformity. After incubation, the soil samples were air-dried, passed through a 2-mm sieve, and stored in plastic containers for subsequent experiments. Approximately 150 g of each gypsiferous soil sample (G1–G7) was taken and adjusted to gravimetric moisture contents of 5%, 10%, 15%, 20%, 25%, and 30%. The samples were thoroughly mixed and stored in appropriate plastic bags to ensure uniform moisture distribution.Compaction tests were conducted for each soil sample (G1–G7) at the specified moisture levels using a Proctor apparatus (Proctor critical density) with metal rings measuring 61 mm in diameter and 20 mm in height. The compaction process involved tamping the soil 25 times using a 2-kg weight dropped from a height of 500 mm, following ASTM Standard (2007). The Proctor critical density, defined as the highest bulk density at a specific moisture content, was calculated using the following relationship:

$$\textbf{Critical bulk density}(\mathbf{BD_{Critical.}}) = \frac{\text{dry wight of compacted soil}}{\text{dry volume of compacted soil}} \quad ....1$$

Where:

- **Dry weight of compacted soil** refers to the oven-dried weight of the compacted soil sample (Mg).
- **Dry volume of compacted soil** represents the total volume of the soil sample after compaction (cm^{-3}).

Natural bulk density(**BD**) corresponds to the undisturbed density of the soil in its natural state (Mg m^{-3}). These relationships facilitated the calculation of bulk density under different compaction and moisture conditions for the gypsiferous soil samples.

$$\textbf{Natural bulk density(BD)} = \frac{M_s}{V_b} \qquad \ldots\ldots\ldots\ldots 2$$

Where:

- **BD** = Bulk density ($Mg\ m^{-3}$).
- **Ms** = Mass of dry soil (Mg).
- **V_b** = Bulk volume of soil (m^3).

The **Relative Bulk Density (RBD)** was determined using the following equation:

$$\textbf{RBD} = \frac{BD_{natural}}{BD_{critical.}} \qquad \ldots\ldots\ldots\ldots 3$$

Where:

- (BD)Natural; bulk density ($Mg\ m^{-3}$).
- (BD)Critical; bulk density (Proctor density, $Mg\ m^{-3}$).

This formula expresses the compactness of the soil as a percentage, representing the ratio of the natural bulk density to the critical bulk density.

$$\textbf{Dc} = \frac{BD_{natural}}{BD_{critical.}} \times 100\% \qquad \ldots\ldots\ldots\ldots 4$$

The moisture content for each gypsiferous soil sample was determined after compacting the samples to bulk densities of **1.3, 1.5, and 1.7 Mg m^{-3}**. The procedure was as follows:

Moistening the Soil Samples: A suitable amount of soil was moistened to achieve a moisture content equivalent to **100 kPa matric potential**. The moistened soil was then placed in tightly sealed plastic bags and left for **two days** to ensure uniform moisture distribution within the sample.

Compaction of the Soil Samples: Each soil sample was compacted to the specified bulk densities (1.3, 1.5, and 1.7 Mg m^{-3}). The required weight of the soil sample needed to fill the metal ring (61 mm in diameter and 20 mm in height) was determined based on the target bulk density and the volume of the ring.

Saturation through Capillary Action: The compacted soil samples were saturated by capillary action. The samples were placed in contact with water and allowed to absorb moisture until they reached saturation. The duration of this process ranged from **2 to 8 days**, depending on the bulk density of the soil, in order to ensure complete saturation of the compacted soils.

This approach ensured accurate determination of the moisture content and uniform saturation for each gypsiferous soil sample compacted to the specified bulk densities.

$$\textbf{Soil mass(dry)} = bulk\ density \times volume\ [(\frac{dimeter}{2})^2\ \pi \times height] \qquad \ldots\ldots\ldots 5$$

The moisture content equivalent to a matric potential of 100 kPa was selected for moistening the soil, based on a previous study (AL-Kayssi, 2021). At this potential, the soil moisture is ideal for compaction purposes, as it ensures the soil is neither too dry (which would hinder compaction) nor too wet (which could damage the soil aggregates before compaction).The moisture content for the compacted soils was determined at various matric potentials of 8, 33, 200, 500, 700, 1000, and 1500 kPa, following the procedure proposed by Klute (1986). For the gypsum soil samples at matric potentials of 0 and 3 kPa, the moisture content was estimated by applying a column of water using ceramic filters (Centerated glass funnels) with pore sizes of 20 micrometers. The moisture retention curve for the compacted gypsiferous soil samples, relating the gravimetric moisture content to the matric potential, was then plotted (Figure 1).

