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Effect of Storage Time on the Structural Integrity of Silts and Organic Soils: An Analysis of Moisture Content, Unconfined Compressive Strength, and Elasticity

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Abstract: The impact of storage duration on the geotechnical properties of soils is a recurring issue in the field of geotechnical engineering. Due to the lack of previous research addressing this topic, an experimental study was conducted to evaluate the variation of these properties over time. Undisturbed samples of silty and organic soil from Quito, Ecuador, were obtained. These samples were subjected to unconfined compressive strength (UCS) and moisture content (MC) tests at various intervals (1, 3, 7, 14, 21, 28, and 56 days). Results revealed a significant correlation between MC, UCS, and modulus of elasticity (ME). A progressive increase in UCS and ME was observed as MC decreased, with peak values observed to occur between 20 and 30 days. These findings suggest that matric suction plays a predominant role in increasing cohesion and, consequently, UCS. Therefore, it is concluded that the time elapsed between sample extraction and testing is a critical factor influencing the preservation of MC and, hence, the accurate assessment of the soil's mechanical properties.

Keywords: organic soil; silt; unconfined compressive strength; moisture content; modulus of elasticity

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1. Introduction

The geomechanical characteristics of soil guarantee adequate soil-structure interactions [1]. However, more information is needed regarding technical aspects, such as the appropriate period to store soil samples for long periods without altering their characteristics.

The permissible timeframe between sample collection and laboratory testing is a subject of considerable uncertainty, and it remains unclear whether extending this period will impact the outcome of the tests. Some studies have focused on sampling methodologies, such as (i) the use of Shelby tubes to obtain better-quality samples [2], (ii) soil characterization with the establishment of new correlations [3], (iii) the use of in situ methods in conjunction with the Cone Penetration Test Unit (CPTU) and dilatometers, which is a crucial aspect of geotechnical engineering [4], and (iv) soil characterization at different depths and loading levels [5]. The duration for which the samples could be stored is not specified.

Soil behavior is fundamental to engineering projects [6]. Therefore, it is crucial to emphasize the importance of soil characterization beyond particle size classification [7]. The Atterberg limit test, for instance, quantifies the alterations caused by differences in the MC [8].

Challenges arise during silt sampling due to the modifications occurring during extraction, leading to sample densifications caused by equipment, handling, storage, or transportation [9]. Shelby tube extraction causes a more significant disturbance at the time of penetration because of the diameter of the sampling tube, method, and extraction speed based on small-scale modeling [10]. Conversely, the use of block sampling in various studies, such as odometers and computerized scanners, has demonstrated superior preservation of soil structure and properties [11]. Nujid et al.'s [12] study on unaltered soil samples demonstrated that silty and organic soils experience a reduction in MC and saturation levels over extended periods. These findings imply that the water content of the samples plays a crucial role in assessing the test outcomes.

The complexity of comparing results from different studies arises from the absence of standardized soil sample collection and storage techniques [13]. While soil has been classified by extraction method and mineralogical composition, no studies have been conducted to assess the fluctuation of soil properties over time, specifically in response to changes in humidity and temperature during the storage period.

The main objective of this study was to assess fluctuations in the UCS, MC, and ME of silt and organic soil at different time intervals following sampling. To achieve this, a controlled methodology was used to analyze the behavior of these geomechanical properties at various time intervals. This study aimed to provide recommendations for the maximum duration for which a sample can be stored without compromising the accuracy of the results. The hypothesis examined was that the strength of the soil would increase, and the MC would decrease with an increase in the storage period.

2. Materials and Methods

2.1. Location

The study was conducted in Quito, Ecuador, covering the neighborhoods of Guamaní, El Rocío, El Garrochal, and Pucara. The coordinates of each site are 0°20′22.7′ S′ 78°33′52.6′ W′ and 0°20′25.4′ S′ 78°31′58.9′ W′, respectively (Figure 1).

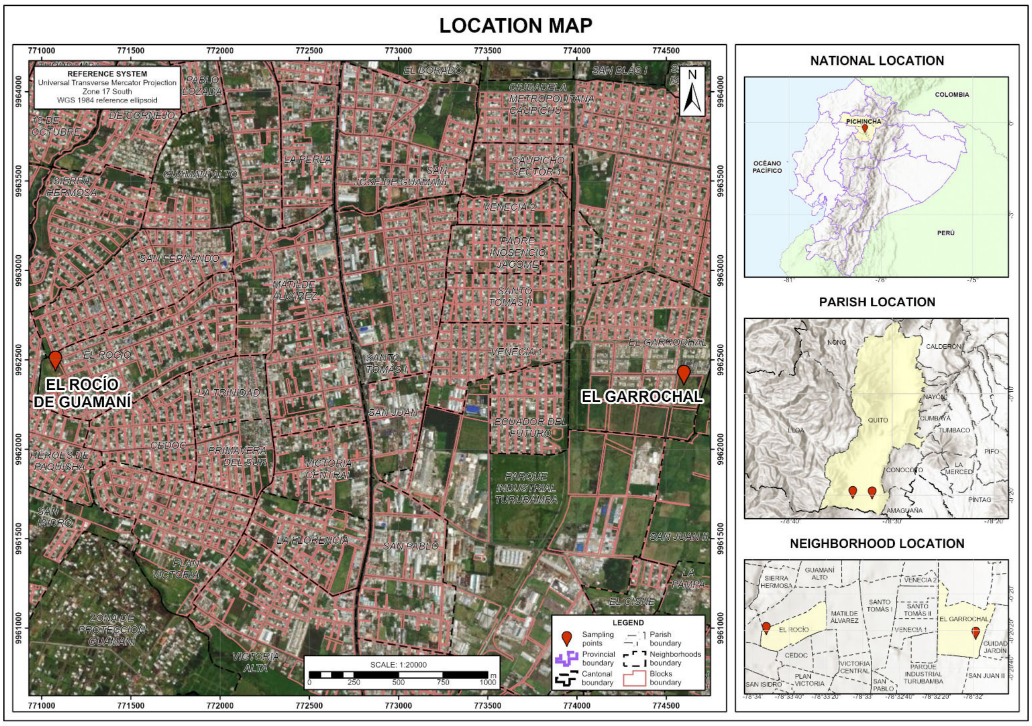


Figure 1. Locations of El Rocío de Guamaní and El Garrochal.

Quito has rugged topography with an elongated shape and geoforms from volcanic activity. Studies in the Machangara River Basin [14] have identified three geomorphological systems: volcanic relief of the Western Cordillera, inter-Andean basin, and relief of anthropic origin. The Garrochal sector is characterized by the presence of fluvial-lacustrine material, which suggests the presence of a prehistoric lagoon that drained into the Machangara River basin over time, leaving a shallow water table typical of swampy soil [15].

