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Hydrated Lime Effects on Geotechnical Properties of Clayey Soil

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ABSTRACT

Cohesive soils present difficulties in construction projects because it usually contains expansive clay minerals. However, the engineering properties of cohesive soils can be stabilized by using various techniques. The research aims to elaborate on the influences of using hydrated lime on the consistency, compaction, and shear strength properties of clayey soil samples from Sulaimnai city, northern Iraq. The proportions of added hydrated lime are 0%, 2.5%, 5%, 7.5% and 10% to the natural soil sample. The results yielded considerable effects of hydrated lime on the engineering properties of the treated soil sample and enhancement its strength. The soil's liquid limit, plasticity index, and optimum moisture content were decreased with the increase of hydrated lime percent. The soil's other geotechnical properties such as plastic limit, maximum dry density, and unconfined compressive strength were increased with the hydrated lime content increase. The oedometer test results produced a notable decrease in the compressibility characteristics of the lime-treated soil sample. Hence, hydrated lime is successfully contributed and can be considered as an effective material to improve the strength, compressibility, and consistency properties of the cohesive soils in Sulaimani city.

Keywords: Cohesive Soil, Soil Stabilization, Hydrated Lime.

تأثيرات الجير المطفأ على الخواص الجيوتقنية للتربة الطينية

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الخلاصة

تواجه التربة المتماسكة صعوبات في مشاريع البناء لأنها تحتوي عادة على معادن طينية موسعة. ومع ذلك، يمكن تثبيت الخصائص الهندسية للتربة المتماسكة باستخدام تقنيات مختلفة. الهدف من البحث هو اكتشاف تأثيرات استخدام الجير المطفأ على

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التماسك، والرص، وخصائص مقاومة القص لعينات التربة الطينية من مدينة السليمانية، شمال العراق. نسب الجير المطفأ المضافة هي 0٪ و 2.5٪ و 5٪ و 7.5٪ و 10٪ لعينة التربة الطبيعية. أسفرت النتائج عن تأثيرات كبيرة للجير المطفأ على الخواص الهندسية لعينة التربة المعالجة وطورت قوتها. تم تقليل حد السائل في التربة، ومؤشر اللدونة، ومحتوى الرطوبة الأمثل مع زيادة نسبة الجير المطفأ. بينما تم زيادة الحد البلاستيكي للتربة وكثافة الجفاف القصوى. أيضًا، زادت قوة الضغط غير المحصورة في التربة بشكل ملحوظ مع زيادة محتوى الجير المطفأ. أنتجت نتائج اختبار الانضمام انخفاضا ملحوظا في خصائص الانضغاطية لعينة التربة المعالجة بالجير. ومن ثم، فإن الجير المطفأ ساهم بنجاح ويمكن اعتباره مادة فعالة لتحسين قوة وخصوبة وتماسك خصائص التربة المتماسكة في مدينة السليمانية.

الكلمات الرئيسية: التربة المتماسكة، تثبيت التربة، الجير المطفأ.

1. INTRODUCTION

In order to obtain an eligible soil foundation for construction projects, its geotechnical characteristics might require some improvement. Therefore, various common methods for soil stabilization exist globally nowadays, which can be used for improving weak foundation soil.

Many techniques may perform soil stabilization; replacement of a part of the weak soil by better materials is one of these techniques. However, stabilization materials might be expensive and/or environmentally insecure. For instance, cement is one of the not desirable stabilization material (**Al-Swaidani et al., 2016; Al-Hadidi and AL-Maamori, 2019**). Then, lime is effectively utilized for soil improvement purposes to stabilize soil's weak geotechnical engineering characteristics. Mechanical properties of soils such as clayey and silty soils were successfully improved by using lime. Notably, lime is used in many civil engineering projects such as road layers, earth embankments, soil foundations, and piles (**Al-Rawas and Goosen, 2006**).

The carried-out studies in the literature on the soil's geotechnical engineering properties improvement yielded significant properties modification.

For soils compaction properties, the addition of lime caused the optimum moisture content to be decreased and the maximum dry density to be increased (**Bell, 1996; Gay and Schad, 2000; Guney et al., 2007; Hossain et al., 2007; Hezmi et al., 2019; Chandak and Babu, 2015; Rao et al., 2019; Nalawade and Jadhao, 2020; Abdalqadir et al., 2020).**

For soils consistency parameters, in one hand, lime decreases the plasticity index, reduces shrinkage cracking, and increases the workability and shrinkage limit (**Guney et al., 2007; Bell, 1996; Gay and Schad, 2000; Hossain et al., 2007; Sante, 2019; Zamin, 2019; Nalawade and Jadhao, 2020**) On the other hand, some researchers (**Al-Rawas et al., 2005; Goswami and Singh, 2005; Lasledj and Al-Mukhtar, 2008; Bagherpour and Choobbasti, 2003; Kavak and Akyarli, 2007; Manasseh and Olufemi, 2008; Ansary et al., 2006**). In most situations, the plasticity properties of the clayey soils more or less are affected instantaneously by the addition of lime.

For soils shear strength characteristics, hence in some recent studies (**Consoli et al., 2012; Calik et al., 2014; Asad et al., 2019; Kumar et al., 2019; Chandak and Babu, 2015; Al-Alwan, 2019**), the addition of lime found to improve the soils significantly strength properties. Besides, on the shear mode of failure for soil stabilized by lime, it showed brittleness properties (**Lin et al., 2007; Chen and Lin, 2009**). Moreover, the capability of the stabilized soil by lime in terms of strength is significantly affected. This is resulted due to the deduction in the voids percent because of the added lime percent increase (**Consoli et al., 2012, 2014**).

For soil compressibility properties, in some studies such as (**Rao and Shivanada, 2005**), the yield stress increase by the increase in the lime content. Similarly, both of (**Sut-Ünver et al., 2018, and Vukicevic et al., 2019**) found that 5% lime content is the crucial percent, which improved both of compressibility and rebound indexes. Lime used in some works with other materials such as the study of (**Hayder, 2016).** The addition of the composite of cement and quick lime can improve the compressibility by reducing both of compression rebound ratios.

This study presents the effect of hydrated lime on the Atterberg limits, compaction characteristics, compressibility parameters, and unconfined compressive strength of Sulaimnai city, Northern Iraq

CL soil, which is classified according to the unified soil classification system (USCS). All tests were conducted following the ASTM standards.

