Analysis of Swelling- Shrinkage Behaviour of Gypsiferous Soils Amended with Compost

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Abstract

Soil samples were collected from the Gypsiferous soil profile at the Agricultural Research Station, University of Tikrit, at depths of 0–70 cm. Seven soil models (G1–G7) represented gypsum concentrations ranging from 59.5 g kg^{-1} at 0–10 cm to 522.5 g kg^{-1} at 60–70 cm. Compost was prepared using air-dried crushed maize residues mixed with nitrogenous and phosphate fertilizers (urea and DAP), decomposed poultry manure, and fertile soil to enhance microbial decomposition. The soil samples were air-dried, ground, and sieved through a 2 mm mesh before being amended with compost at 2, 4, 6, and 8% (w), along with a control (0%). The mixtures were moistened to two-thirds of field capacity and incubated in sealed plastic bags with daily mixing for two months to ensure homogeneity. After incubation, samples were air-dried, sieved again, and subjected to soil shrinkage curve (SSC) measurement using the balloon method to estimate soil shrinkage capacity and coefficient of linear extensibility (COLE).Results indicated that shrinkage curves for G1 and G2 samples exhibited the four shrinkage phases: structural, proportional, residual, and zero shrinkage, with the structural phase diminishing as gypsum content increased. Soil shrinkage capacity showed a positive polynomial relationship with compost addition but decreased with higher gypsum content, whereas COLE increased linearly with compost addition and decreased significantly with gypsum enrichment. The findings indicate that compost amendment enhances the shrinkage–expansion behavior of gypsiferous soils, whereas elevated gypsum content diminishes their structural flexibility.

Keywords: Gypsiferous Soils, Compost, Soil Shrinkage Curve ,Soil Shrinkage Capacity, COLE.

Introduction

Gypsiferous soils appear compacted when their moisture content decreases, leading to an increase in bulk density. They are characterized by a certain degree of shrink–swell behavior, particularly in response to changes in water content, primarily due to their low organic matter, which limits soil elasticity. As moisture increases, gypsiferous soils absorb water and expand, whereas water loss induces shrinkage. These volumetric changes cause multiple issues, including surface cracking, as shrinkage during drying leads to fissures that may affect plant cultivation and structural stability. Repeated shrink–swell cycles also reduce the mechanical stability of the soil, lowering its penetration resistance and load-bearing capacity, in addition to causing fluctuations in porosity that influence water and air movement within the soil. Over time, these

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processes weaken particle cohesion and increase soil disintegration, negatively affecting the overall soil structural integrity [3]. Soil shrinkage is defined as the reorganization of soil aggregates and particles and the redistribution of pores as a result of water loss Water Stress or Mechanical Stress[11,27]. One of the main causes of soil shrinkage or contraction is the low organic matter content and the swelling of clay. Pore volume increases during water absorption due to clay expansion, while it decreases during drying. Thus, soil volume changes during wetting and drying cycles primarily depend on the pore structure of the Soil Texural Pores[27]. Generally, when a swelling and shrinking clay soil dries out,four shrinkage stages can be distinguished: 1) structural shrinkage, (2) normal shrinkage, (3) residual shrinkage and (4) zero shrinkage Each region reflects varying degrees of structural rigidity as the soil dries. Generally, the soil shrinkage curve is characterized by two pronounced curvatures at the wet and dry ends, with an inflection point located between these [19]. Soil sample volume changes occur both vertically and horizontally during swelling and shrinkage. Vertical volume increases during swelling, while subsidence occurs during shrinkage Horizontal volume changes involve the closing or widening of cracks[14]. A study conducted by[35] Short-term incubation was effective in highlighting the applications of compost in soil aggregates and mechanical properties, as the organic waste component played a key role in aggregate stability, water conductivity, bulk density, soil moisture content, liquid and shrinkage limits, plasticity, and the coefficient of linear extensibility (COLE). The results also indicated that compost application can improve agricultural soils and enhance aggregate stability and other physical properties. According to their findings, adding compost at a rate of 4% had the most pronounced effect on enhancing soil aggregation and physical properties. On the other hand, the effect of compost on the mechanical properties of silty clay soil was found to be less significant compared to its impact on soil aggregate characteristics. It was reported[7] that soil shrinkage capacity increases with higher clay and organic matter content. Moreover, this relationship is influenced by water content, pore volume, and clay type. A positive correlation was also observed between shrinkage capacity and cation exchange capacity (CEC), as CEC depends on the amount of organic matter and clay content.

