Research Article

The Effect of Compaction Levels and Amendments on Physical and Hydraulic Properties of Silty Clay Soil

Aya Majeed Abdulsalam[1]* and Mohammed Ali Abood[2]

[1]Department of Soil Science and Water Resources, College of Agriculture, University of Diyala, Diyala, Iraq.

Abstract | Soil compaction is among the most important physical soil properties that can affect seed germination and field establishment, and its effects can be reduced by using soil amendments. To achieve this goal, silt clay soil samples were taken and analyzed. The experiment was designed using a completely randomized design (CRD) with three replications, and two factors: the first is the compaction treatment with three levels (without compaction, symbolized as C0, compaction with 10 hits using a 2 kg weight from a height of 50 cm, symbolized as C1, compaction with 20 hits using a 2 kg weight from a height of 50 cm, symbolized as C2). The second factor is the addition of amendments, which includes four types of amendments (without adding amendments A0, gum acacia A1, ECO RWP fertilizer A2, bentonite A3). The results of this study showed that the soil compaction levels did not have a significant effect on the studied characteristics. While the treatment of adding gum acacia recorded the highest average value of saturated hydraulic conductivity (3.277 cm h^{-1}), and water infiltration in soil (3.340 cm h^{-1}). The bentonite treatment yielded the highest average bulk density and mass soil moisture content, reaching 66.800% and 1.185 μg m^{-3}. The ECO.WRP treatment yielded the highest mean weighted diameter (mm), reaching 3.140 mm.

Received | April 22, 2025; **Accepted** | July 02, 2025; **Published** | June 30, 2026
***Correspondence** | Aya Majeed Abdulsalam, Department of Soil Science and Water Resources, College of Agriculture, University of Diyala, Diyala, Iraq; **Email:** ayamajeed@uodiyala.edu.iq, Mohammed.Ali.Abood@uodiyala.edu.iq
Citation | Abdulsalam, A.M. and M.A. Abood. 2026. The effect of compaction levels and amendments on physical and hydraulic properties of silty clay soil. *Pakistan Journal of Agricultural Research,* 39(2): 75-82.
DOI | https://dx.doi.org/10.17582/journal.pjar/2026/39.2.75.82
Keywords | Compaction, Gum acacia, ECO WRP fertilizer, Bentonite, Silty clay soil

Introduction

Iraqi soils suffer from numerous problems resulting from natural and human causes that have significantly harmed agricultural activity, reduced horizontal and vertical expansion in agricultural production, and increased production costs. One of the most important of these problems is soil compaction, which refers to the process of bringing soil particles (partially saturated with water) together using mechanical methods or when subjected to pressure, resulting in a rearrangement of soil particles under a specific water influence. This process is called soil compaction. Compaction brings the soil closer together (usually mechanically) and increases its dry density (Sabir and Al-Qaysi, 2021). Air volume cannot be reduced to zero, but a certain level of control is required. Compaction occurs in soil by reducing the air volume in the voids without reducing its water content. This should not be confused with the process of consolidation, which involves the release of water from between soil particles under the influence of constant and continuous gravity. Air voids cannot be completely eliminated by compaction, but they can be minimized to the greatest extent possible through appropriate control (Baqir, 2013; Lahhob *et al*., 2025; Tarmooz *et al*., 2025). Compaction also increases the apparent density of the soil due to the reduction of interstitial pores available for fluid flow and the increased curvature of flow paths due to the increased contact points between particles per unit volume of soil. Soil compaction creates unusual conditions that affect the course of chemical reactions in the soil, including the dissolution of nutrients in the soil solution and their movement to the plant. Under such conditions, the movement and exchange of gases, including oxygen, decreases, causing reductive conditions to prevail over oxidative conditions (Hakansson and Voorhees, 2020).