2.EXPERIMENTAL INVESTIGATION

2.1Used Materials

2.1.1 Soil

The used soil in this study was obtained from a site, namely Barika soil, **Fig.1**, situated in the Sulaimani Governorate, northern Iraq (Latitude = 35.393755 and Attitude = 45.595097). The natural soil was collected at a depth of 0.5 to 1 m from the natural ground level and is usually consolidated clay. The undisturbed and disturbed soil samples were excavated and then extracted, placed in plastic bags, and transported to the geotechnical laboratory for testing. Extreme precautions were taken during soil sampling to keep the collected soil samples in their natural moisture content and field density conditions (**Kalkan, 2003; Kalkan and Bayraktutan, 2008; Rashed et al., 2017; Asad et al., 2019; Abdalqadir and Salih, 2020**). Soil laboratory tests were performed on the samples to determine their geotechnical properties. The obtained sample was light brown clayey soil and is composed of some clay. It can be defined as low plasticity soil (CL) according to the Unified Soil Classification System (D-422, 2007). The soil's particle size distribution shown in **Fig.2** and the other properties are summarized in **Table 1**.

Table 1. Geotechnical properties of the natural Barika soil sample.

Property	**Value**
Natural moisture content (%)	18.682
Color	Light Brown
LL (%)	45
PL (%)	19
PI	26
Specify gravity (G_s)	2.67
Maximum dry density (g/cm^3)	1.573
Optimum moisture content (%)	27.25
Unconfined compressive strength (kPa)	174.23
Soil classification (USCS)	CL

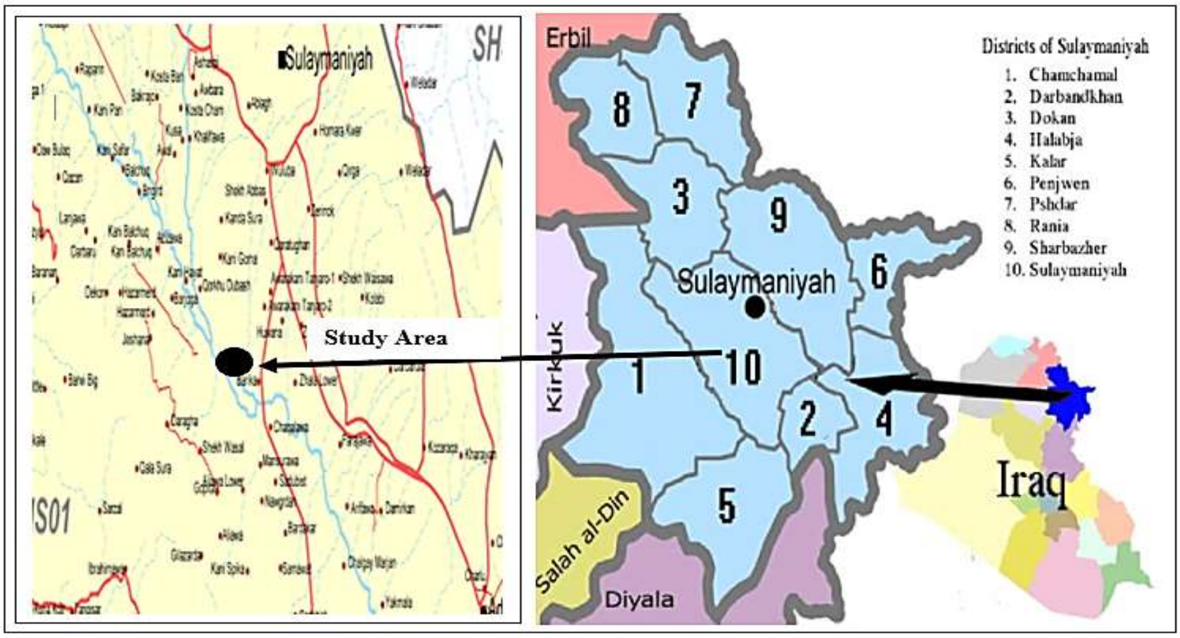

Figure 1. Parts of the Iraqi map showing the selected soil sample location.

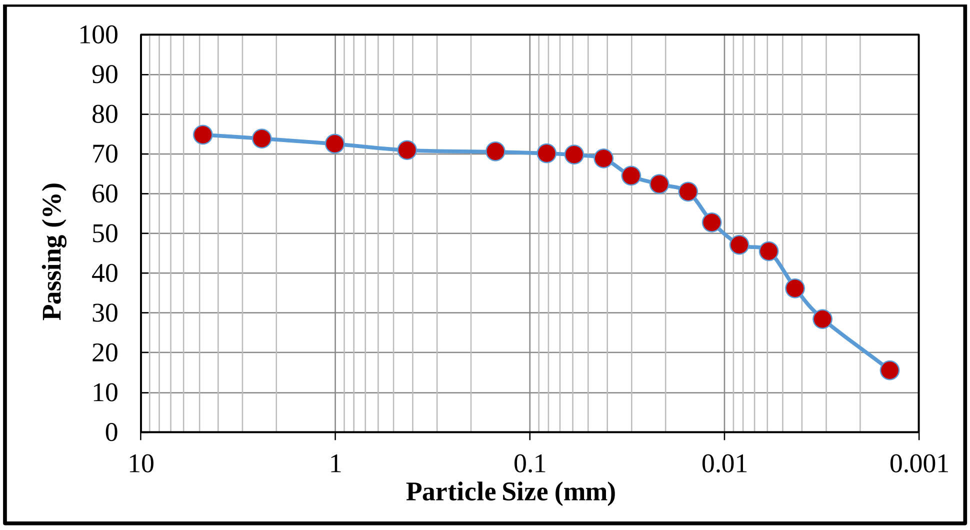

Figure 2. Particle size distribution curve for the natural Barika CL soil sample.

2.1.2 Hydrated Lime

The used hydrated lime in the current study is locally-available lime typically used for construction purposes. It is obtained from the Karbala Lime Factory located in the southeast of Baghdad, Iraq. The chemical and physical properties of the used lime are presented in **Table 2**.

Table 2. Physical and chemical properties of the used hydrated lime for the stabilization purpose.

Chemical Properties (%)	
CaO	56.1
MgO	0.13
Fe_2O_3	0.12
Al_2O_3	0.72
SiO_2	1.38
SO_3	0.21
LO I	40.6
Physical Properties	
Percent passing sieve No.200 (%)	98
Surface Area (m^2/kg)	398
Specific gravity	2.78

2.2 METHODS OF TESTING

The collected soil sample was divided into five equal parts with the same natural properties. Then, each part was mixed with 0%, 2.5%, 5%, 7.5%, and 10% of hydrated lime, which was replaced from the total dry mass of the natural soil sample, and then the required water content was added. The mixtures were stored in waterproof containers for 24 hours to allow for homogeneity and mature. By using the maximum dry density and optimum moisture content (**Table 1**), the testing samples were prepared for all the proposed geotechnical characteristics of this study. These prepared samples were performed for all of the above selected hydrated limes percentages.
The performed laboratory tests were particle size distribution, specific gravity, Atterberg limits, standard Proctor compaction, and unconfined compression tests. All these laboratory tests were conducted on the natural and stabilized soil samples, respectively.