This study aimed to analyze the effect of compost amendment on the swelling–shrinkage behavior of gypsiferous soils .

Material and Methods

Sample preparation:

Gypsiferous soil samples were collected from the Agricultural Research Station at the University of Tikrit, located at 34°40′48″ N latitude and 43°38′23″ E longitude, at an elevation of 250 m above sea level. The study included seven soil horizons, from the surface layer down to 70 cm depth, distributed as follows: 0–10 cm with a gypsum content of 59.5 g kg^{-1} (G1), 10–20 cm at 147.3 g kg^{-1} (G2), 20–30 cm at 226.5 g kg^{-1} (G3), 30–40 cm at 313.7 g kg^{-1} (G4), 40–50 cm at 391.2 g kg^{-1} (G5), 50–60 cm at 453.3 g kg^{-1} (G6), and 60–70 cm at 522.5 g kg^{-1} (G7.(

Compost preparation:

Compost was prepared from air-dried maize residues, ground to an average particle size of approximately 4 mm. To 140 kg of maize residues, 1.4 kg of urea, 1.4 kg of DAP, 5.6 kg of decomposed poultry manure, and 8 kg of fertile soil were added and thoroughly mixed[2,33]. The mixture was shaped into a pyramid, moistened with water, and covered with plastic for 3–4 days. The pile was then turned approximately three times per week, with watering and monitoring of temperature and humidity to ensure proper aeration and homogeneous aerobic decomposition. During the process, the pile temperature rose to 85°C due to microbial activity and gradually decreased as decomposition proceeded. The process lasted for two and a half months (12 June–23 August 2023), after which the compost was sieved through 2 mm and 1 mm meshes to obtain uniform granules. The compost was then mixed with soil at rates of 2, 4, 6, and 8%, moistened, and left for two months to ensure homogeneity, after which the samples were air-dried and stored in plastic bags for subsequent use.

Studied traits:

Soil Shrinkage Curve

The balloon method [34,8] was applied on 50gm disturbed soil samples of air-dried soil were placed into a rubber balloon, and 35 cm^3 of water was added to bring the soil to saturation. Water was slowly added along the balloon walls to allow bottom-up wetting and to expel air, preventing the disruption of soil aggregates due to rapid immersion. The balloon was then sealed with a rigid rubber stopper. The soil water filled balloon was left aside for four days to allow saturation, with the sample unconfined due to the balloon’s elasticity. Subsequently, the stopper was replaced with one equipped with air inlet and outlet ports made of compressed rubber, which could be closed with a valve to allow drying; both valves remained open during this stage. The air inlet of each balloon was connected to an air pump (a small aquarium pump with a power of 5 W, typically generating a pressure of 0.015–0.03 MPa, i.e., 150–300 kPa, approximately 1.5–3 bar). Air was passed at low pressure over the sample to avoid breaking soil aggregates. Once the sample reached an appropriate level of dryness (progressively over time), it was placed on a holder using a suspended hook. The balloon was then lowered into a beaker filled with water positioned on a sensitive balance to measure the weight of water displaced by the balloon according to Archimedes' principle. The soil sample and balloon were weighed by placing the beaker with 1000 mL of water on the sensitive balance and leaving it to measure the sample weight in water, recording the weight of the displaced water each time. Before each measurement, it was ensured that the water volume in the beaker was exactly 1000 ml. Figure 1 illustrates the procedure for weighing the soil sample and balloon in water. Air was removed from the balloon by closing the air inlet valve and opening the outlet valve for each sample. The dried soil sample along with the balloon was weighed using a sensitive balance in water. The sequential air-drying process of the soil samples lasted from one to four weeks, depending on the compost content. After completing the drying stages, the samples from each balloon were oven-dried at 105°C

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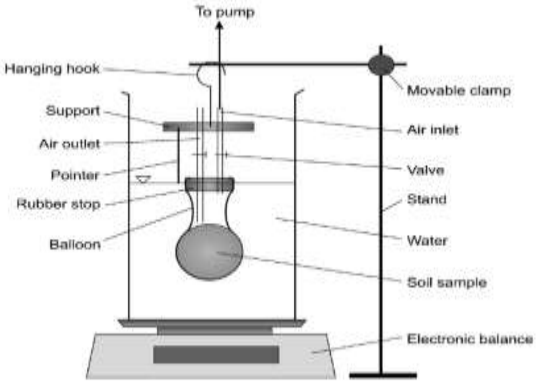