Soil mechanical properties are critical for achieving high agricultural production. Therefore, physical fertility takes precedence over nutritional fertility, as seed germination and seedling emergence are the first stage of plant life and are directly related to soil hardness, which determines plant growth. This issue is of particular importance in gypsum soils, which are characterized by their high hardness. The soil hardens when it dries, making it difficult to carry out agricultural operations and facilitate root growth and penetration unless it is rehydrated. The concept of soil hardening, which occurs in soil without external influences, differs from the concept of soil compaction, which occurs as a result of external influences. The mechanical force exerted by the soil when it hardens hinders seedling emergence on the one hand and root growth and penetration on the other, thus deteriorating agricultural production in such conditions. Soils (Saber and Al-Qaisi, 2021). The natural compaction of soil, measured by micromorphological parameters, tensile strength, soil penetration resistance, and bulk density, is the main factor that directly or indirectly affects the physical and micromorphological properties analyzed and is responsible for the marked difference between compacted and non-compacted soil horizons (Fabiola *et al*., 2003). Compacted soils, or those exhibiting compaction behavior, are those with horizons that harden significantly when dry, forming a structureless mass. Compacted soils exhibit high mechanical strength when dry and lose a significant portion of this strength when rehydrated (Farahani *et al*., 2019).

Extensive inorganic fertilization in conventional agriculture reduces soil quality. Amendment through balanced fertilization with soil amendments is expected to improve soil quality and increase plant productivity (Sofyan *et al*., 2024).

To improve some soil properties, soils are used. Different types of soil amendments, and soil amendments are technologies used to improve the soils of arid and semi-arid areas that are degraded due to problems related to their physical, chemical, fertility and biological properties, which lead to poor plant growth. Amendments are known as organic or chemical materials of natural or manufactured origin. They are classified from a physical point of view as (water-hating or water-loving materials) that are added to the soil in order to reduce soil losses due to erosion by improving the soil structure and increasing its stability, improving the water and fertility properties of the soil by increasing the capacity to hold water and nutrients and their availability and preserving the soil from loss (Billingham, 2015).

Accordingly, this study was conducted to investigate the effect of compaction, soil amendments, and their interaction on some of the physical properties of silty clay soils.

Materials and Methods

The experiment was carried out in the Soil Physics Laboratories - Department of Soil Sciences and Water Resources - College of Agriculture - University of Diyala. A silty clay soil was taken from Baladruz district in Diyala Governorate, which is located between latitudes (30-33°) north and longitudes (30-45°) east. The sample was taken from the surface horizon (0-30) cm, air-dried, ground with a wooden hammer, and passed through a sieve with holes' diameter (2) mm. The experiment was carried out according to the completely randomized design (CRD) with three replicates. The main panels included the compaction treatment. The compaction treatments included three levels without compaction (C0), compaction with 10 strikes using a weight of 2 kg from a height of 50 cm, symbolized by C1, compaction with 20 strikes using a weight of 2 kg from a height of 50 cm, symbolized by C2. The secondary panels included the addition of 3 types of improvers [without adding improvers (A0), Gum Arabic at 2% (A1), ECO RWP fertilizer at 2% (A2) and Bentonite (A3)] were added based on the dry weight of the soil. An iron base was designed to support the plastic pipes vertically, with three bases, each carrying 12 columns. The pipes, with a diameter of 0.1016 m, were cut to a length of 0.3 m and their concave cover was used, with a central hole drilled using a 10 mm diameter screw. A layer of gravel with a thickness of 0.02 m and a layer of glass wool were placed at the base of the pipe. The inner surface of the pipes was covered with paraffin wax to prevent water leakage from the sides of the soil. The amendments were mixed with the soil at a concentration of 2% based on the dry weight of the soil. The treatments were incubated for 14 weeks and continuously moistened to the field capacity of each treatment.

Saturated hydraulic conductivity

A static 1 cm water column was applied to the soil surface, and the volume of water falling down the column was calculated. Time, and the water conductivity of the saturated soil was calculated using the Darcy equation mentioned in Hillel (2004):

$$Ks = \frac{Vl}{At(h+L)}$$

Where:
Ks = saturated soil water conductivity (cm min^{-1})
V = volume of water descending from the column (cm^3)
A = cross-sectional area of the soil column (cm^2)
t = time (min)
L = length of the soil column (cm)
H = height of the water column above the soil surface (cm)

Water infiltration in soil

was measured in the laboratory using a mini disk infiltrometer according to the method of (Zhang, 1997). The volume of water in the tank was recorded at regular intervals, and readings were taken and calculated using a Microsoft Excel file. Figure 1 shows the parts of a mini disk infiltrometer.