2.2.1 Atterberg Limit Tests

Liquid limit (LL), plastic limit (PL), and plasticity index (PI) were obtained following the method given in the ASTM D4318 (2000). Variations in the plasticity index of the natural soil before and after the addition of hydrated lime were then studied. The natural soil sample was air-dried and sieved through No. 40. The required percent of hydrated lime was added after that, de-ionized water was added to the soil-lime mixture, and the paste was left in an airtight container for 24 hours to be matured. The consistency limits test then performed on the prepared paste at room temperature.

2.2.2 Compaction Tests

The method given in the ASTM D698 (2000) was applied to determine the maximum dry density (MDD) and the optimum moisture content (OMC) of the soil samples. Two compaction series were performed by using de-ionized water. The first one was for the determination of the natural soil compaction parameters (OMC and MDD). The second one is for the compaction properties determination of the stabilized sample by hydrated lime.

2.2.3 Unconfined Compression Tests

Unconfined compressive strength tests were conducted according to ASTM D2166 (2000). Field dry density (1.56 g/cm^3) and natural moisture content (18.68 %) were chosen to prepare the unconfined compression test samples. All the prepared samples were kept in plastic bags to prevent any moisture change due to evaporation.

2.2.4 One-Dimensional Consolidation Test

ASTM D 2435-2011 was chosen to be considered for the conduction of compaction tests by using an oedometer device. The sample size is 50 mm in diameter and 20 mm in height. The testing style is consisting of cumulative time-dependent loading. A seating load (5.0 kPa) is applied to obtain a suitable contact between the porous stone on the soil sample and the loading cap, also, by taking into consideration that the pressure is equal to the vertical overburden pressure corresponding to the depth of sample 0.5 to 1 m from the natural ground level. The vertical static loading consists of 25, 50, 100, 200, 400, and 800 kPa with a load increase ratio of $\Delta\sigma/\sigma$=1.0 is applied, and each loading left for 24 hours. Besides, vertical static unloading steps are also performed.

3. RESULTS AND DISCUSSIONS

3.1 Results of consistency tests

The Atterberg limits test results regarding Barika CL soil and hydrated lime mixtures at various percentages are presented in **Table 3** and **Fig. 3**. The reduction in liquid limit and plasticity index is a consequence of exchanges between the free calcium of the hydrated lime and the absorbed cations of the clay mineral. This leads to a decrease in the size of the diffused water layer surrounding the clay particles. The decrease in the size of the diffused water layer enables closer contact among the clay particles resulting in flocculation of these particles, which yielded in significant reductions in LL and PI.

Table 3. Consistency tests results of the natural and stabilized Barika soil samples by hydrated lime.

Hydrated Lime (%)	LL (%)	LL reduction (%)	PL (%)	PL Increase (%)	PI	PI reduction (%)
0	45	-	25	-	20	-
2.5	41	8.631	27.78	10.36	13	33.2
5	39	13.34	32.88	30.62	5.8	70.2
7.5	36	19.34	31.01	23.19	4.99	74.4
10	32	28.300	26.88	6.78	5.12	73.69

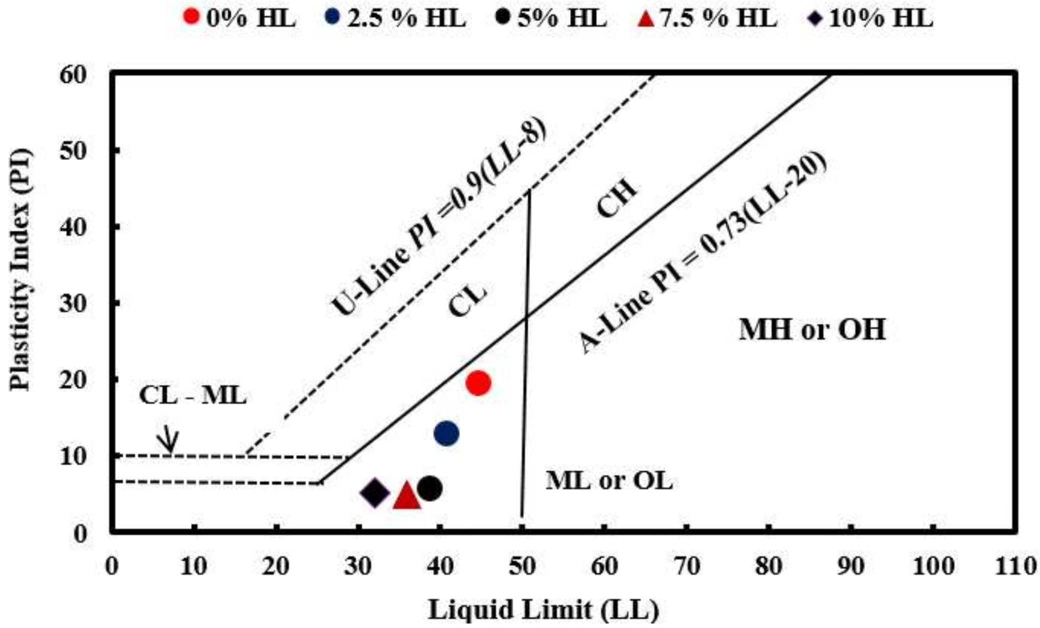

Figure 3. Locations of the natural and stabilized Barika soil samples on the plasticity chart of the unified soil classification system (USCS).

3.2 Effect of hydrated lime on unconfined compressive strength (UCS)

UCS tests were performed on the natural and stabilized Barika CL soil samples with hydrated lime. The stabilized samples prepared at various percentages of hydrated lime are shown in **Fig. 4**. The UCS of hydrated lime-treated samples develops rapidly with the hydrated lime percentage increase until the optimum hydrated lime content is reached. The soil samples in this study exhibit a rapid initial increase in the UCS with the addition of hydrated lime. The added optimum percentage of the hydrated lime to the natural soil sample further increased its UCS values from 174.23 kN/m^2 to 960.85 kN/m^2. In comparison, similar results have been observed by various researchers who studied soils UCS properties such as (**Elhassan, 2006).** The addition of hydrated lime might generate bonds among soil particles, which strongly bind the particles together and resist strongly any externally applied forces. This is notably can be noticed in the obtained increase in the UCS value due to 10% hydrated lime.