Fig.1.Experimental setup to determine the soil shrinkage characteristic curve according to the balloon method [34.[

The water content (Water ratio) and void ratio for each gypsiferous soil sample treated with different compost rates were determined by weighing each sample two hours after exposing it to air. The weighing process was repeated every two hours until the weight stabilized. Estimating the Soil Shrinkage Characteristic Curve (SSCC) requires sequential measurement of the soil pore volume and water volume within the soil sample at different moisture content stages[12]. The shrinkage behavior of each soil model, resulting from changes in soil volume during drying stages, was described by plotting the void ratio (Equation 1) against the water content (Equation 2) [10,34,18]As follows:

$e=V_f/V_s =PD/BD-1$ ……………….(1(

$v=V_w/V_s$ or $W*PD$ ……………….(2(

e: Void ratio(cm3 cm-3.(

v: Water ratio(cm3 cm-3.(

V_f: Pore volume (cm^3.(

V_w : Water volume (cm^3.(

V_s : Solid volume(cm^3.(

W: Gravimetric water content (cm^3.(

PD: Particle density (g cm^{-3}.(

BD: Bulk density (g cm^{-3}.(

Soil Shrinkage Capacity:

The Soil Shrinkage Capacity (ShC) was calculated[27] using the following equation:

$Shc=(e_s-e_r)$………………(3(

Shc : Soil Shrinkage Capacity

e_s : Saturation Voide ratio) cm3.(

〗e〗 _(r) Dry Voide ratio) cm3.(

COLE:

The volumetric moisture content of each gypsiferous soil sample treated with different compost rates (2, 4, 6, and 8%) as well as the control (0%) was estimated according to the Richards method described in [22] To determine the soil water retention curve (SWRC), a Pressure Plate apparatus was used at a matric suction of –33 kPa after saturation. The coefficient of linear extensibility (COLE) of the soil samples was calculated by measuring the sample height in cylindrical rings (50 mm diameter and 50 mm height) at a matric suction of –33 kPa before and after oven drying. COLE was calculated using the following equation[19:[

$COLE = Zw/Zd-1$……………(4 (

where Zw is the length of a wet soil sample at −33 kPa and Zd is the length of an oven-dry soil sample. Threshold values for COLE have been proposed to classify the soil's shrinkage potential [24] A COLE value below 0.03 indicates low shrinkage potential, values between 0.03 and 0.06 indicate moderate shrinkage potential, values from 0.06 to 0.09 indicate high shrinkage potential, and values

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greater than 0.09 indicate very high shrinkage potential.

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

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

Property	G1	G2	G3	G4	G5	G6	G7
Soil granulometry	Loamy	Loamy	Sandy loam	Sandy loam	Sandy loam	*	*
Sand (g kg^{-1})	444	490	525	554	627	*	*
Silt (g kg^{-1})	336	308	280	276	260	*	*
Clay (g kg^{-1})	220	202	195	170	113	*	*
Bulk Density (Mg m^{-3})	1.45	1.35	1.30	1.25	1.20	1.11	1.04
pH 1:1	7.27	7.47	7.61	7.79	7.88	7.90	7.99
Electrical Conductivity (dS m^{-1}) EC 1:1	3.90	3.79	3.67	3.55	3.24	3.16	2.81
Organic content (g kg^{-1})	13.9	11.6	9.7	8.4	6.9	4.4	2.9
Gypsum Content (g kg^{-1})	59.5	147.3	226.5	313.7	391.2	453.3	522.5
Calcium Carbonate (g kg^{-1})	229.1	201.7	179.9	161.6	120.5	90.9	59.9

(*)The texture of G6 and G7 soils could not be determined due to high gypsum content causing coagulation of the samples. The high gypsum content is due to gypsum-rich parent materials and the arid climate, where limited leaching and repeated dissolution–precipitation cycles promote gypsum accumulation.