Bulk density (μg m^{-3})

Bulk density of different soil treatments was estimated using the core method. The cylinder diameter and height were 3 and 3.3 cm, respectively. The samples were oven-dried at 105°C for 24 hours. Bulk density was calculated by dividing the dry soil mass by the cylinder volume, as described in (Al-Tamimi and Mahdi, 2017).

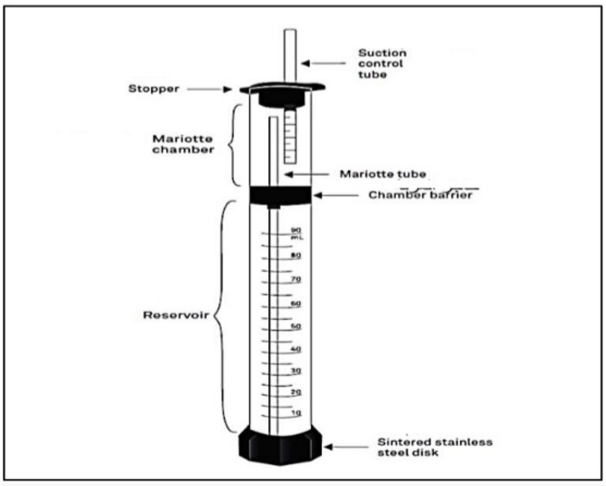

Figure 1: *Schematic diagram of the soil sizing device parts.*

Mean weight diameter

Soil samples were taken and crushed at a specific moisture content. The samples were sieved between 4- and 9-mm sieves. 25 g of soil was taken and placed on a set of sieves with opening diameters of 4.75, 2.36, 1.0, 0.5, and 0.25 mm. The sample was moistened from below by capillary action for six minutes. The sieves were placed on a Youder apparatus (Youder, 1936) for six minutes at 30 rpm. The contents of each sieve were transferred to a humidity tray and oven-dried at 105°C for 24 hours. The weight of each sieve was recorded, based on the mean weighted diameter (MWD) according to the equation below and described in (Al-Tamimi and Mahdi, 2017).

MWD = mean weighted diameter (mm).
Wi = mass of aggregates as a percentage of the total weight of the sample (without units).
Xi = mean diameter of those aggregates (mm).

Mass moisture content

Soil samples were taken from soil columns for all treatments at a depth of 0.15 m using a special knife to estimate the soil moisture content using the gravimetric method. The soil samples were dried in an oven at 105°C for 24 hours. The gravimetric moisture content was estimated on a dry weight basis using a Chinese-made TZS-IW moisture meter according to the method described in (Dane and Top, 2020).

Curve retention water soil

The relationship between volumetric moisture content and structural tension was estimated by saturating the dry soil samples, sieved with a 2 mm mesh diameter screen, for 24 hours and placing them in a pressure plate apparatus. The applied tensions were 0, 5, 10, 33, 500, 1000, and 1500 kPa. The pressure plate apparatus was used for high tensions. Centered glass funnels with 20-micrometer holes were used to determine the relationship between soil tension and bulk moisture, as stated in Black (1965).

Table 1: *Effect of compaction levels and amendment type on saturated water conductivity values (cm h^{-1}).*

Compaction levels (C)	Type of amendments (A)				Mean (C)
	A_0	A_1	A_2	A_3	
C_0	1.476b	2.976ab	0.656 b	2.736ab	1.961A
C_1	2.113b	4.476a	1.016 b	1.493b	2.275A
C_2	2.616ab	2.380ab	1.790 b	1.980b	2.191A
Means (A)	2.068 AB	3.277A	1.154 B	2.070AB	

Means with the same letter for each factor or the interaction between them are not significantly different (P ≤ 0.05) according to Duncan's multiple range test ± SD.