2.2. Sample Extraction

Sampling was conducted by extracting 16 specimens from El Garrochal and Guamaní regions. In the Guamaní sector, eight trenches were excavated at 1.00 m each, whereas in the El Garrochal sector, eight additional trenches were excavated at 1.30 m each. The methodology used was based on the standard ASTM D 7015M-18, Standard Practices for Obtaining Intact Block (Cubical and Cylindrical) Samples of Soils [16].

The sampling process was carried out by excavating L-shaped trenches that extended to a depth of 1.30 m, thereby illustrating variations in the lithology of the soil, as shown in Figure 2a. After extraction, three layers of cheesecloth and wax were applied to the exposed faces of each sample (Figure 2b,c). Finally, a wooden box filled with sawdust was used to prevent disturbance during transportation.

(**a**) (**b**) (**c**) (**d**)

Figure 2. (**a**) Excavation of El Garrochal location; (**b**) placement of cheesecloth on samples; (**c**) placement of wax layer with cheesecloth to form three layers; and (**d**) samples placed in a wooden box for transport.

Sampling in the El Rocío neighborhood began with the removal of the surface layer of soil containing organic material, as shown in Figure 3a, and was then excavated to a depth of 1.00 m to remove excess material around the block to facilitate its extraction and make a careful cut at the base (Figure 3b). Once the sample was extracted, it was covered with three layers of cheesecloth and wax. Finally, it was transported in a wooden box to which sawdust was added to eliminate voids between the box and sample.

(**a**) (**b**) (**c**) (**d**)

Figure 3. (**a**) Location of sampling point El Rocío-Guamaní; (**b**) sample extraction as intact blocks; (**c**) placement of a wax layer with cheesecloth to form three layers; and (**d**) sample placed in a wooden box for transport.

In accordance with the prescribed sample transport protocol, specimens were transferred and stored under conditions designed to preserve their integrity. A visual inspection conducted prior to testing confirmed the absence of fissures or fractures that might compromise the experimental results.

2.3. Storage

Two approaches were adopted to ensure that sample storage met the objectives of the study. Initially, a standard sample was prepared and stored in a temperature- and humidity-controlled room, in compliance with the ASTM C 511-21 standard, which outlines the "Standard Test Method for Moisture-Resistance of Dry-Use Building Materials by the Water Absorption Method" [17]. This allowed the initial reference value to be obtained for other samples.

The remaining samples were stored in the laboratory without controlling environmental conditions, resulting in exposure to variations in temperature and humidity.

The standard samples were kept in a room with controlled humidity and temperature, as shown in Figure 4b. The remaining samples were stored in the laboratory in the transportation boxes in which they arrived (Figure 4a).

(**a**) (**b**)

Figure 4. (**a**) Samples in the laboratory were exposed to temperature and humidity variations; (**b**) samples were stored in a temperature- and humidity-controlled room.

2.4. Laboratory Tests

Laboratory tests were performed to characterize the physical and mechanical samples, and the details of the tests are listed in Table 1.

Table 1. Summary of silt and organic soil laboratory test.

Laboratory Test	Parameter	Number of Tests
Atterberg Limits	LL, LP, IP (%)	2
Particle-Size Distribution	%Fine	2
USCS Classification	Soil Classification	2
Ash and organic content	Ash Content, Organic material	8
Specific Gravity	Gs	16
Moisture Content	W (%)	42
Unconfined Compressive Strength	Qu, E	42

2.5. Sample Preparation

The examinations were conducted at the Laboratory of Strength of Materials, Soil Mechanics, Pavements, and Geotechnics affiliated with the Pontificia Universidad Católica del Ecuador. The specimens were subjected to testing at various intervals following extraction, with specific timeframes designated for each day: 1, 3, 7, 14, 21, 28, and 56. A separate test specimen was designated on each testing day.

At the outset of our laboratory experiments, manual visual identification was conducted in accordance with ASTM D2488-17e1, Standard Practice for Description and Identification of Soils (Visual-Manual Procedures) [18]. The El Rocío-Guamani sample exhibited a light brown color, devoid of any discernible odor or moisture, and displayed a smooth texture and a consistent structure. Conversely, the sample from El Garrochal shows a dark color containing organic matter in the form of roots, accompanied by a noticeable odor of decomposition, clear indication of moisture, soft texture, and homogeneous structure.

3. Results

Owing to the lack of substantial differences between the findings obtained from the standard sample, which was stored in a temperature- and humidity-controlled environment, and the results obtained from the day 1 sample, it was determined that it would not be necessary to compare them with the standard sample. Consequently, we analyzed only the results of all tests conducted on samples that were not subjected to controlled conditions.

3.1. Atterberg Limits

The results of Atterberg limit tests of soil from El Rocío showed that the liquid limit, plastic limit, and plasticity index were 38%, 34%, and 4%, respectively. These values indicate that the sample was low-plasticity silt (ML) in the plasticity chart.

Tests on sample from El Garrochal revealed a liquid limit of 222%, plastic limit of 114%, and plasticity index of 108, when placed within the plasticity chart. The relationship between the oven-dried liquid limit and the air-dried liquid limit is a ratio of 0.36. Therefore, these values indicate that the material corresponds to a high-plasticity organic soil (OH).

3.2. SUCS Classification

Sieve test was carried out according to the following standards: ASTM D6913-17 Standard Test Methods for Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis [19]. Analysis of the grain size curves of the samples revealed a predominance of fine material, with 95% passing through the No. 4 sieve in both cases. This indicated that the soils had a granular distribution with many small particles [20]. This observation led to the use of sieve tests based on the hydrometric method, as shown in Figure 5.

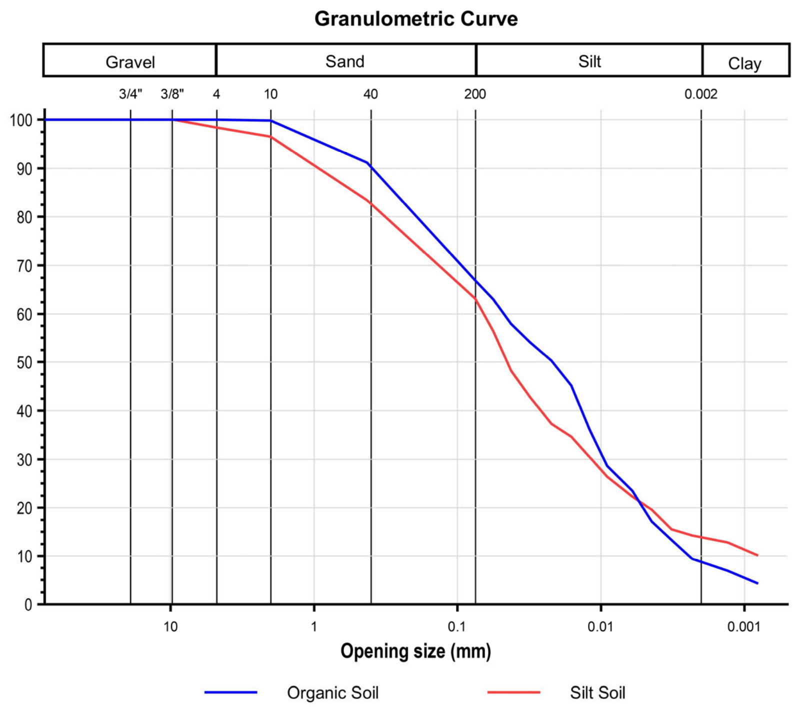


Figure 5. Granulometric curve (hydrometer), silt and organic soil.