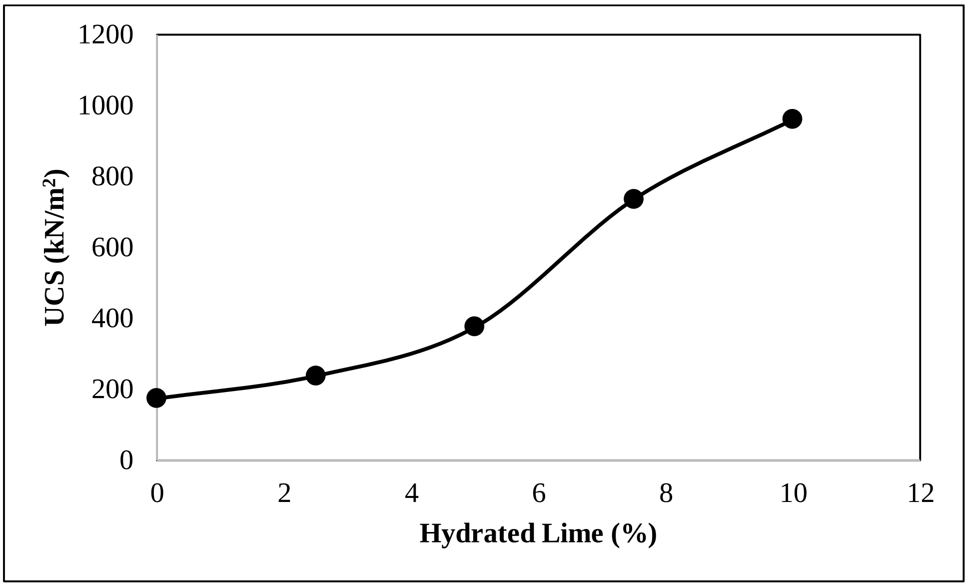

Figure 4. Variation of UCS values for the natural and stabilized Barika soil samples with various percentages of hydrated lime.

3.3 Results of compaction tests of the natural and stabilized Barika CL soil with hydrated lime

The results for the compaction tests performed on the untreated and treated Barika CL soil samples with hydrated lime were measured via using the standard proctor compaction method. The addition of hydrated lime at various percentages to the soil samples increases their maximum dry density and reduces their optimum moisture content for the same compaction effort, as shown in **Fig. 5**. A similar trend of behavior has also been observed for the case of hydrated lime treated clay in the study of (**Ingles and Metcalf, 1972)**. Added hydrated lime absorbs some percent of the added water for compaction purposes. This was resulted in a significant decrease in the required amount of water to achieve the MDD. Similar to the previous improved properties, hydrated lime might generate bonds among soil particles, which strongly bind the particles together and resist strongly any externally applied forces. This is notably can be noticed in the obtained increase in the MDD value due to 10% hydrated lime.

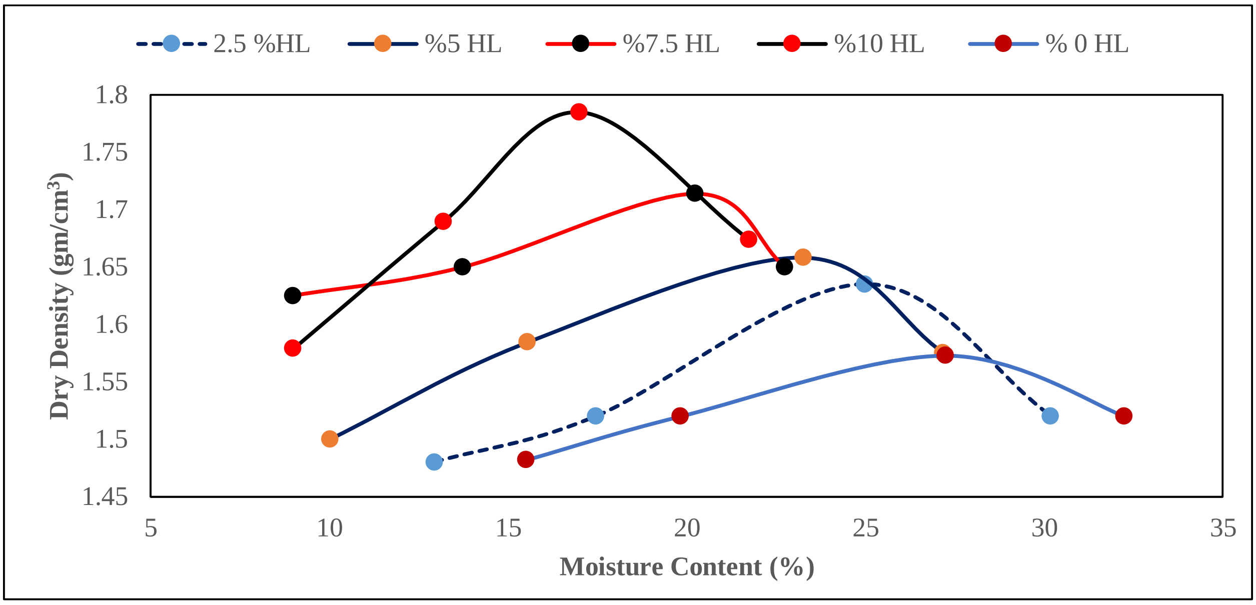

Figure 5. Water content-density relationships from the performed compaction tests on the natural and stabilized Barika soil samples with various percentages of hydrated lime.

3.4 Results of consolidation tests of the natural and stabilized Barika CL soil with hydrated lime

From applied pressure-void ratio (e-log p) graphs, all the added hydrated lime percentages, in addition to the natural soil's graph, are given in **Fig. 6,** and all test results are shown in **Table 4**. With the addition of hydrated lime up to 10% the value of C_c and m_v decreases with the increase of lime content by 89.61% and 79.41%, respectively. The expansion index (C_r) decreases with the increment of lime percent by 69.54%, but the rapid increase occurs at 7.5% after that, the value of the expansion index starts to decrease up to 10%. Generally, the compressibility properties (C_c, C_r, and C_v) decrease distinctively as the lime content increases due to suction and cementation bonding. These results are in agreement with the findings of (**Shareef 2016**, **Sut-Ünver et al., 2018**, and **Mavroulidou et al., 2013)**. Similar to the previous improved properties, hydrated lime might generate bonds among soil particles, which strongly bind the particles together and resist strongly any externally applied forces. This is notably can be noticed in the obtained reductions in the values of C_c, C_r and C_v due to 10% hydrated lime.