Table 2: *Effect of compaction levels and type of amendments on water infiltration in soil (cm^3 h^{-1}).*

Compaction levels (C)	Type of amendments (A)				Mean (C)
	A_0	A_1	A_2	A_3	
C_0	2.463ab	3.456 a	1.096 b	3.003ab	2.505A
C_1	2.493ab	3.536 a	2.376 ab	2.193ab	2.650A
C_2	2.716ab	3.026ab	2.600 ab	2.673ab	2.754A
Means (A)	2.557 AB	3.340 A	2.024 AB	2.623 AB	

Means with the same letter for each factor or the interaction between them are not significantly different (P ≤ 0.05) according to Duncan's multiple range test ± SD.

Results and Discussion

Saturated hydraulic conductivity (cm h^{-1})

The results shown in Table 1 indicate that the gum acacia treatment recorded the highest average of saturated hydraulic conductivity value, reaching 3.277 cm h^{-1}, compared to the control treatment and the addition of ECO.WRP and bentonite, which recorded values of 2.068, 1.154, and 2.070 cm h^{-1}, respectively, with increases of 58.46%, 183.96%, and 58.30%, respectively. As for the compaction treatment, the results indicate that the highest value of saturated hydraulic conductivity was in treatment C1, reaching 2.275 cm h^{-1}, and no significant difference was recorded between treatments C0 and C2, in which the value of saturated hydraulic conductivity reached 1.961 and 2.191 cm h^{-1}, respectively. As for the binary interaction treatment, the results showed that treatment C1A1 recorded the highest value of water conductivity, reaching 4.476 cm h^{-1}, while treatment C1A2 recorded the lowest value of saturated hydraulic conductivity, reaching 1.016 cm h^{-1}, with a decrease rate of 77.30%. The reason behind this is that the improvers have a major role in increasing the values of saturated hydraulic conductivity in the soil due to the decrease in the apparent density, which is indicated by the results shown in Table 3. This is consistent with what Habibi *et al.* (2019) found, who found that using 10 g kg^{-1} Gum acacia increased water conductivity by 317%. This indicates that gum acacia improved soil structure by binding small particles together, creating larger water paths and reducing compaction and compaction.

Water infiltration in soil (cm h^{-1})

The gum acacia treatment produced the highest average water infiltration in soil value, reaching 3.340 cm h^{-1}, compared to the control treatment and the addition of ECO.WRP and bentonite, which reached values of 2.557, 2.024, and 2.623 cm h^{-1}, respectively, with increases of 30.70%, 65.01%, and 27.33%, respectively (Table 2). As for the compaction treatments, the results indicate that the highest value of water infiltration in soil was in the C2 compaction treatment, reaching 2.754 cm h^{-1}. No significant difference was recorded between the C0 and C1 treatments, in which the soil water infiltration value was 2.505 and 2.650 cm h^{-1}, respectively. As for the binary interaction treatment, the results showed that treatment C1A1 recorded the highest value of soil water infiltration rate, reaching 3.536 cm h^{-1}, while treatment C0A2 recorded the lowest value of soil water infiltration rate, reaching 1.096 cm h^{-1}, with a decrease rate of 69%. The reason behind this is that gum acacia acts as an aggregate, helping to form larger and more stable soil aggregates, which leads to an increase in large spaces between the aggregates and improves ventilation and water permeability. It also works to reduce the dispersion of clay soil particles due to its containing natural polymeric compounds such as polysaccharides. Gum acacia also works to reduce soil density. This is what the results of Table 3 explain.

Bulk density (μg m^{-3})

The bentonite treatment recorded the highest average bulk density value, reaching 1.185 μg m^{-3}, compared to the control, gum acacia, and ECO.WRP treatments, which recorded values of 1.158, 1.130, and 1.116 μg m^{-3}, respectively, with increases of 2%, 4%, and 6%, respectively (Table 3). As for the compaction treatments, the results indicate that the highest value of the apparent density in the soil was in treatment C2, reaching 1.189 μg m^{-3}, and no significant difference was recorded between treatments C0 and C1, in which the value of the apparent density in the soil reached 1.158 μg m^{-3}, respectively. As for the binary interaction treatment, the results showed that it reached 0.980 μg m^{-3} and a decrease rate of 20%. The reason behind this is that increasing compaction leads to a reduction in the size of the air pores in the soil and an increase in the cohesion of its particles, which raises the apparent density. These differences indicate that the effect of some treatments can change depending on the level of compaction. This is consistent with Ferreira *et al.* (2021), that soil compaction led to a deterioration in the physical properties of the soil by increasing the apparent density, and what Adeboye *et al.* (2021) indicated regarding the effect of soil compaction on the physical properties of the soil. The experiment included three treatments (no compaction 0, medium compaction and high compaction). The increase in Medium and high compaction increased soil bulk density.