The results obtained using the hydrometer and sieving granulometry are presented in Table 2.

Table 2. Summary of granulometry laboratory test.

Type of Soil	Sieving Pass Granulometry	Granulometry by Hydrometer
Silt	Sieve N° 10: 100% Sieve N° 40: 89% Sieve N° 200: 64%	Particles smaller than 0.075 mm: 63.1% Particles smaller than 0.005 mm: 20.6% Particles smaller than 0.002 mm: 13.6%
Organic Soil	Sieve N° 10: 100% Sieve N° 40: 91% Sieve N° 200: 67%	Particles smaller than 0.075 mm: 65.7% Particles smaller than 0.005 mm: 16.5% Particles smaller than 0.002 mm: 8.0%

3.3. Organic and Ash Content

To determine the content of organic matter and ash in the sample, the procedure described in the regulations was applied (ASTM D 2974-2, Standard Test Method for Loss on Ignition of Weight-Loss-on-Ignition Test of Soil) [21]. This method involves incinerating soil samples to determine the organic matter present. After incineration, ash content was calculated as the difference between the initial mass and weight of the sample.

The results indicate that the percentage of ash in the sample ranged from 70% to 85%, as shown in Figure 6.

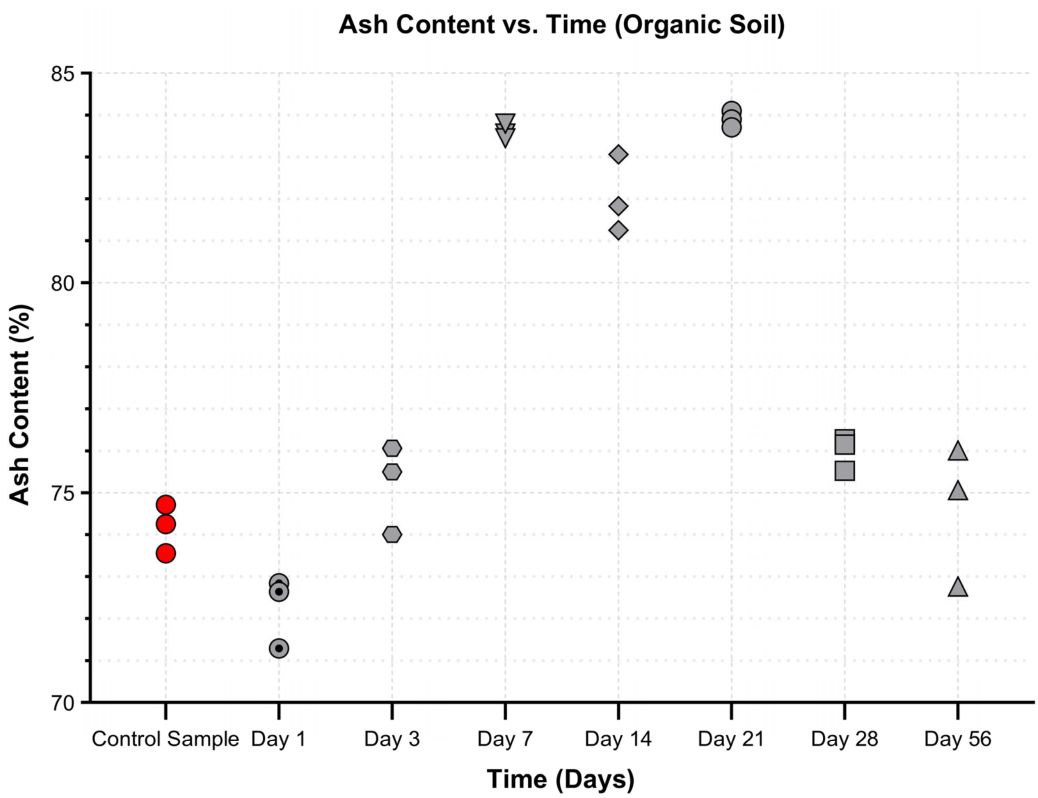


Figure 6. Ash Content.

According to Sutejo et al. [22] (Table 3), and ASTM D653-22, Standard Terminology Relating to Soil, Rock, and Contained Fluids [23], the standard suggests that to distinguish between an organic soil and a peat, the organic content must be less than 25% of its dry weight. Consequently, the results obtained can be used to establish an organic soil with a high ash content.

Table 3. Specific gravity summary.

Time (Days)	Organic Soil Specific Gravity	Silt Specific Gravity
	2.18	2.66
1	2.18	2.66
3	2.18	2.64
7	2.20	2.66
14	2.20	2.65
21	2.22	2.65
28	2.25	2.67
56	2.40	2.68

3.4. Specific Gravity

Specific gravity was determined according to ASTM D854-23, Standard Test Methods for Specific Gravity of Soil Solids by the Water Displacement Method [24] by method A, Procedure for Moist Specimens used for organic soils and fine soils, which consists of introducing a representative amount of sample without altering its moisture state in a pycnometer with distilled water and removing the air trapped in the mixture. The results are summarized in Table 3.

According to Siddiqua et al. [25], their research indicated that biological decomposition can result in an increase in specific gravity. Microbial degradation of organic matter leads to alterations in density and specific gravity over time. Furthermore, Valencia et al. [26] mentioned that a progressive loss of water can contribute to an increase in specific gravity.

Below are the results of the soil characterization (Table 4).

Table 4. Characterization summary of soil.