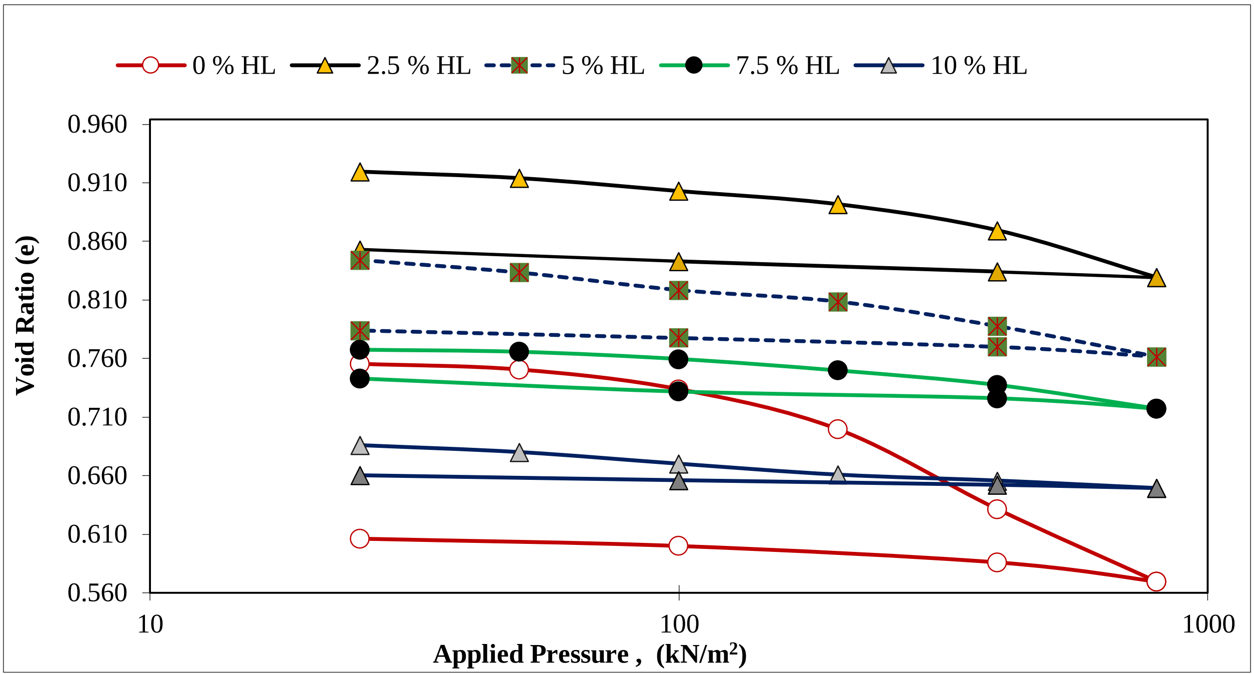

Figure 6. Applied pressure-void ratio relationships for the natural and stabilized Barika soil samples with various percentages of hydrated lime.

Table 4. Consolidation test results of the natural and stabilized Barika soil samples with hydrated lime.

Hydrated Lime (%)	C_c	C_c reduction (%)	C_r	C_r reduction (%)	C_v (m^2/MN)	C_v reduction (%)
0	0.2052	-	0.0243	-	0.287307	-
2.5	0.1337	34.84	0.0159	34.6	0.12401	56.88
5	0.0868	57.69	0.015	38.27	0.117079	59.24
7.5	0.067	67.34	0.017	30	0.073275	74.5
10	0.0213	89.62	0.0074	69.54	0.059147	79.41

4.CORRELATION OF CONSISTENCY, COMPACTION, AND STRENGTH PARAMETERS WITH THE HYDRATED LIME (HL)

4.1 Consistency Properties Correlations

A good correlation was obtained between liquid limit as a function of hydrated lime content in the form of a linear equation with the coefficient of determination R^2 equal to 0.8021, as shown in **Fig. 7** and the corresponding linear equation as follows:

$$LL\ (\%) = -1.2018\ HL + 44.427 \quad (1)$$

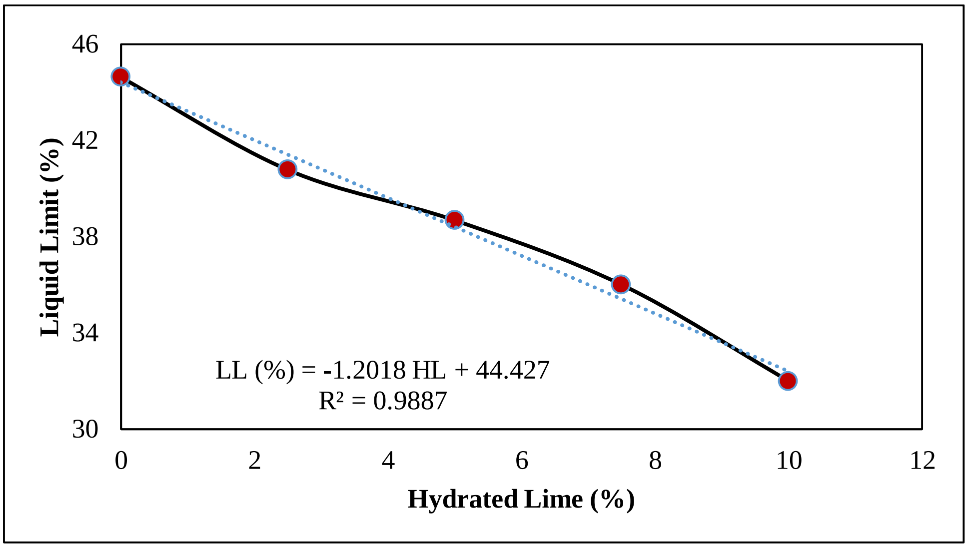

Figure 7. Liquid limit relationship with the used hydrated lime content.