The soil texture was estimated according to the method developed for gypsiferous soils by[25]. Bulk density was determined using the core method, according to the procedure proposed by[6]. The pH was measured in a 1:1 soil-to-water extract using a pH meter, and electrical conductivity (EC) was measured in a 1:1 soil-to-water extract using an EC meter[32]. Organic matter was determined using the Walkley and Black method as described in[32]. Gypsum content in the soil samples was determined using the method described by[23] and modified by[4]. Calcium carbonate content was determined by calculating the CO_2 loss after treating the soil with 3 N HCl [32.[

Results and Discussion

Soil Shrinkage Characteristic Curves (SSCC :(

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Figure 2 illustrates the effect of adding compost at rates of 0, 2, 4, 6, and 8% on the Soil Shrinkage Characteristic Curves (SSCC) of gypsiferous soil samples (G1–G7). The curve for all studied soil samples begins at the saturated water ratio (υ□) and saturated void ratio (e□) and ends at the dry water ratio (υ_0) and dry void ratio (e_r). The shrinkage curves of G1 and G2 soils exhibited the four shrinkage phases: structural shrinkage, which depends on the soil structure; proportional shrinkage; residual shrinkage; and zero shrinkage, progressing from the wet to the dry side, for all compost rates compared to the control samples, in which the structural shrinkage phase was not observed. The absence of a clear structural shrinkage phase in the control samples may be due to rapid total shrinkage without passing through a distinct structural shrinkage stage, as compost provides the soil with the ability to retain water for a longer period and maintains the soil's structural framework. Additionally, soils poor in organic matter lose water more rapidly compared to organic-rich soils, meaning moisture is lost quickly from nearly all pores, leaving little difference between water loss from large or small pores, which reduces the likelihood of a distinct structural shrinkage phase[20.[

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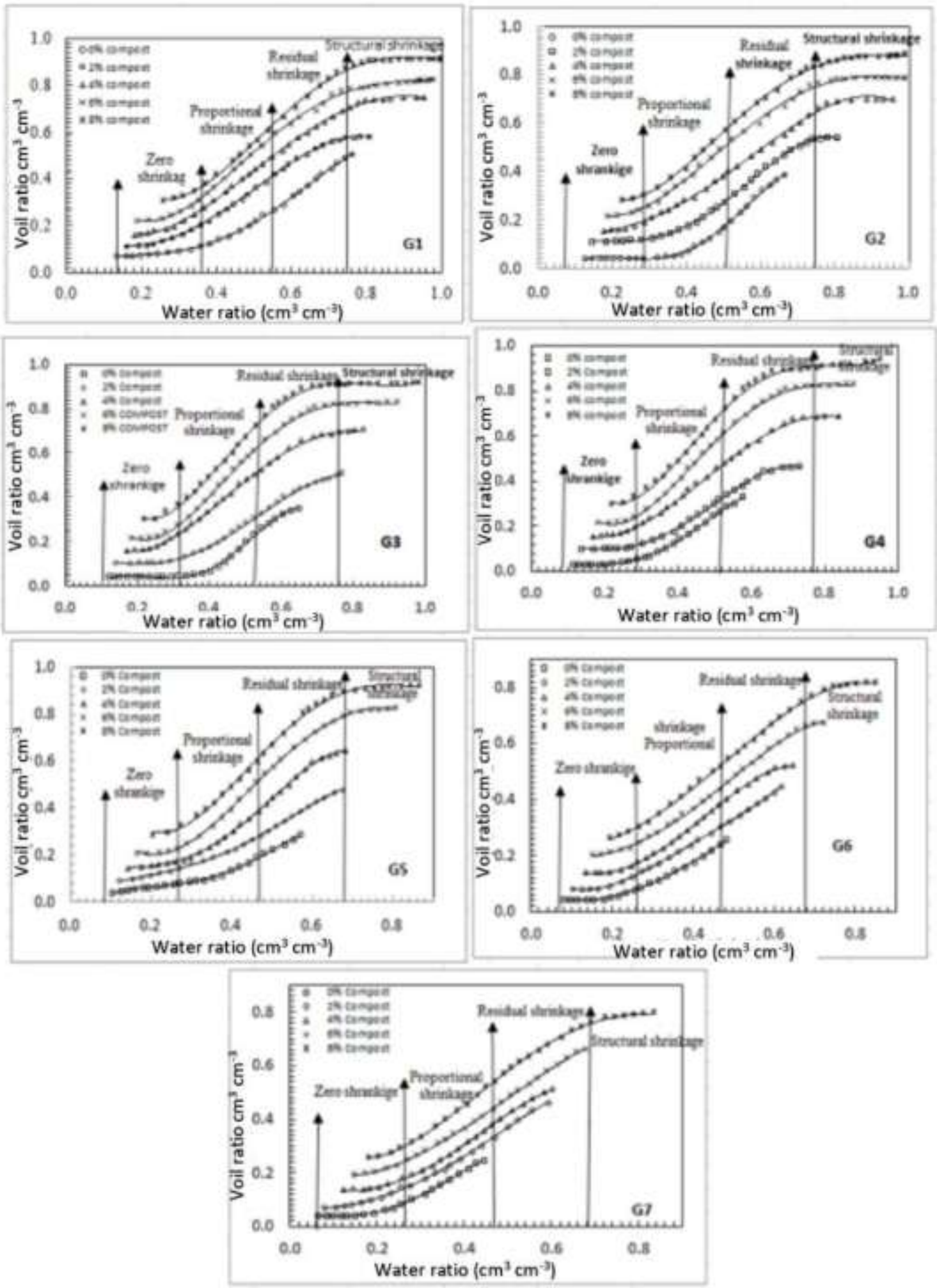