Soil	Sieving Pass N° 200	LL	LP	IP	Organic Content	USCS Classification
Silt	64%	38%	34%	4%	-	ML
Organic	67%	222%	114%	108%	22.27%	OH

3.5. Moisture Content

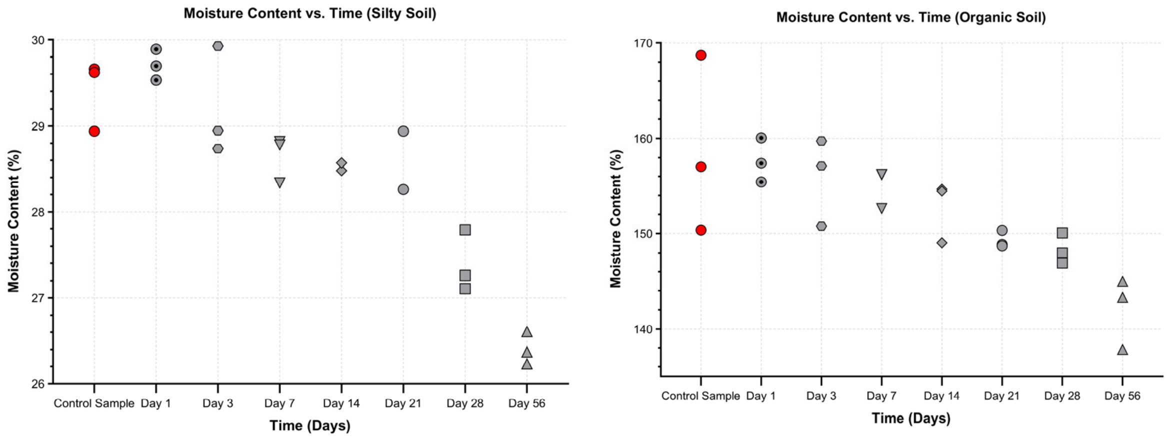
This is defined as the ratio of the mass of water in the soil pores to the mass of dry soil solid. The standard ASTM D 2216-19, Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass [27], details the methodology to be followed to obtain the MC and for the research; it was done by method A, known as oven drying, which is based on the measurement of mass loss after being dried at a temperature of 110 °C ± 5 °C until a constant weight is reached.

The MC of the silty samples gradually decreased between days 1 and 21 by approximately 1%, and after day 21, it decreased by 2% until day 56. The moisture loss recorded during the study period was ~3%. The results for the silt samples are shown in Figure 7a.

The organic soil sample exhibited a decline of approximately 2% in MC from day 1 to day 28, and then again from day 28 to day 56, resulting in a total reduction of approximately 16% during the study period, as shown in Figure 7b. In contrast, no significant changes were observed in the silty soil samples during the same period.

3.6. Unconfined Compressive Strength

A test is performed to determine the ultimate UCS of the soil by applying an axial load with deformation control, using cylinder-shaped samples with a height/diameter ratio equal to 2; the applied standard is ASTM D 2166-16, Standard Test Method for Unconfined Compressive Strength of Soil [28].

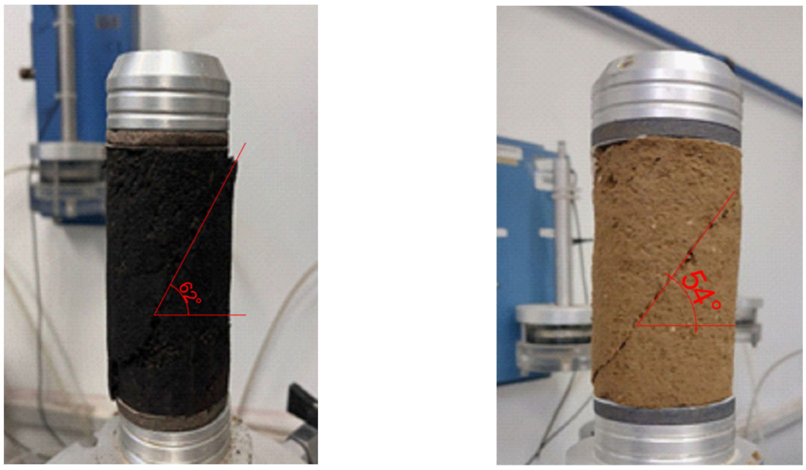


(**a**) (**b**)

Figure 7. Moisture content. (**a**) Silt; (**b**) organic Soil.

It started with the perimetral cutting of each sample according to the dimensions given by the standards. It is a factor to consider in MC. The specimen was placed in the equipment without lateral confinement to apply an axial load and to determine the ultimate load before specimen failure.

After testing the specimens, the inclination of the failure plane was measured at 62° for the organic soil sample, as shown in Figure 8a, and 54° for the silt sample, as shown in Figure 8b. Both samples exhibited brittle behavior.



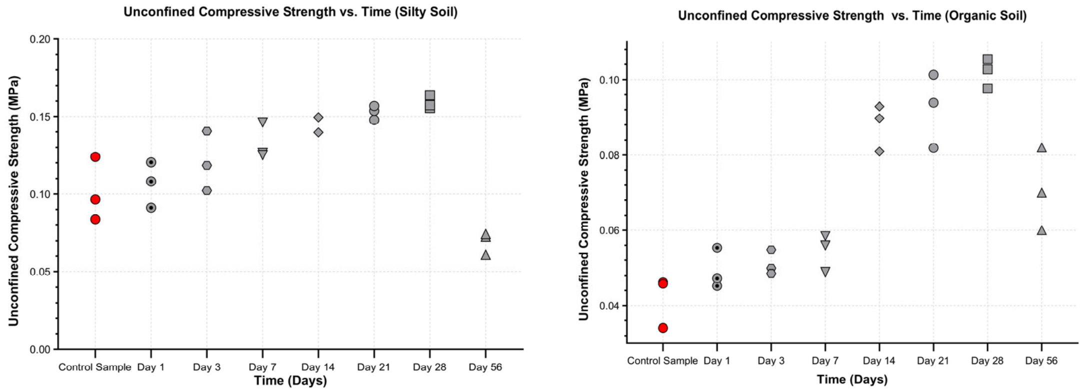
(**a**) (**b**)

Figure 8. (**a**) Sample of organic soil tested; (**b**) sample of silt soil tested.

The UCS data are plotted in Figure 9, which depicts the maximum UCS of each specimen, as determined by the test day of the silt sample. On the opening day of the test, the measure obtained was 0.11 MPa, and the maximum resistance recorded at 28 days was 0.17 MPa; this demonstrated an increase of 0.06 MPa (61.0%) from the initial value. However, there was a decrease of 0.10 MPa from the 28-day mark, with the resistance reaching 0.07 MPa on day 56, which was 65.0% less than the initial value on the first day, illustrated in Figure 9a.

The maximum stresses in the organic soil specimens are shown in Figure 9. The initial UCS of 0.05 MPa and maximum strength of 0.10 MPa at 28 days demonstrated an increase of 0.05 MPa (106.8%).

However, starting on day 28, a decrease of 0.03 MPa was observed, ultimately reaching 0.07 MPa on day 56, which is still greater than the initial UCS on day 0.