The best relationship between plasticity index (PI) and used hydrated lime content, as compared to the plastic limit (PL) and used hydrated lime content, can be seen in **Fig. 8** in the form of polynomial equations with the coefficient of determination R^2 equal to 0.8181 and 0.7204 respectively and the corresponding non-linear equations as follows:

$$PI\ (\%) = -0.2337\ HL^2 + 2.6025\ HL + 24.494 \quad (2)$$

$$\text{PL}\ (\%) = 0.2237\ \text{HL}^2 - 3.7024\text{HL} + 19.808 \quad (3)$$

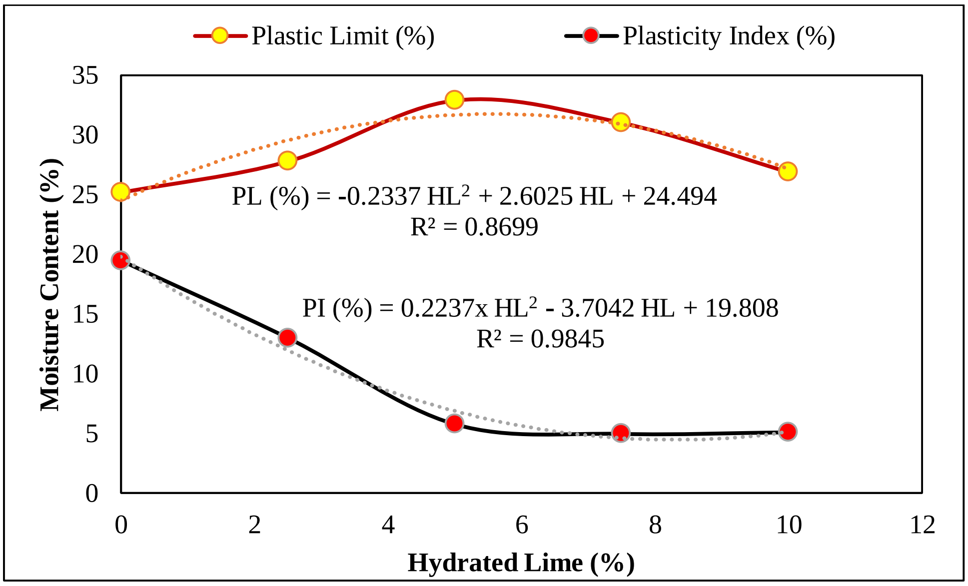

Figure 8. Plastic limit and plasticity index relationships with the used hydrated lime content.

4.2 Unconfined compressive strength (q_u) values correlations

The best trend line between q_u versus used hydrated lime content plot has given a high coefficient of determination R^2 equal to 0.9818 in the form of a non-linear equation as shown in **Fig. 9** and the corresponding equation as follows:

$$q_u\ (kN.m^{-2}) = 163.65\ e^{0.1817HL} \qquad (4)$$

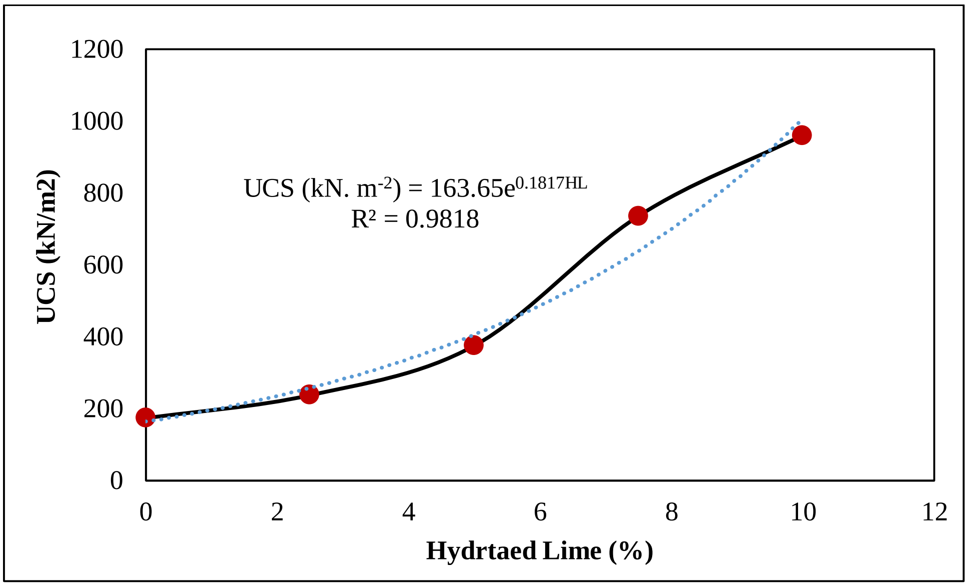

Figure 9. Unconfined compressive strength (q_u) relationship with the used hydrated lime content.

4.3 Compaction Parameters Correlations

The relationship between maximum dry density (MDD) and the used hydrated lime content, in addition to the optimum moisture content (OMC) relationship with the used hydrated lime content, can be seen in **Figs. 10** and **11**. The best trend line for the MDD versus HL plot is the linear correlation with a high coefficient of determination R^2 equal to 0.9792, as shown in **Fig.10** and the obtained corresponding linear equation as follows:

$$MDD\ (gm.cm^{-3}) = 0.0201\ HL + 1.5728 \qquad (5)$$

The linear trend line for the OMC versus HL plot gave a high coefficient of determination (R^2 = 0.9854), as shown in **Fig. 11** and the obtained corresponding linear equation as follows;

$$OMC\ (\%) = -1.01\ HL + 27.604 \qquad (6)$$

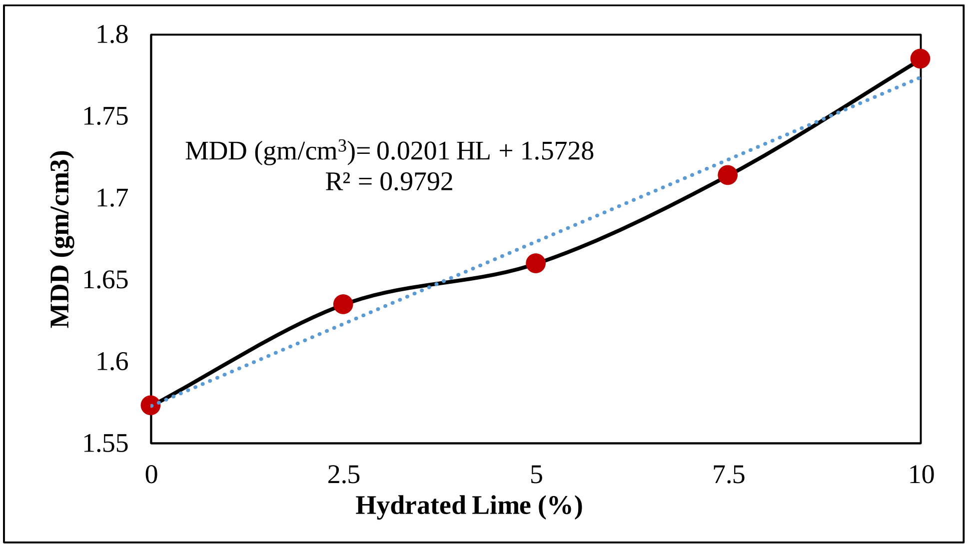

Figure 10. Maximum dry density (MDD) relationship with the used hydrated lime content.