Figure 2. Effect of adding compost at rates of 0, 2, 4, 6, and 8% on the soil shrinkage curves of gypsiferous soils (G1–G7.(

It is also observed from Figure 2 that the structural shrinkage phase did not appear in the control treatments for all gypsiferous soil samples (G1–G7) and gradually disappeared with increasing gypsum content, even in the presence of compost. For instance, the

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structural shrinkage phase was not observed in G3 and G4 soils at 2% compost, in G5 and G6 soils at 2% and 4% compost, and in G7 soil at 2%, 4%, and 6% compost. This phase appeared only at the 8% compost level, which increased the proportion of large pores and resulted in greater structural shrinkage compared to soils with low organic matter content, consistent with the findings of [9,26] who reported that macropores represent the structural shrinkage phase, during which shrinkage is less pronounced than in micropores. The absence of a structural shrinkage zone (structural phase) in the typical shrinkage curve of the control treatments, as well as in the aforementioned soil samples namely, soils with low compost content and high gypsum content may be attributed to several interacting factors. These include the absence of macropores, the high structural stability of gypsiferous soils, and the rapid loss of moisture. Furthermore, gypsum tends to increase soil compaction and cohesion, resulting in uniform water loss without abrupt structural changes. In addition, the low proportion of compost reduces soil flexibility and promotes gradual shrinkage without distinct structural phases in the shrinkage curve, which can be attributed to the weak structure of the gypsiferous soil samples (G1–G7). This is in agreement with the findings of [16]. In the absence of structural shrinkage, the maximum curvature of the wet branch does not appear in the soil shrinkage curve. Instead, the proportional shrinkage zone begins from the saturation point (ʋs, es) rather than from the maximum curvature of the wet branch (ʋw, ew). Due to the absence of macropores, structural shrinkage and the corresponding maximum curvature point of the wet branch were not observed. However, an inflection point and maximum curvature of the dry branch were present, and the proportional shrinkage started directly from the saturation point (ʋs, es) [5,27,28]. The gypsum soil models G1 and G2, under all compost application rates, exhibited a high capacity for swelling and shrinkage due to their elevated clay content (Table 2) compared to the other soil models. The clay content and type play a significant role in controlling the swelling–shrinkage behavior of soils[7.[

Soil Shrinkage Capacity (SCC :(

Figure 3 illustrates the effect of compost addition at rates of 0, 2, 4, 6, and 8% on the Soil Shrinkage Capacity (SCC) of gypsum soil models with varying gypsum contents (G1–G7). It is evident that SCC values increased with higher compost application across all soil models (G1–G7). For instance, in the G1 soil model, SCC reached 0.435, 0.478, 0.589, 0.639, and 0.648 at compost levels of 0, 2, 4, 6, and 8%, respectively. The increase in SCC with compost addition may be attributed to the improved water-holding capacity of soils amended with organic matter. When soils absorb water, they expand, whereas they shrink upon drying. Thus, higher compost levels enhance soil swelling and shrinkage responses to changes in moisture availability. A positive relationship was observed between SCC and saturated water content, as clay surfaces absorb more water, leading to soil volume expansion and consequently higher shrinkage capacity. Conversely, during drying, soil volume decreases as water is lost.The higher SCC in water-saturated soils can be ascribed to the dominance of smectitic clay minerals (particularly montmorillonite) with high swelling potential, as well as the contribution of organic matter and reduced bulk density resulting from greater structural