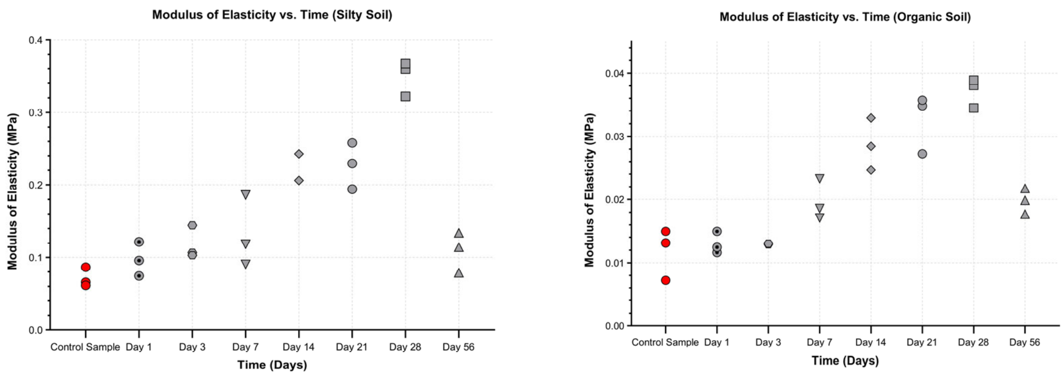
(**a**) (**b**)

Figure 9. Unconfined compressive strength. (**a**) Silt; (**b**) organic Soil.

3.7. Modulus of Elasticity

The ME was obtained from the elastic portion of the stress-strain curve (secant). It is characterized by a linear relationship, meaning that the soil deforms proportionally to the applied load. For the silt sample, an ME of 0.10 MPa was obtained on the first day, which increased to 0.35 MPa at 28 days, the maximum value reached in the research period.

After 28 days, there was a decrease of 0.24 MPa, resulting in an ME of 0.11 MPa at the 56th day, as shown in Figure 10a. The initial ME value of the organic soil sample was measured to be 0.01 MPa on the first day, which subsequently rose to 0.04 MPa on day 28, before declining to 0.02 MPa after 56 days, as depicted in Figure 10b.



(**a**) (**b**)

Figure 10. Modulus of elasticity. (**a**) Silt; (**b**) organic Soil.

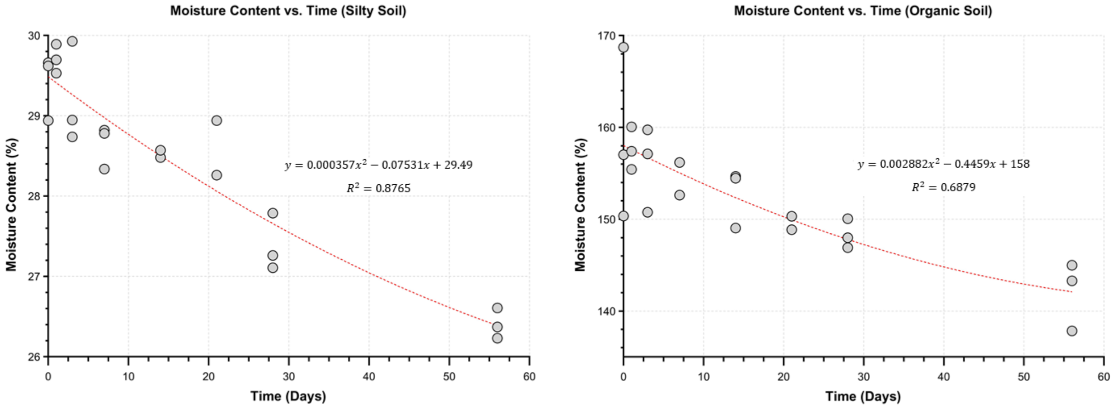
The correlation between the UCS and ME is significant; as the stiffness of the soil increases, its ability to withstand stress and return to its original form when subjected to a straight-line force also increases.

4. Discussion

According to the experimental data, four mathematical formulations can be used to determine the values of MC, saturation, UCS, and ME; the statistical software GraphPad Prism 10 was used to determine the trend curves.

4.1. Moisture Content

Figure 11a depicts the MC of the silt sample, which displays a decreasing trend and a steep slope as the storage period increases. The coefficient of determination (R^2) is 0.8765. This value suggests that the relationship between the decrease in MC and storage period is well represented by the data.



(**a**) (**b**)

Figure 11. Correlation equation based on test results and elapsed time for the moisture content of (**a**) silt; (**b**) organic Soil.

In addition to Figure 11a, Equation (1) was obtained based on laboratory results according to the established storage period.

$$y = 0.000357x^2 - 0.07531x + 29.49 \quad (1)$$

where x is time (days).

Similarly, the organic soil sample showed a decreasing trend in MC as the storage period increased, with a steep slope up to day 28, and a gentler slope as the material dried up to day 56. The coefficient of determination (R^2) is equal to 0.6879, which means that only a portion of the variability observed in the data can be explained, and it cannot be assumed that all moisture loss is only due to the passage of time but can also be caused by other factors such as the dielectric permittivity existing in the ground [29].

Equation (2) was also obtained based on the laboratory results and the storage period shown in Figure 11b.

$$y = 0.002882x^2 - 0.4459x + 158 \quad (2)$$

where x is time (days).

4.2. Saturation

Moisture loss in the soil samples led to a gradual decrease in saturation, which affected their properties. This decreases the volume of water between the pores and increases the void ratio; that is, the volume of voids is greater than that of solids.

The decrease in saturation in the silt sample presented a decreasing trend, with a smooth slope from days 1 to 56 and a coefficient of determination (R^2) of 0.6421, indicating that its fit was moderate to the laboratory data, resulting in Equation (3) (Figure 12a).

Similarly, the organic soil sample showed a decreasing trend with a slight concave curvature and a coefficient of determination (R^2) of 0.6382, which could be due to the presence of organic matter and not only the storage period of the samples, but also due to the degree of decomposition, the chemical composition of the organic matter, and fiber dispersion [30]. Equation (4) was also obtained from Figure 12b.

$$y = \frac{58.44}{\frac{216.9}{x}^{-1.279} + 1} + 34.82 \quad (4)$$

where x is time (days).

It should be noted that the decrease in saturation was directly related to moisture loss. However, there are other factors to consider in moisture loss, such as variations in temperature and humidity experienced in the laboratory during the development of this research.

$$y = 0.001946x^2 - 0.2716x + 77.96 \quad (3)$$

where x is time (days).