The moisture content was estimated using the Van Genuchten (1980) equation and Mualem's (1976) model, with the calculations being performed using the RETC program 1991. The Van Genuchten equation is given by.

$$w(h) = w_r + (w_s - w_r)[1 + (\alpha h)^n]^{[\frac{1}{n}-1]} \quad \text{............}\mathbf{6}$$

The equations and terms mentioned are used to describe the soil's moisture retention curve and its relationship with soil moisture content under varying matric potentials (tensions). Here's a breakdown of the terms:

w(h) (Matric potential):The soil moisture retention curve describes the relationship between soil moisture content and matric potential w(h). It typically covers a range of matric potentials from **0.1 kPa to 1500 kPa**, as defined by **Dexter *et al.*, 2008**.

w_r (Residual moisture content):This represents the **residual moisture content**, the minimum moisture level in the soil that is retained under high tension (i.e., at high matric potential), usually expressed in **kg kg^{-1}**.

w_s (Saturated moisture content):This is the **saturated moisture content**, the amount of moisture in the soil when it is fully saturated, typically expressed in **kg kg^{-1}**.

α (Shape factor):The **α** parameter is the **shape factor** and controls the steepness of the soil's moisture retention curve. It helps define how quickly the soil dries out or how much moisture is retained at specific tension levels.

n (Shape parameter):The **n** parameter determines the shape of the soil's moisture retention curve, influencing its **curvature**. It controls the transition from a fast drop in water content at low tensions to a more gradual decrease as the soil becomes drier.

These parameters, **w_r**, **w_s**, **α**, and **n**, are crucial for describing the water retention behavior of soils. The **Van Genuchten model** (1980) is often used to relate these parameters mathematically, and it is widely applied in soil science to model soil-water relationships.For reference, the Van Genuchten equation is typically written as

The appropriate parameters of the model were used to calculate the coordinates of the inflection point of the moisture retention curve (Dexter, 2004a) from the following equations: Weight moisture content

$$\boldsymbol{w_i} = w_r + (w_s - w_r)\left(\frac{2n-1}{n-1}\right)^{[\frac{1}{n}-1]} \quad \text{................}7$$

$$h_i = \frac{1}{\alpha}\left[\frac{n}{n-1}\right]^{\frac{1}{n}} \quad \text{.............}8$$

Where:

- w_s : Saturated gravimetric moisture content (kg kg^{-1}).
- w_r : Residual gravimetric moisture content (kg kg^{-1}).
- n : A parameter that controls the shape of the appropriate moisture description curve.
- $\boldsymbol{S_{index}}$: is the Soil Physical Quality index.

Estimation of some physical and chemical properties of the soil samples:

The soil samples were air-dried, then ground and passed through a sieve with a mesh size of 2 mm. Some physical and chemical properties of the study site were determined, as