Table 3: *Effect of compaction levels and type of amendments on soil bulk density (μg m^{-3}).*

Compaction levels (C)	Type of amendments (A)				Mean (C)
	A_0	A_1	A_2	A_3	
C_0	1.113 a	1.096 a	0.980 a	1.193 a	1.095 A
C_1	1.183 a	1.110 a	1.143 a	1.196 a	1.158 A
C_2	1.180	1.183 a	1.22 a	1.166 a	1.189 A
Means (A)	1.158 A	1.130 A	1.116 A	1.185A	

Means with the same letter for each factor or the interaction between them are not significantly different (P ≤ 0.05) according to Duncan's multiple range test ± SD.

Mean weight diameter (mm)

The results shown in Table 4 indicate that the ECO.WRP treatment had the highest average weighted diameter (mm), reaching 3.140 mm, compared to the control, gum acacia, and bentonite treatments, which reached 0.660, 1.744, and 1.697, respectively. Increases reached 375%, 80%, and 212%, respectively. Significant differences were recorded between the treatment averages. Regarding compaction treatments, the results indicate that the highest weighted average soil diameter value was recorded in treatment C2, reaching 1.189 mm. No significant difference was recorded between treatments C0 and C1, which recorded a weighted average soil diameter of 1.095 and 1.158 mm, respectively. Regarding the two-way interaction treatment, the results showed that treatment C2A2 recorded the highest weighted average soil diameter value, reaching 4.973 mm, while treatment C0A0 recorded the lowest value for bulk density in the soil, reaching 0.513 mm. This decrease of 89% is attributed to the increase in weighted average soil diameter due to the addition of ECO.WRP. This confirms that this fertilizer is capable of resisting the effects of high compaction and enhancing aggregates by promoting the formation and stability of clumps and improving the organic matter that binds mineral particles into a stable, disintegration-resistant structure.

Table 4: *Effect of compaction levels and type of amendments on mean weight diameter (mm).*

Compaction levels (C)	Type of amendments (A)				Mean (C)
	A_0	A_1	A_2	A_3	
C_0	0.513a	0.736c	3.163b	0.840c	1.095A
C_1	0.500c	3.903ab	1.283c	1.183c	1.158A
C_2	0.966c	0.593c	4.973a	0.990c	1.189A
Means (A)	0.660C	1.744B	3.140A	1.004CB	

Means with the same letter for each factor or the interaction between them are not significantly different (P ≤ 0.05) according to Duncan's multiple range test ± SD.

Mass moisture content (%)

The bentonite treatment recorded the highest average mass moisture content, reaching 66.800%, compared to the control, gum acacia, ECO.WRP, and bentonite treatments, which reached values of 68.033%, 62.000%, and 65.944%, respectively, with increases of 9%, 3%, and 2%, respectively. Regarding the compaction treatments, the results indicate that the highest mass moisture content was in the C2 compaction treatment, reaching 66.842%. No significant difference was recorded between treatments C0 and C1, which reached 66.333% and 63.908%, respectively. Regarding the binary interaction

Table 5: *Effect of compaction levels and type of amendments on mass moisture content (%).*

Compaction levels (C)	Type of amendments (A)				Mean (C)
	A_0	A_1	A_2	A_3	
C_0	66.467ba	71.267a	62.700ba	64.900ba	66.333A
C_1	68.433a	53.500b	65.467ba	68.233a	63.908A
C_2	69.200a	61.233ba	69.667a	67.267ba	66.842A
Means (A)	68.033A	62.000A	65.944A	66.800A	

Means with the same letter for each factor or the interaction between them are not significantly different (P ≤ 0.05) according to Duncan's multiple range test ± SD.