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porosity. Under saturated conditions, clay minerals absorb more water, expand significantly, and thereby result in a higher saturated water content[13]. Moreover, organic matter also has a significant effect on soil shrinkage capacity[36.[

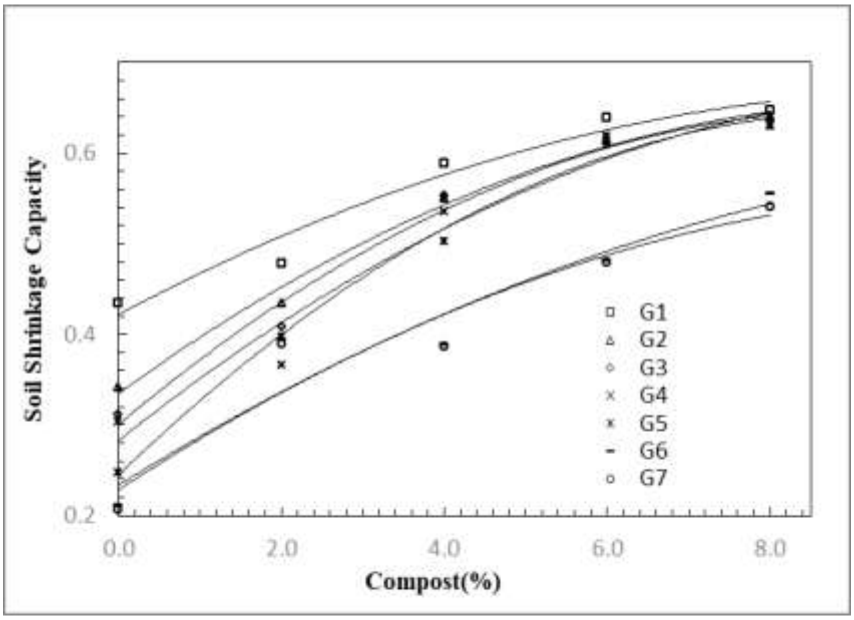

Figure 3. Effect of compost additions at rates of 0, 2, 4, 6, and 8% to soils with different gypsum contents (G1–G7) on soil shrinkage capacity .

It is also observed from Figure 3 that soil shrinkage capacity values decreased with the increase in gypsum content of the soil, with reductions of 0.021, 0.020, 0.030, 0.040, 0.051, and 0.052 recorded for the gypsiferous soil samples G2–G7 compared with soil sample G1. This decrease may be attributed to the decline in clay content, as well as to the type of clay minerals present in the soil as gypsum content increases[7]. Bulk density [29,17] and organic matter[30,21] (Table 2) are among the key factors influencing soil shrinkage capacity. The highest value of soil shrinkage capacity was recorded in the soil sample with low gypsum content (G1), reaching 0.435. The increase in shrinkage capacity of soil sample G1 may be attributed to its higher clay content, as there is a clear positive relationship between soil shrinkage capacity and clay content. Shrinkage capacity increases with clay content because clay particles have a high specific surface area, which provides them with a strong ability to shrink [31.[

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Table 2. Effect of selected physical properties on soil shrinkage capacity.

Soil samples	Clay content ($g\ kg^{-1}$)	Bulk density ($Mg\ m^{-3}$)	Organic matter content ($g\ kg^{-1}$)
G1	220	1.45	13.9
G2	202	1.35	12.2
G3	195	1.30	10.5
G4	170	1.25	9.3
G5	113	1.20	6.8
G6	-	1.11	4.8
G7	-	1.04	2.9

COLE:

Figure 4 illustrates the effect of compost addition at rates of 0, 2, 4, 6, and 8% on the Coefficient of Linear Extensibility (COLE) of soils with varying gypsum contents. COLE values increased with higher compost rates; for example, in the G1 soil model, COLE values were 0.031, 0.047, 0.054, 0.065, and 0.072 for compost rates of 0, 2, 4, 6, and 8%, respectively. Compost enhances the water-holding capacity of soils due to its high organic matter content, and this increase in moisture leads to greater soil expansion upon wetting, thereby increasing COLE values. Consequently, COLE increases with higher organic matter content in the soil[1 .[