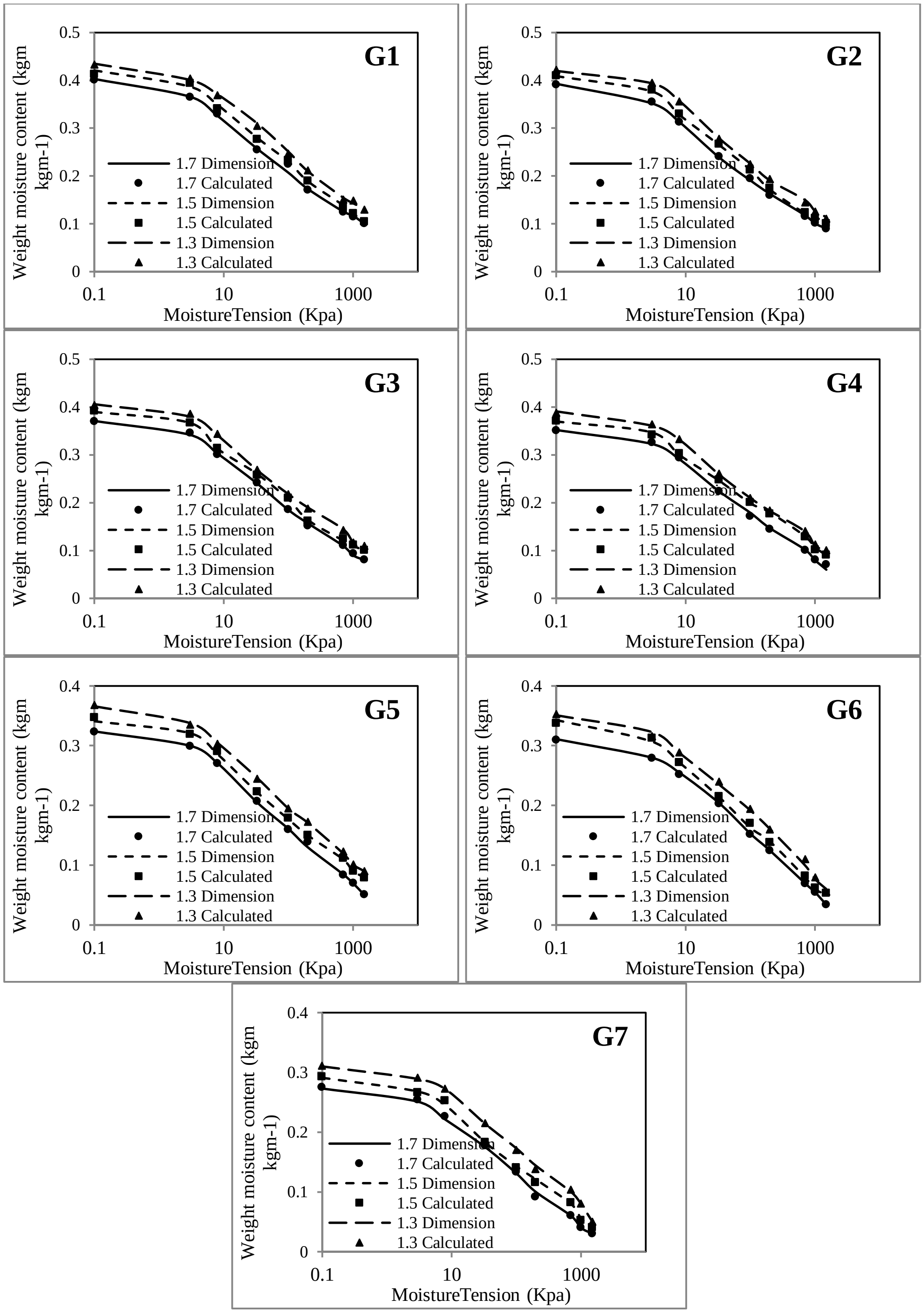

Figure 1. Measured and calculated moisture retention curves using the van Genuchten (1980) equation for soil samples G1, G2, G3, G4, G5, G6, and G7.

Where hih_ihi and wiw_iwi are the logarithm of the matric potential (kPa) and the gravimetric moisture content (kg kg^{-1}) at the inflection point of the moisture retention curve, respectively. The Soil Physical Quality (S-index) was calculated using equation 9 through the RETC program (RETC, 2008) and Dexter (2004a, b), which states the following:

$$S_{index} = \left|\frac{dw}{d\ln h}\right|_i = n(w_s - w_r)\left[\frac{2n-1}{n-1}\right]^{\left[\frac{1}{n}-2\right]} \quad ......9 ,$$

shown in Table 1:

Table 1. Some physical and chemical properties of the soil samples.

Property	G1	G2	G3	G4	G5	G6	G7
Texture	Loamy	Loamy	Sandy loam	Sandy loam	Sandy loam	*	*
Sand (g kg^{-1})	450	488	525	551	632	*	*
Silt (g kg^{-1})	320	301	291	277	260	*	*
Clay (g kg^{-1})	230	211	184	172	108	*	*
Bulk Density (mg m^{-3})	1.40	1.35	1.32	1.25	1.22	1.16	1.12
pH 1:1	7.33	7.45	7.61	7.83	7.89	7.94	7.97
Electrical Conductivity (dS m^{-1}) EC 1:1	3.93	3.80	3.73	3.55	3.24	3.16	2.88
Organic Matter (g kg^{-1})	13.9	12.7	10.5	9.3	7.5	5.1	2.9
Gypsum Content (g kg^{-1})	61.1	104	151	214	279	363	414
Calcium Carbonate (g kg^{-1})	225.5	210.9	183.3	162.6	125.5	92.9	66.7

*The texture for the soil samples G6 and G7 could not be determined due to coagulation resulting from the high gypsum content.