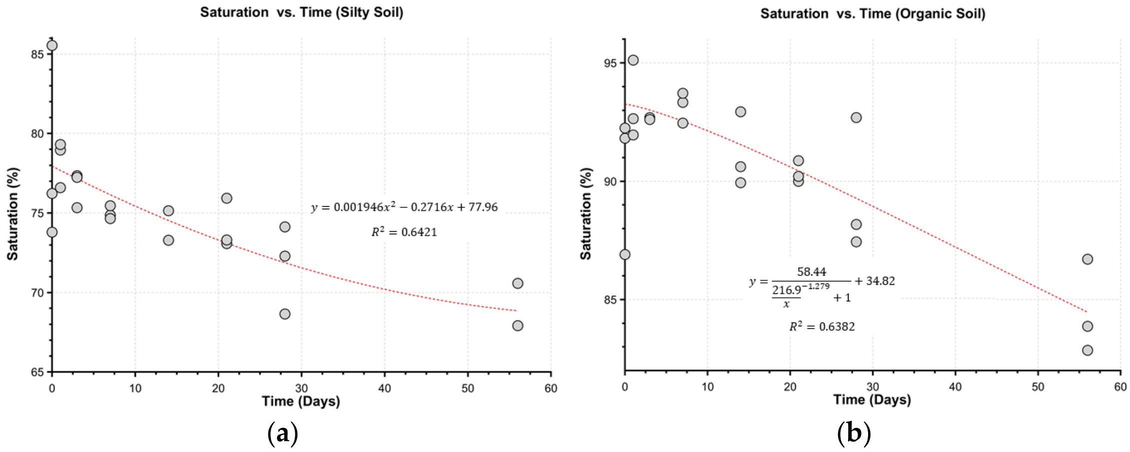


Figure 12. Correlation equation based on test results and elapsed time for the saturation of (**a**) silt; (**b**) organic soil.

4.3. Unconfined Compressive Strength

Moisture loss causes the water film around the particles to become thinner, leading to greater cohesion and increased soil strength.

From Figure 13 we obtained a coefficient of determination (R^2) of 0.8721 for the silt sample, thus providing a model that fits the laboratory data well and provides Equation (5).

$$y = -0.00008872x^2 + 0.004353x + 0.1039 \quad (5)$$

where x is time (days).

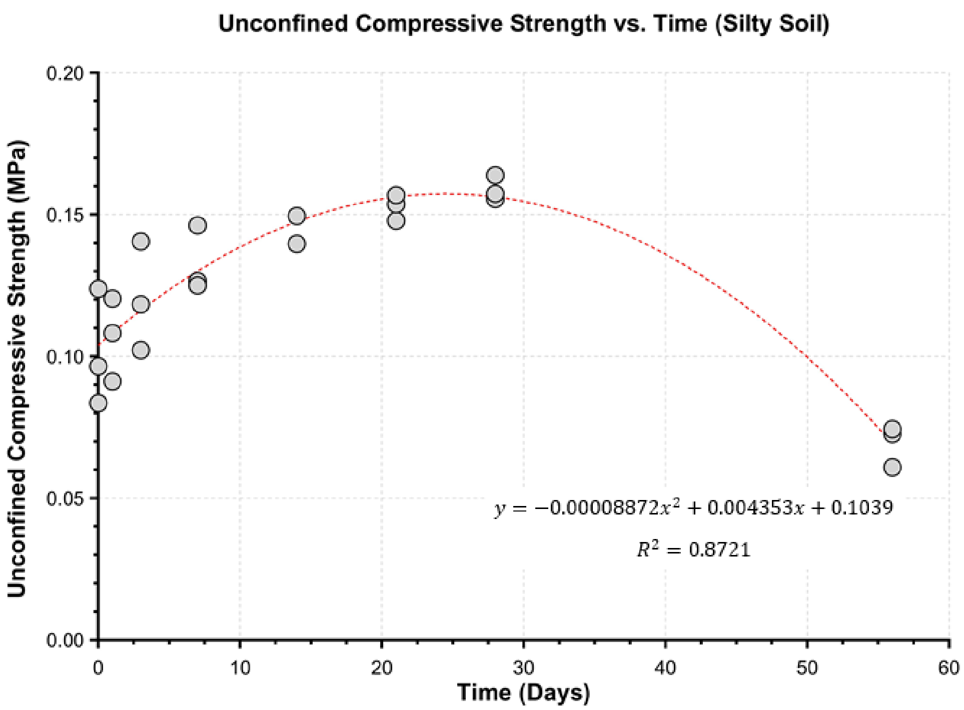


Figure 13. Correlation equation based on test results and elapsed time for unconfined compressive strength-silt.

As mentioned above, the relationship between moisture loss due to sample storage and UCS is not linear. As the storage time increased, the MC decreased, and its resistance started to reach a maximum value and then decreased. The particles became more brittle because the sample was too dry, thus reducing the cohesion.

Similarly, for the organic soil sample (Figure 14), the data were adjusted to a mathematical model using linear regression, resulting in a concave curve with a coefficient of determination (R^2) of 0.8935, as shown in Equation (6).

$$y = -0.00005675x^2 + 0.003711x + 0.04116 \quad (6)$$

where x is time (days).

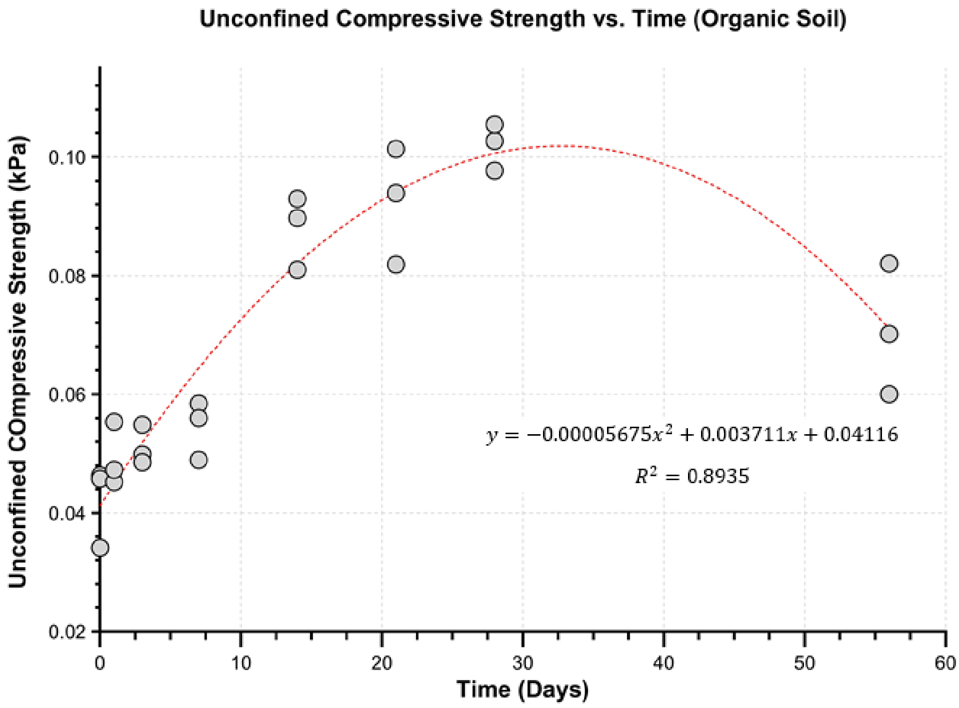


Figure 14. Correlation equation based on test results and elapsed time for unconfined compressive strength-organic soil.

Figure 14 shows that the UCS initially increased with storage period, leading to moisture loss; however, by day 28, its critical point was reached, where the resistance began to decrease again. This could also be caused by the organic matter and minerals present in the soil.