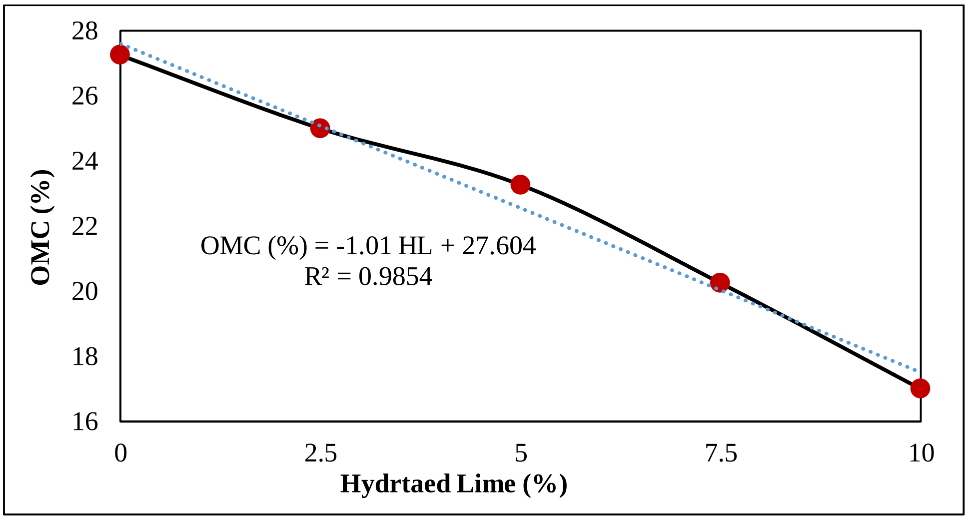

Figure 11. Optimum moisture content (OMC) relationship with the used hydrated lime content.

4.4 Consolidation Characteristics Correlations

Compression index property (C_c) correlated with hydrated lime content yielded an excellent relationship, which can be noticed from the obtained $R^2 = 0.9622$ (**Fig. 12**). At the same time, the correlation between hydrated lime percent with expansion index (c_r) and coefficient of consolidation (C_v) individually showed lower R^2, which are 0.7383 and 0.7753, respectively (**Figs. 13** and **14**). The obtained corresponding linear equations are as follows:

$$C_c = -\ 0.0435\ HL + 0.2332 \quad (7)$$

$$C_r = -\ 0.0033\ HL + 0.0257 \quad (8)$$

$$C_v = -\ 0.0507\ HL + 0.2843 \quad (9)$$

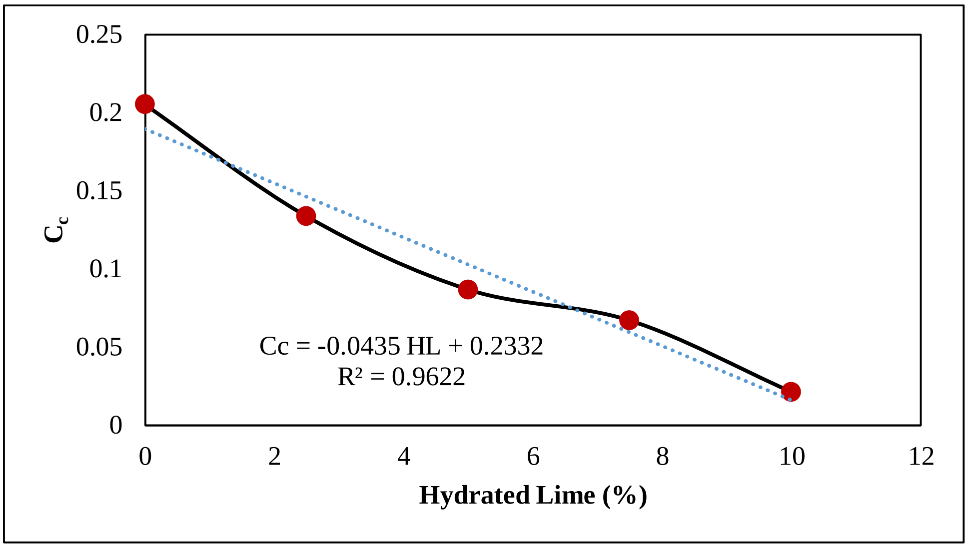

Figure 12. Compression Index (C_c) relationship with the used hydrated lime content.

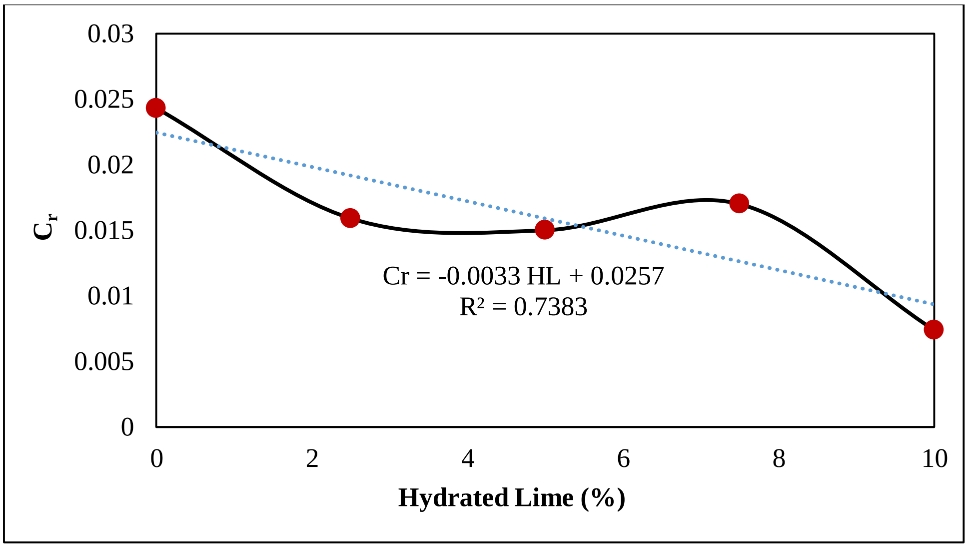

Figure 13. Expansion Index (C_r) relationship with the used hydrated lime content.