The texture was determined using the method developed for gypsum soils by Pearson *et al*. (2015). The bulk density was measured using the core method, as proposed by Blacke and Hortge (1986). The pH was measured in a soil: water extract (1:1) using a pH-meter , Electrical conductivity (EC) was measured in a soil: water extract (1:1) using an EC-meter (Richards, 1954). Organic matter content was estimated using the Walkley and Black method, as described by Richards (1954). Gypsum content in the soil samples was determined using the method described by Lagerwerff *et al*. (1965) and modified by Al-Zubaidi *et al*. (1981). Calcium carbonate content was determined by calculating the loss in weight of CO2 after treating the soil with 3 N HCl, according to Richards (1954).

RESULTS AND DISSCUSION

Figure 2 shows the compaction curves of gypsum soils. The highest bulk density for gypsum soil samples (G1, G2, G3) was obtained at a moisture content of 15 kg kg^{-1}, while the optimum moisture content (OMC) for compaction increased for gypsum soil samples (G4, G5, G6, G7). The gypsum soil samples with lower gypsum content required a lower moisture content (OMC) to achieve optimum compaction, as less water was needed to wet the soil and fill the voids due to the absence of large amounts of soluble gypsum. In contrast, gypsum soil samples with higher gypsum content required a higher moisture content (OMC), as the presence of more gypsum increased the need for water to dissolve the gypsum, rearrange soil particles, and fill voids, making it necessary to use more water to reach maximum density (Bhat, 2017).The highest critical bulk densities (1.68, 1.662, 1.654) Mg cm^{-3} were observed for the gypsum soil samples (G1-G3), and these densities decreased as the gypsum content in the soil increased, reaching (1.628, 1.6, 1.584, 1.565) Mg cm^{-3} for the gypsum soil samples (G4-G7). This decrease in bulk density with increasing gypsum content may be attributed to the increased porosity of gypsum soils, which are less cohesive due to the presence of gypsum crystals. These crystals disrupt the soil structure, creating more voids that trap air. This increased porosity makes it more difficult to achieve the same compaction density that is achievable in soils with lower gypsum content. As a result, gypsum-rich soils achieve lower Proctor densities. Additionally, the ability of gypsum to dissolve in water can also affect the compaction process. During compaction at moisture levels, gypsum tends to dissolve, leading to temporary structural instability, which reduces the maximum density achievable during soil compaction (NRCS, 2015; Wallace & Wallace, 1995).

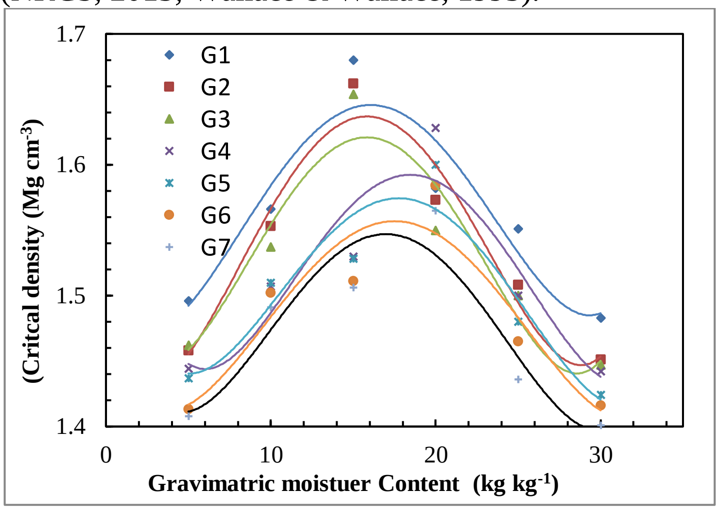

Figure 2: Effect of gypsum content in soil on the compaction curve.

Figure 3: The positive exponential relationship between the Soil Physical Quality Index (S_index) and gypsum content in the soil, with high determination coefficients of 0.9529, 0.9488, and 0.9256 for the densities of 1.3, 1.5, and 1.7 Mg cm^{-3}, respectively. It is observed that the values of S_index increase with the gypsum content in the soil and decrease with bulk density. The highest value of S_index (0.055) was recorded for the G7 soil sample at a bulk density of 1.3, indicating very good soil physical quality (Dexter, 2004a). The Soil Physical Quality Index for the studied gypsum soils increased significantly with the gypsum content, and these results are consistent with the findings of Al-Kayssi (2021).