It is also observed from Figure 4 that the Coefficient of Linear Extensibility (COLE) decreased with increasing gypsum content for all gypsiferous soil samples (G1–G7), with the lowest COLE value of 0.009 recorded for G7, which contains 522.5 $g\ kg^{-1}$ gypsum, compared with G1. This reduction can be attributed to several interacting factors. High gypsum content reduces the effectiveness of the clay fraction, both through physical displacement of clay particles and the chemical effect of calcium ions released from gypsum dissolution, which promotes flocculation of fine particles and the formation of soil aggregates with lower extensibility. Soils with high gypsum content also exhibited a marked decrease in cation exchange capacity (CEC) (Table 2), an indirect indicator of clay activity, particularly in soils where accurate clay content estimation is complicated by gypsum-induced structural disruption. Gypsum improves structural stability but limits soil expansion upon wetting due to reduced plasticity and flocculation. Furthermore, the dominant clay mineral (paligorskite) is non-expanding and has low cation exchange capacity (~10 $cmol\ kg^{-1}$) compared with 2:1 smectite minerals (~40 $cmol\ kg^{-1}$) common in non-gypsiferous soils, which contribute to higher linear extensibility[12. According to[15]. COLE values for the gypsiferous soils were low (<0.03). However, compost addition significantly increased COLE values: for G1, from 0.031 to 0.072, and for G2, from 0.027 to 0.063, placing them in the high range (0.06–0.09). For G3, G4, and G5, COLE increased from 0.020 to 0.057, 0.017 to 0.052, and 0.013 to 0.043, respectively, reaching the moderate range (0.03–0.06). For G6 and G7, COLE remained low (<0.03), indicating that compost addition did not change their classification. Linear regression provided a good fit between compost rates and COLE, with high coefficients of determination (R^2 = 0.9777,

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0.9696, 0.9842, 0.9531, 0.9916, 0.9944, and 0.989 for G1–G7, respectively.(

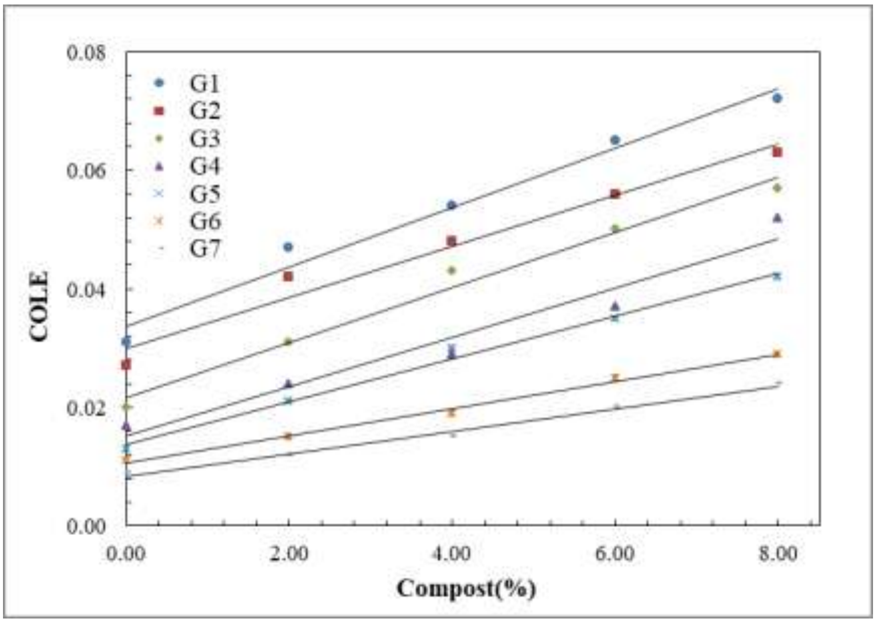

Figure 4. Effect of compost addition at rates of 0, 2, 4, 6, and 8% on the Coefficient of Linear Extensibility (COLE) of gypsiferous soils (G1–G7 .(

Conclusion

Compost improved the structure of gypsiferous soils, reducing shrink–swell and cracking, with the strongest effect at 8%. At this level, all four shrinkage phases appeared, and COLE increased with water retention and fine pore distribution, ranking high in G1–G2, moderate in G3–G5, and low in G6–G7.

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