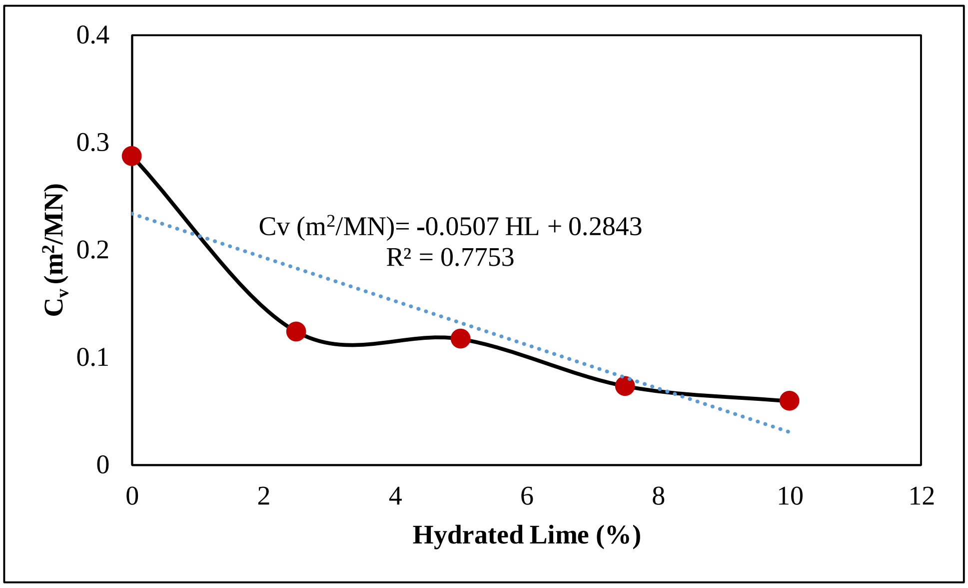

Figure 14. Coefficient of Consolidation (C_v) relationship with the used hydrated lime content.

5. RESEARCH OUTCOMES COMPARISON

The results of the conducted geotechnical laboratory tests on the selected CL soil samples yielded insignificant outcomes. The obtained improvements have notably worked with this type of cohesive soils. From **Table 5**, the perfect percent for stabilization purposes is 10%, which is clearly within the obtained range of lime perfect percent for soil stabilization. Although the achieved percent in this study is higher than most of the listed recent lime stabilization researches, it may be due to various reasons. These reasons might be various, such as particle size distribution, clay minerals percent, soil parent materials, impurities, soil depth, and the used lime composition. More on that, the examined geotechnical properties in this study are more than some of the listed researches, which some of them just checked few properties. Hydrated lime may work perfectly for some of the soil geotechnical properties as those properties may require materials such as lime to decrease water absorption and increase the particle's densification, which can be noticed in the improved consistency and shear strength characteristics.
Hence, lime stabilization works notably to stabilize the geotechnical properties of soils in general. Besides, and from the outcomes of this research, lime significantly works to stabilize cohesive soils (CL soil), which is replaced by a part of the problematic composition of that soil and substituted by capable materials to stick to soil particles. Locally-available hydrated lime check to stabilize local CL soil, it strengthened this soil and resulted in favorable changes happened in this soil's natural properties.

Table 5. Comparison of current study outcomes with similar outcomes available in the literature.

Researchers	Soil Type	Lime (%)	Examined Geotechnical Properties	Outcome (best percent)
Ola (1977)	Tropical Lateritic (Nigeria)	2, 4, 6, 8, and 10%	Consistency, compaction, shear strength, and CBR	The mentioned properties improved successfully (6%)
Baquir (1990)	FAO Clay (Iraq)	3, 5, 7, and 9%	Shear strength	Increase shear strength (7%)

Bell (1996)	kaolinite, montmorillonite, and quartz of clay deposits (South Africa)	2, 4, 6, 8, and 10%	Consistency, compaction, shear strength, and CBR	The mentioned properties improved successfully (4 - 6%)
Ansary et al. (2006)	Cohesive Soil (Bangladesh)	0, 1, 3, 5, and 7%	Consistency, unconfined compressive strength, CBR, and flexural strength	The mentioned properties improved successfully (7%)
Amu et al. (2011)	Lateritic Soil (Nigeria)	0, 2, 4, 6, 8, and 10%	Consistency, unconfined compressive strength, and CBR	The mentioned properties improved successfully (CBR = 6%, UCS = 8%)
Dash & Hussain, (2012)	Expansive and non-expansive residual soil (India)	1, 3, 5, 9, and 13%	Liquid limit, plastic limit, swelling, and compressive strength	The mentioned properties improved successfully (13%)
Gharib et al., (2012)	Golestan Province Soil (Iran)	1, 3, 5, 9, and 13%	Consistency properties	(13% for PI = 20-30) (9% for PI = 35) (5% for PI = 40)
Mohammed & Elsharief (2015)	expansive soil (Sudan)	0.5% to 7%	Consistency, compaction, and unconfined compressive strength and CBR	The mentioned properties improved successfully (7%)
Current Study	CL Soil (Iraq)	0, 2.5, 5, 7.5, and 10%	Consistency, Unconfined compressive strength, compaction, and consolidation	The mentioned properties improved successfully (10%)

5. CONCLUSIONS

Based on the test results, the following conclusions can be drawn:

- Cl soil consistency properties varied in their response to stabilization by hydrated lime. For the 10% of hydrated lime content, liquid limit and plasticity index reduced significantly by 28 % and 73 %, respectively. While the plastic limit slightly increased by 6%.
- The stabilized soil maximum dry density and optimum moisture content were notably improved. The stabilization yielded a 13% increase in maximum dry density and a 37% decrease in the optimum moisture content due to 10% of hydrated lime content.
- A significant increase of the CL soil's unconfined compressive strength value, was found for the 10% of hydrated lime content to be 81% increase.
- The obtained coefficient of determination, R^2, for the established relationships between the measured CL soil geotechnical characteristics and the selected hydrated lime content, indicate that these expressions are suitable for the determination of the compaction and strength characteristics for CL soil stabilized with hydrated lime.
- The addition of hydrated lime yielded in a valuable decrease in the CL soil's compressibility characteristics values (C_c, C_r, and C_v), which yielded in 89%, 69%, and 79% reductions, respectively.
- Overall the experimental outcomes presented the significant role of hydrated lime on the CL soil geotechnical properties. 10% hydrated lime is the best percent to be used for stabilization of the selected CL soil.

List of Symbols

ASTM = American Society for Testing and Materials
Cc = Compression Index
Cr = Expansion Index
LL = Liquid Limit
PL = Plastic Limit
PI = Plasticity Index
HL = Hydrated Lime
MDD = Maximum Dry Density
Cv = Coefficient of Consolidation
OMC = Optimum Moisture Content
UCS = Unconfined Compressive Strength
USCS = Unified Soil Classification System

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CONFLICT OF INTEREST

Authors have no conflict of interest relevant to this article.

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