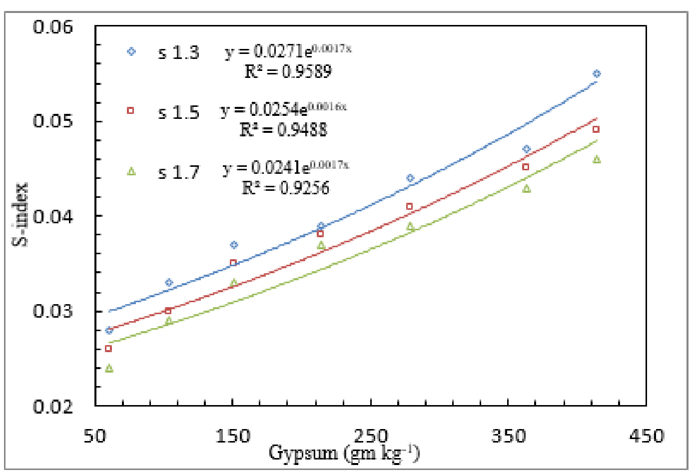

Figure 3: The relationship between gypsum content and the Soil Physical Quality Index (S_index).

It is observed that the Soil Physical Quality Index (S-index) decreases with an increase in bulk density for all studied gypsum soil models. This decrease is attributed to the compaction of the soil, which alters the pore structure of the soil and results in negative effects on a wide range of soil properties. Consequently, the physical quality index of the soil (S-index) is reduced, as most physical, chemical, and biological soil properties and processes are affected by soil compaction. Therefore, the value of the Soil Physical Quality Index decreases as the bulk density of the soil increases (Dexter, 2004a). This effect may also be attributed to the negative impact of soil compaction on the Soil Physical Quality Index (S-index) (Nadri-Boldaji and Keller, 2016).

Figure 4: illustrates the negative polynomial relationship between soil gypsum content and compaction degree (DC%), with a high coefficient of determination (R^2) of 0.9959. It is observed that the soil compaction degree (DC%) decreases with an increase in gypsum content, with the lowest compaction degree recorded for the G7 soil model. This decrease is attributed to the lower value of the natural bulk density ($BD_{natural}$) (Table 1) and the reduced critical bulk density (Proctor density). Since the compaction degree is related to both of these densities (Equations 3 and 4), the highest compaction degree was observed for the G1 soil model, reaching 83.809%. Additionally, it is observed that the degree of soil compaction increases as the gypsum content in the soil decreases, and the calcium carbonate content increases (Table 1). Therefore, the compaction degree has a positive relationship with calcium carbonate content and a negative relationship with gypsum content in the soil (AL-Kayssi, 2021).

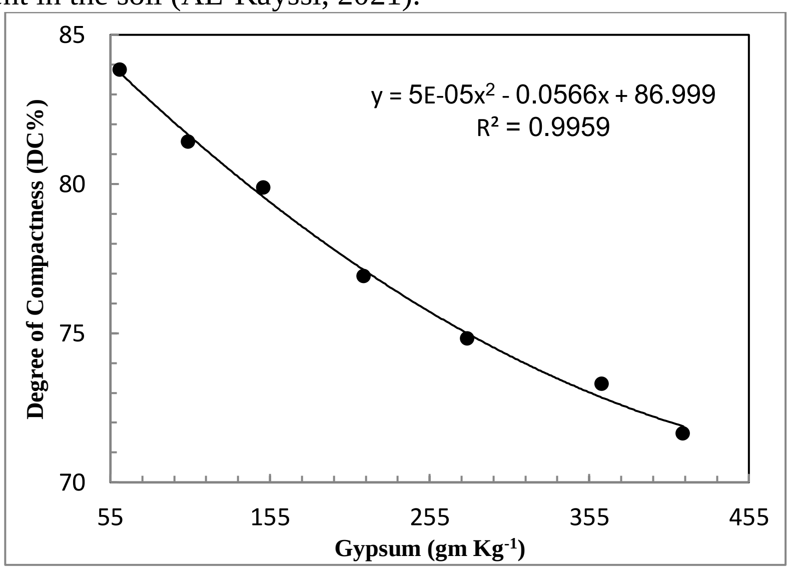

Figure 4. The relationship between gypsum content and soil compaction degree (DC%).