4.4. Modulus of Elasticity

The UCS test provided important information about each soil type's load-bearing capacity prior to failure, while the ME test complemented this analysis by describing the stiffness of the soil when the material was still within the elastic range.

As shown in Figure 15, the silt sample exhibits a concave curve, which indicates a nonlinear relationship between ME and storage time. The maximum stiffness was reached after 28 days.

The coefficient of determination (R^2) for this correlation is 0.8838, indicating a strong relationship between the variables and Equation (7).

$$y = 0.003831x + 0.0003984\,x^2 - 0.000008213x^3 + 0.08845 \quad (7)$$

where x is time (days).

Similarly, the organic soil sample presented a concave curve, where the critical point was at 28 d, with a maximum ME and breakage of the curve, with a coefficient of determination (R^2) of 0.9123 and Equation (8), as shown in Figure 16.

$$y = -0.00002647x^2 + 0.001654x + 0.01033 \quad (8)$$

where x is time (days).

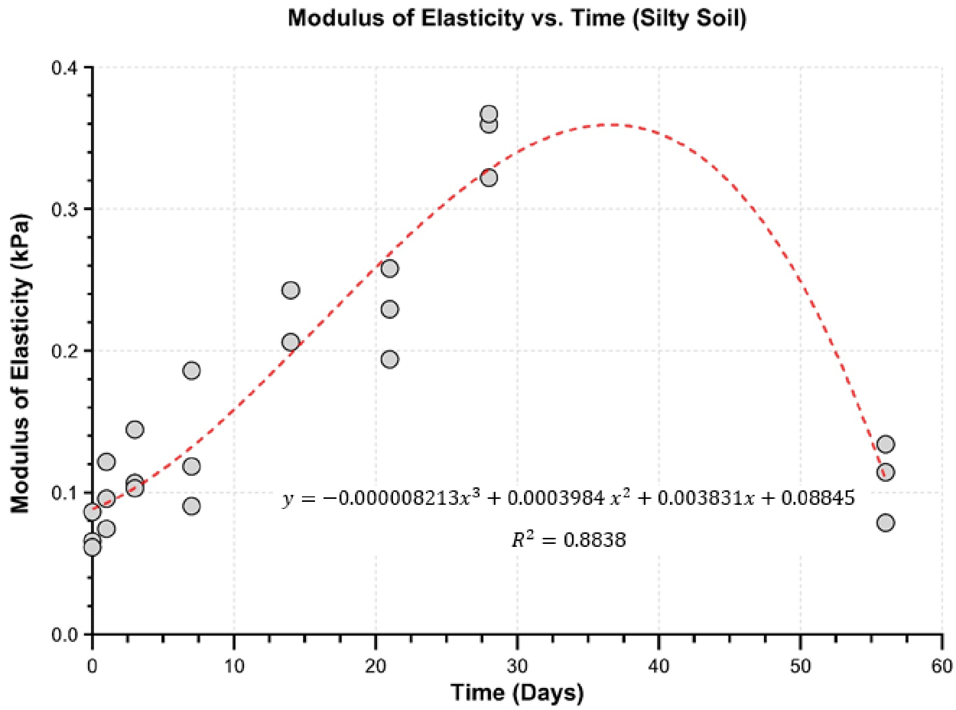


Figure 15. Correlation equation based on test results and elapsed time for the modulus of elasticity-silt.

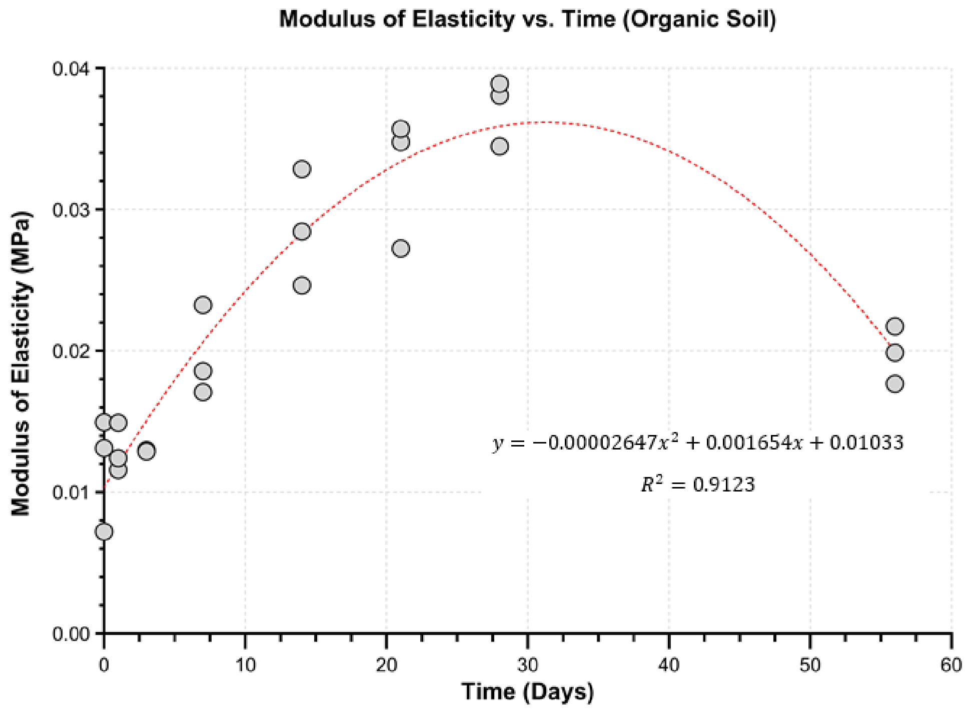
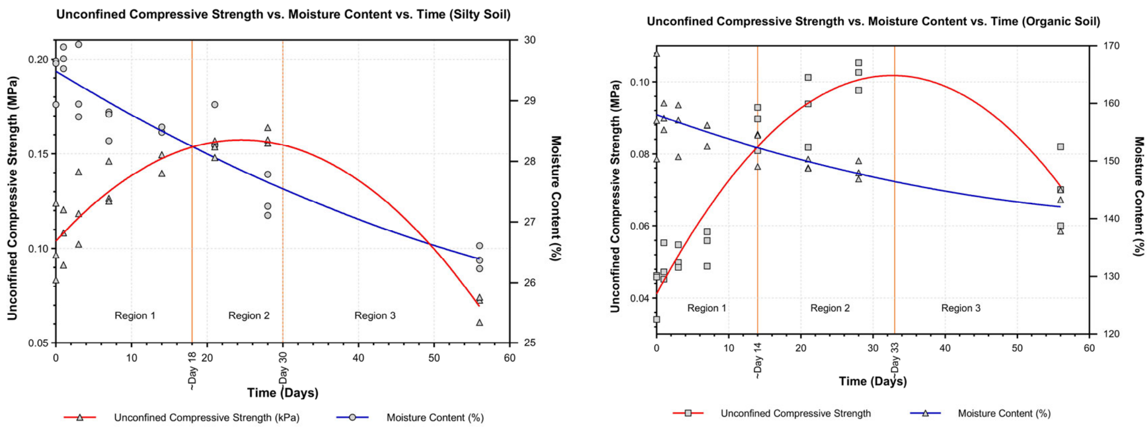


Figure 16. Correlation equation based on test results and elapsed time for the modulus of elasticity-organic soil.