Table 6: *Average values of water moisture content ($cm^3\ cm^{-3}$) for compaction levels and types of amendments for experimental treatments at different tension values.*

Sequence	Treatment	Tension values						
		0	50	100	330	5000	10000	15000
1	C_0A_0	0.53	0.43	0.37	0.33	0.31	0.22	0.12
2	C_0A_1	0.57	0.50	0.43	0.39	0.29	0.21	0.12
3	C_0A_2	0.60	0.54	0.45	0.41	0.26	0.18	0.11
4	C_0A_3	0.54	0.46	0.41	0.30	0.28	0.21	0.13
5	C_1A_0	0.58	0.55	0.47	0.39	0.28	0.20	0.13
6	C_1A_1	0.56	0.51	0.42	0.30	0.27	0.17	0.11
7	C_1A_2	0.58	0.55	0.40	0.38	0.29	0.25	0.10
8	C_1A_3	0.55	0.51	0.38	0.34	0.32	0.25	0.10
9	C_2A_0	0.57	0.55	0.41	0.32	0.30	0.19	0.08
10	C_2A_1	0.56	0.54	0.44	0.32	0.31	0.20	0.08
11	C_2A_2	0.61	0.61	0.46	0.29	0.22	0.14	0.08
12	C_2A_3	0.57	0.49	0.48	0.31	0.20	0.13	0.08

Means with the same letter for each factor or the interaction between them are not significantly different (P ≤ 0.05) according to Duncan's multiple range test ± SD.

treatment, the results showed that treatment C0A1 recorded the highest soil moisture content, reaching 71.267%, while treatment C1A1 recorded the lowest soil moisture content, reaching 53.50%, a decrease of 24.93% (Table 5). This is because bentonite is a clay mineral characterized by high swelling properties and a large specific surface area, making it highly effective at retaining water, consistent with what was indicated by El-Nagar *et al.* (2021) and Al-Amri (2023).

Curve retention water soil ($cm^3\ cm^{-3}$)

It is noted from the results of Table 6 that the volumetric moisture content decreases with increasing tension (0-15,000 kPa). This is consistent with the characteristics of soil moisture retention curves and logical behavior in soil physics. At low tension (0-100 kPa), water is readily available within the large pores. As tension increases, water becomes more bound to the particles and its retention capacity decreases. Therefore, the moisture content gradually decreases when treated without adding A0 improver. We note that the volumetric moisture content increases with increasing compaction at low tension (0-330 kPa). This is because compaction reduces the size of the large pores and increases water retention at high tension (5,000 kPa and above). The difference between the compaction levels decreases, and the moisture content increases significantly when treating with ECO WRP fertilizer and bentonite, especially at medium tensions (330-1,000 kPa). This indicates the effectiveness of these materials in improving the soil's ability to retain water available to plants. They were the most effective in Retaining water available to the plant. Treatments A2, ECO WRP fertilizer treatment, and A3 bentonite treatment showed clear superiority compared to the rest of the treatments, as they contributed to improving the ability to retain moisture across the entire tension range. Treatment C2A2, treated at a compaction level of 20 passes with the addition of ECO WRP fertilizer, recorded the highest moisture content value at a tension of 0 kPa (0.61 cm^3 cm^{-3}). It also maintained good moisture levels at high tensions, indicating the effectiveness of the fertilizer in modifying the structure and enhancing its ability to retain moisture. While some values in A2 and A3 may not be the highest at a certain tension, their behavior was more balanced and they maintained high moisture levels within the vital range for plant growth (330-1500 kPa), making them the most efficient in terms of retaining water available to the plant. The most effective in retaining moisture at tension (330-1000 kPa) was treatment C2A2, treated at a compaction level of 20 passes with the ECO fertilizer enhancer treatment. WRP and C2A3 treatment at a compaction level of 20 troughs with bentonite addition treatment. We conclude that increasing compaction leads to improved moisture retention at low tensile strengths but may negatively affect aeration and roots if it exceeds a certain limit. Zhou *et al.* (2019) demonstrated the effect of adding bentonite on the physical and chemical properties of sandy soil. The experiment included the addition of 30 µg ha^{-1}. Without addition, the addition of bentonite improved soil properties, including soil moisture content. Mi *et al.* (2020) demonstrated the effect of adding bentonite on the physical properties of sandy soil. The experiment included three levels of bentonite (0, 10, and 15 µg ha^{-1}). It was found that adding bentonite at all levels improved soil properties, such as the moisture content at the wilting point and the moisture content of the available water. El-Nagar *et al.* (2021) demonstrated the effect of adding bentonite on the physical and chemical properties of sandy soil. The experiment included Three levels of bentonite (0, 5, and 10 t h^{-1}) were used. Adding bentonite at a level of 10 t h^{-1} improved soil properties, including soil density, soil moisture content, available nitrogen concentration, and soil water holding curve. Al-Amri (2023) demonstrated the effect of adding bentonite on the physical and chemical properties of sandy soil. The experiment included six levels of bentonite (0, 6, 12, 18, 24, and 30 µg ha^{-1}). Adding bentonite at a level of 10 megagrams ha^{-1} improved soil properties, including the moisture content at wilting point and the available water content.