Figure 5. The negative linear correlation between bulk density and Soil Physical Quality Index (S-index). The reduction Bulk density is considered one of the key indicators of soil physical quality (SPQ) (Reynolds *et al*., 2009). Good soil physical quality was obtained for gypsum soil samples (G3-G7) at bulk densities of 1.3 and 1.5 Mg m^{-3} (Dexter, 2004a). Additionally, good soil physical quality indicators were observed for a bulk density of 1.7 Mg cm^{-3} in gypsum soil samples (G4-G7) (Dexter, 2004a). It is evident that the values of the Soil Physical Quality Index (S-index) decrease as bulk density increases for each of the gypsum soil samples. The S-index was poor for a bulk density of 1.7 Mg cm^{-3} for soil samples (G1-G3), with values of 0.04, 0.029, and 0.033, respectively (Dexter, 2004a). Soils

with high bulk density were associated with poor soil physical quality when compared to soils with lower bulk densities (Keller *et al*., 2007).

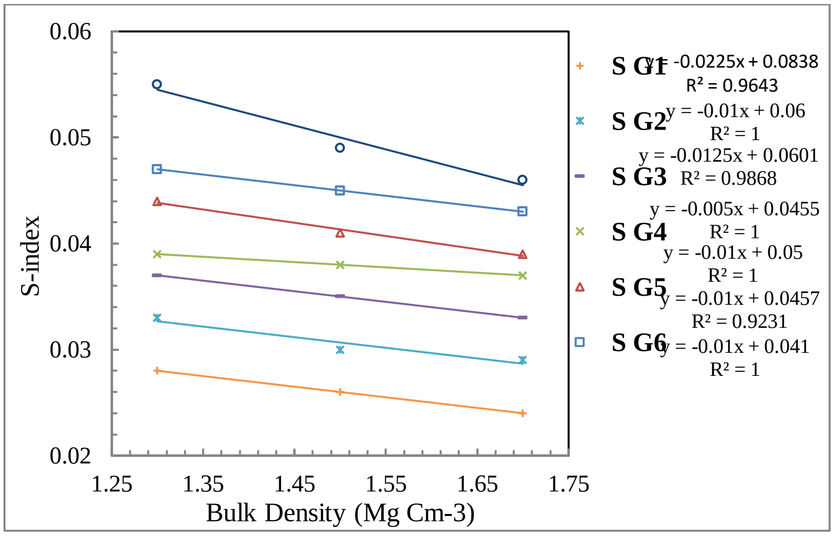

Figure 5. The relationship between bulk density and Soil Physical Quality Index (S_{index}) for soil samples G1, G2, G3, G4, G5, G6, and G7.

Figure 6. The inverse linear correlation between Soil Physical Quality Index (S_index) and Degree of Compaction (DC%) with high determination coefficients (R^2) of 0.9456, 0.9262, and 0.9406, and 0.9784 for bulk densities of 1.3, 1.5, and 1.7 Mg cm^{-3}, respectively. It is observed that the values of S_index decrease as the Degree of Compaction (DC%) increases for each gypsum soil sample. This is because the pore structure is primarily disrupted during compaction, and these pores largely control the Soil Physical Quality Index (Richard *et al*., 2001).

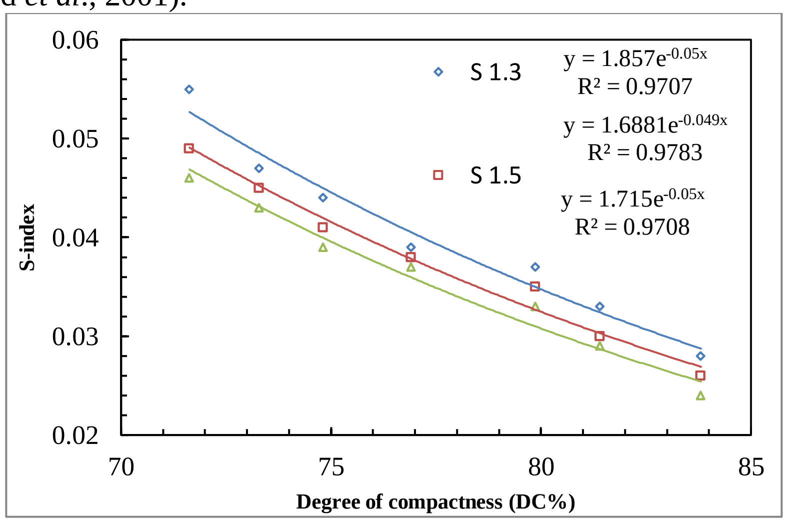

Figure 6. The relationship between Soil Physical Quality Index (S_index) and Degree of Compaction (DC%) for bulk densities of 1.3, 1.5, and 1.7 Mg m^{-3} for gypsum soil samples.

It can be observed from **Table 2** that the lowest value of Degree of Compaction (DC) was obtained for the G7 soil sample, with a value of 71.629. The highest Soil Physical Quality Index (S_index) for the same soil sample at a bulk density of 1.3 Mg cm^{-3} was

0.055, which represents very good soil physical quality .The lowest value for S_index was 0.024, representing very poor soil physical quality (Dexter, 2004a), at a bulk density of 1.7 Mg cm^{-3} when the maximum Degree of Compaction (DC) value of 83.809 was observed for the same soil sample. The decrease in the Soil Physical Quality Index with increasing compaction degree is likely due to the damage to the pore structure caused by compaction (Farahani *et al*., 2019).

CONCLUSION

The critical bulk density ($BD_{critical}$) decreased with an increase in gypsum content in the soil, with reductions of 1.07%, 0.48%, 1.57%, 1.72%, 1.00%, and 1.21% for soil samples (G2-G6) compared to the gypsum-poor soil sample (G1). The degree of compaction (DC%) increased as gypsum content decreased, with increases of 2.87%, 1.89%, 3.71%, 2.72%, 2.03%, and 2.27% for soil samples (G2-G6) compared to G1. The soil physical quality index (S-index) improved with a reduction in bulk density during compaction and an increase in the degree of compaction (DC%) with higher gypsum content. Additionally, the soil moisture retention curve (SMRC) values for different tension levels decreased as bulk density increased during compaction to densities of 1.3, 1.5, and 1.7 Mg m^{-3}.

Table 2: the Degree of Compaction (DC%) and the corresponding Soil Physical Quality Index (S-index) for each soil sample (G1 to G7) at three different bulk densities (1.3, 1.5, and (1.7 Mg /cm^3).

Samples	Degree of Compaction (DC%)	S-index (1.3 Mg/cm^3)	S-index (1.7 Mg /cm^3)	S-index (1.7 Mg /cm^3)
G1	83.809	0.028	0.026	0.024
G2	81.407	0.033	0.03	0.029
G3	79.866	0.037	0.035	0.033
G4	76.904	0.039	0.038	0.037
G5	74.812	0.044	0.041	0.039
G6	73.295	0.047	0.045	0.043
G7	71.629	0.055	0.049	0.046

CONFLICT OF INTEREST

The authors declare no conflicts of interest associated with this manuscript.

ACKNOWLEDGMENTS

The authors sincerely acknowledge the College of Agriculture and the Department of Soil Science and Water Resources for their technical and general support.

REFERENCES

AL-Kayssi, A. W. (2021). Use of water retention data and soil physical quality index S to quantify hard-setting and degree of soil compactness indices of gypsiferous soils. Soil and Tillage Research, 206, 104805.

Al-Asafi, R. B., & Al-Hadeethi, I. K. (2024). Influence of peatmoss and polymer on moisture characteristic curve of soils with different gypsum and clay contents. Tikrit Journal for Agricultural Sciences, 24(1), 67-78.

Al-Zubaidi, A. H., Abdul-Aziz, F., & Saleh, A. (1981). Evaluation of different methods for estimating gypsum in Iraqi soils. Iraqi Journal of Agricultural Sciences, 16, 133–142.

ASTM Standard D698, (2007). Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort. ASTM, International, West Conshohocken, PA

BALL, B. C., Campbell, D. J., Douglas, J. T., Henshall, J. K., & O'sullivan, M. F. 1997. Soil structural quality, compaction and land management. European Journal of Soil Science, 48(4), 593-601.

Bhat, Z. A. (2017). IMPROVEMENT OF PROPERTIES OF SOIL USING JUTE AND GYPSUM.

Blacke, G.R., & K.H. Hortge. (1986). In methods of soil Analysis, part1. Physical and Mineralogical Methods_ Agronomy Monograph no. 9 (2nd Edition), American Society of Agronomy_ Soil Science Society of America, 677, south segoe Road, Madison, WI 53711, USA.