Conclusions

This study concludes that improved soil yielded better results compared to unimproved soil, and that soil amendments positively improved certain indicators more than others. Gum acacia was the best at improving saturated hydraulic conductivity and water infiltration in the soil, but the addition of bentonite improved bulk density and mass moisture content, and the best weighted diameter was achieved with the addition of ECO WRP fertilizer. Therefore, each specific type of soil amendment has a different role, but they ultimately improve the physical properties of the soil. It is worth noting that soil compaction levels had no clear effect on the physical properties of the soil studied.

Acknowledgements

I extend my heartfelt gratitude and appreciation to all those who contributed to the completion of this research. I am particularly grateful to my supervisor and my family for their constant support and encouragement.

Author's Contributions

Conceptualization: M.A.A.; Methodology: M.A.A.; Investigation: A.M.A.; Supervision: M.A.A.; Funding Acquisition: A.M.A

Generative AI or AI assisted technology statement

The authors declare that no generative AI and AI assisted technology was used in the creation of this manuscript.

Conflicts of Interest

The authors declare that they have no conflict of interest.

References

Adeboye, O.B., S.O. Odediran, A.P. Adeboye and O.K. Adekalu. 2024. Impact of Soil Compaction and Mulching on Growth and Yield of Cowpea in Ile-Ife, Nigeria. Arid zone J. Engineer. Technol. Environ., 20(1): 83-92

Al-Amri, Z.A.M. 2023. The role of bentonite, perlite, and vermicompost in improving some physical and chemical properties of desert soil and the growth and yield of potato (*Solanum tuberosum* L.). Ministry of Higher Education - College of Agricultural Engineering Sciences - University of Baghdad.

Al-Tamimi, M.I.O. and N.T. Mahdi . 2017. Analysis of physical properties of soil. University House for Printing, Publishing and Translation.