Bronick, C. J., & Lal, R. (2005). Soil structure and management: a review. Geoderma, 124(1-2), 3-22.

Dexter, A. R., Czyż, E. A., Richard, G., & Reszkowska, A.(2008). A user-friendly water retention function that takes account of the textural and structural pore spaces in soil. Geoderma, 143(3-4), 243-253.

Dexter, A.R., (2004a). Soil physical quality. Part I. Theory, effects of soil texture, density, and organic matter, and effects on root growth. Geoderma 120: 201–214.

Dexter, A.R., (2004b). Soil physical quality. Part II. Friability, tillage, tilth and hard-setting Geoderma 120: 215–225.

Farahani, E., Mosaddeghi, M. R., Mahboubi, A. A., & Dexter, A. R. (2019). Prediction of soil hard-setting and physical quality using water retention data. Geoderma, 338, 343-354.

Håkansson, I. (1990). A method for characterizing the state of compactness of the plough layer. Soil and tillage research, 16(1-2), 105-120.

Keller, T., Arvidsson, J., & Dexter, A. R. (2007). Soil structures produced by tillage as affected by soil water content and the physical quality of soil. Soil and Tillage Research, 92(1-2), 45-52.

Kibblewhite, M. G., Ritz, K., & Swift, M. J. (2008). Soil health in agricultural systems. Philosophical Transactions of the Royal Society B: Biological Sciences, 363(1492), 685-701.

Klute, A. (1986). Water retension: Laboratory method of soil analysis Part 1, Physical and Mineralogical Method, 2nd ed. Edited. P.635-660.

Lagerwerff, J. V., G.W. Akin, S.W. Moses. 1965. Detection and determination of gypsum in soils. Soil Sci. Soc. Am. Proc. 29(5): 535-540.

Moncada, M. P., Gabriels, D., & Cornelis, W. M. 2014. Data-driven analysis of soil quality indicators using limited data. Geoderma, 235, 271-278.

Mualem, Y. (1976). A new model for predicting the hydraulic conductivity of unsaturated porous media. Water resources research, 12(3), 513-522.

Naderi-Boldaji, M., & Keller, T. 2016. Degree of soil compactness is highly correlated with the soil physical quality index S. Soil and Tillage Research, 159, 41-46.

Naderi-Boldaji, M., Weisskopf, P., Stettler, M., & Keller, T. (2016). Predicting the relative density from on-the-go horizontal penetrometer measurements at some arable top soils in Northern Switzerland. Soil and Tillage Research, 159, 23-32..

NRCS, N. (2015). Amending soil properties with gypsum products.

Pearson, M. J., Monteith, S. E., Ferguson, R. R., Hallmark, C. T., Hudnall, W. H., Monger, H. C., ... & West, L. T.(2015). A method to determine particle size distribution in soils with gypsum. Geoderma, 237, 318-324.

RETC (RETention Curve), (2008). RETC model. USDA-ARS U.S. SalinityLaboratory,Riverside,CA,USA.

Reynolds, W. D., Drury, C. F., Tan, C. S., Fox, C. A., & Yang, X. M. (2009). Use of indicators and pore volume-function characteristics to quantify soil physical quality. Geoderma, 152(3-4), 252-263.

Richard, G., Cousin, I., Sillon, J. F., Bruand, A., & Guérif, J. (2001). Effect of compaction on the porosity of a silty soil: influence on unsaturated hydraulic properties. European Journal of Soil Science, 52(1), 49-58.

Richards, L. A. (Ed.). (1954). Diagnosis and improvement of saline & alkali soils (No. 60). US Government Printing Office.

Valipour, M. (2014). Drainage, waterlogging, & salinity. Archives of Agronomy and Soil Science, 60(12), 1625-1640.

Van Genuchten, M. V., Leij, F. J., & Yates, S. R. (1991). The RETC code for quantifying the hydraulic functions of unsaturated soils.

Van Genuchten, M.TH. (1980). A closed-form equation for predicting the hydraulic conductivity of unsaturated soils. Soil Sci. Soc. Am. J. 44(5): 892-898.

Wallace, A., & Wallace, G. A. (1995). Gypsum is almost a universal soil amendment. Soil amendments and amendment technologies, Wallace Laboratories, El Segundo.

Wösten, J. H. M., Lilly, A., Nemes, A., and Le Bas, C. 1999. Development and use of a database of hydraulic properties of European soils. Geoderma, 90(3-4), 169-185.