Ministry of Higher Education and Scientific Research. University of Baghdad. College of Agriculture. Iraq.
Baqir, H.H. 2013. A Comparison between Results of Compaction for Soil. J. Engineer. Technol., 31(1):14-31. https://doi.org/10.30684/etj.2013.71258
Billingham, K. 2015. Humic products: potential or presumption for agriculture. NSW Agriculture.
Black, C.A. 1965. Methods of soil analysis, part 1. Physical and mineralogical, properties. Wisconsin, Madison. American Society of Agronomy. Inc. Publishier. https://doi.org/10.2134/agronmonogr9.1
Dane, J.H. and G.C. Topp. 2020. Methods of soil analysis. part 4: Physical methods. John Wiley & Sons.
El-Nagar, D.A. and D.H. Sary .2021. Synthesis and characterization of nano bentonite and its effect on some properties of sandy soils. Soil Tillage Res., 208: 104872. https://doi.org/10.1016/j.still.2020.104872
Fabiola, N.B., Giarola, A.P. Silva, S. Imhoff, and A.R. Dexter. 2003. Contribution of natural soil compaction on hard setting behavior. Geoderma., 113(1-2): 95-108. https://doi.org/10.1016/S0016-7061(02)00333-6
Farahani, E.M.R., Mosaddeghi, A.A. Mahboubi, and A.R. Dexter. 2019. Prediction of soil hard-setting and physical quality using water retention data. Geoderma., 338: 343-354. https://doi.org/10.1016/j.geoderma.2018.12.012
Ferreira, C.J.B., C.A. Tormena, E.D.C. Severiano,L. Zotarelli, and E. Betioli Júnior. 2021. Soil compaction influences soil physical quality and soybean yield under long-term no-tillage. Archiv. Agron. Soil Sci., 67(3): 383-396 https://doi.org/10.1080/03650340.2020.1733535.
Habibi, Z. M.Rahmati, A.A. Alilou and E. Karimi. 2018. The Efficiency of Arabic Gum on Improvement of Physical and Chemical Properties of Saline-Sodic and Non-Saline-Sodic Soils near Lake Urmia. Water Soil., 32(5): 987-1001.
Hakansson, I., and W.B. Voorhees. 2020. Soil compaction. In Methods for assessment of soil degradation (pp. 167-179). CRC Press. https://doi.org/10.1201/9781003068716-8
Hillel, D. 2004.Introduction to Environmental Soil Physics. Elsevier Academic Press, Amsterdam. Boston. Int. Confer. Agric. Engineer., July 8–12, Valencia, Spain.
Lahhob, Q.R., M. Mudhafar, H.A. Alsailawi, & M.A. Zaidan. 2025. A revolutionary CRISPR-based detection and genetic profiling of parasitic infections in domesticated animals. J. Anim. Health Prod., 13(s1): 158–166. https://doi.org/https://dx.doi.org/10.17582/journal.jahp/2025/13.s1.158.166
Mi, J.E.G., Gregorich, S. Xu, N.B. McLaughlinand J. Liu. 2020. Effect of bentonite as a soil amendment on field water-holding capacity, and millet photosynthesis and grain quality. Scient. Report., 10(1): 18282. https://doi.org/10.1038/s41598-020-75350-9
Rahmati, M. and M. Kosallo. 2019. Effects of Chitosan and Arabic Gum Biopolymers on Some Physical Properties of Swelling Soils. J. Soil Water Sci., 29(1): 28-43.)In Persian.
Saber, R.K. and A.A.S. Al-Qaisi. 2021. Predicting soil stiffness from the moisture characteristic curve and its relationship to the degree of compaction of gypsum soil. Anbar J. Agric. Sci., 19 (2): 182-194. https://doi.org/10.32649/ajas.2021.175872
Sofyan, E.T. BJoy, and F. Raidasari. 2024. Effect of Combination of Soil Improvers and N, P, K Fertilizer on Organic C, Total N, Uptake N, and Yield of Lowland Rice (*Oryza sativa* L.) in Inceptisols from Jatinangor, West Java, Indonesia. Int. J. Plant Soil Sci., 36(3): 142-149. https://doi.org/10.9734/ijpss/2024/v36i34409
Tarmooz, A.A., T.H. Al-Yasiri, Q.R. Lahhob, M. Mudhafar, H.A. Alsailawi, & A.A. Ayada. 2025. Antimicrobial resistance in respiratory pathogens of domestic and wild felids. J. Anim. Health Prod., 13(s1): 208–217. https://doi.org/https://dx.doi.org/10.17582/journal.jahp/2025/13.s1.13.s1.208.217
Youder, R. 1936. A direct method of aggregate analysis of soil and a study of the physical nature of erosion losses.J.Am.Soc.Agron. 28:337-351.
Zhang, R. 1997. Infiltration models for the disk infiltrometer. Soil Sci. Soc. Am. J., 61: 1597-1603. https://doi.org/10.2136/sssaj1997.03615995006100060008x
Zhou, L.C.M., Monreal, S. Xu. N.B. McLaughlin, H. Zhang, G. Hao, and J. Liu. 2019. Effect of bentonite-humic acid application on the improvement of soil structure and maize yield in a sandy soil of a semi-arid region. Geoderma., 338: 269-280. https://doi.org/10.1016/j.geoderma.2018.12.014