Considering that the two samples presented a similar trend, the organic soil had a higher coefficient of determination than the silt sample, implying that the relationship between ME and storage time had a higher correlation between the variables.

4.5. Relationship between Moisture Content and Unconfined Compressive Strength

On the first day, the silt sample with an MC of 29.71% exhibited a strength of 0.11 MPa. When the sample had an MC of 27.39%, a strength of 0.11 MPa and a resistance of 0.17 MPa were obtained. This is the critical point at which MC remains optimal before decreasing further and losing its strength. Three zones were identified for the analysis of the storage behavior of the silty soil, as shown in Figure 17a.



(**a**) (**b**)

Figure 17. UCS vs. MC vs. time: (**a**) silt; (**b**) organic Soil.

- Region 1 (days 0–18) is characterized by an increase in the UCS with a decrease in MC. The soil resistance increases, and suction decreases. Initially, there was an increase in strength, and thus in the ME, followed by a critical point at which the strength began to approach the UCS peak point at approximately day 18.
- Region 2 (day 18–30) shows that the UCS reached its maximum value, while the MC continued to decrease. The MC was between the maximum values of the UCS, which was approximately 28.25%. It is assumed that suction intensifies the attractive forces between the particles and increases cohesion because the surrounding water film becomes thinner.
- Region 3 (>day 30): a decrease in moisture content results in a thinner and more discontinuous water film, significantly reducing capillary forces and cohesion. Consequently, both UCS and MC exhibited a decreasing trend.

The organic soil sample exhibited a strength of 0.05 MPa with an MC of 157.65% on the first day, which decreased to 148.32%. The maximum strength of 0.10 MPa was observed at 28 days. The soil demonstrated a decrease in moisture content and strength after 56 days (0.07 MPa), which can be observed in all three regions, similar to the silty soil, for the purpose of analyzing the storage behavior of the silty soil (Figure 17b).

- Region 1 (days 0–14) is characterized by an increase in the UCS with a decrease in MC. It was observed that the soil became more resistant, and the suction decreased, similar to the behavior of silty soil. In this region, there was an increase in strength, and thus in the ME, followed by a critical point where the strength began to approach the UCS peak point at approximately day 14.
- Region 2 (day 14–33) shows that the UCS reached its maximum value, while the MC continued to decrease. The MC is between the maximum values of the UCS, 152% and 165%. This region has a larger gap of days to reach the maximum value of the UCS compared to silty soil.

- Region 3 (>day 30) showed a trend of decreasing UCS and MC, considering that the initial and final values of UCS (day 0) and (day 56) were lower than those of silty soil.

One factor that could influence the obtained results is the effect of suction in the soil, which influences the determination of the strength. First, the suction was composed of matric and osmotic suction [31], where the matric suction was the negative pressure experienced by the water within the soil pores owing to the capillary forces acting between the soil particles and water molecules. On the other hand, osmotic suction refers to the difference between the solutes between the water inside the soil pores and the water around it, attracting water molecules with lower concentration to those with higher concentration, creating a negative pressure between the soil pores [32].

Farouk-Lamboj et al. [33] reported that the relationship between resistance and suction is complex and can be affected by factors such as soil type and density.

According to Albuja-Sánchez et al. [34], as the MC decreases, the suction matric increases, and in turn, the percentage of deformation increases because the sample is very dry, which reduces its resistance.

On the other hand, Abd et al. [35] concluded that the relationship between the strength of the soil and the suction matric is composed of two parts: the first is linear, in which it presents an increase in the UCS test results, and the second is nonlinear, which indicates a point of maximum stress, and the cohesion of the matric decreases owing to the rapid rise in the suction matric, which leads to a decrease in cohesion.

Additionally, in a study by Hoyos et al. [36], it was observed that matric suction plays a vital role in the properties of unsaturated soils because the increase in strength with increasing suction is practically linear for SM soil but nonlinear for SC-SM soil.

Song et al. [37] concluded that both particle distribution and mineralogy affect soil properties and that there are significant changes in water content with minor changes in the suction matric, producing hysteresis between the drying and wetting processes due to the bottleneck effect, contact angle effect, and air trapped between the pores, implying that the shear strength for a given matric suction may be different depending on whether the soil is dry or wet.

Based on the above investigations and the results obtained, it can be assumed that the suction effect is involved in the soil strength, which may vary according to the MC or saturation. This relationship is where UCS and MC are compared, confirming the absence of a linear relationship (Figure 17).

Based on the results obtained for the compressive strength of both types of soil, a significant decrease in the strength of the silty soils was evident after the 56th day of testing of the sample. In contrast, while experiencing fluctuations in strength similar to loam soils, organic soils did not exhibit such a marked loss at 56 days. It is assumed that roots in organic soil could mitigate the loss of strength, as determined in previous studies on the effect of time and model prediction of the shear strength of rooted soil under dry-wet cycles. This analysis concluded that roots improve the compressive strength over time [38]. Additionally, according to Shirkavand et al. [39], it is challenging to correlate the compressive strength by considering only the MC and organic content without considering the presence of organic fibers.

5. Conclusions

This research was conducted using soil samples obtained from Guamaní and El Garrochal in Quito, Ecuador. This study consisted of 16 specimens that were collected and preserved for testing. The tests were carried out on days 1, 3, 7, 14, 21, 28, and 56, and the moisture content (MC) and unconfined compressive strength (UCS) of the soil samples were measured. The findings revealed a correlation between MC, UCS, and modulus of elasticity (ME). As the moisture content decreased, the UCS and ME increased, reaching their maximum values between 20 and 30 days.

There is a relationship between UCS and MC for silty and organic soils over time. Initially, the soil exhibited an increase in the UCS as the MC decreased to a certain point

(Region 1). However, when the MC function intersects with the UCS function, the curves depicted in Figure 17 show that the soil reaches its maximum UCS value (Region 2). These findings suggest a correlation between the UCS and MC, indicating that moisture loss during the analyzed periods leads to an increase in matric suction. This increase, in turn, leads to an increase in the soil cohesion and friction angle, thereby establishing a maximum point of resistance. However, as matric suction increases due to the reduction in MC over time, soil cohesion and friction angle decrease, resulting in a reduction in strength, according to Zhang et al. [40]. After reaching its maximum UCS value (Region 2), the effect of decreasing MC causes the soil to become saturated, and water begins to act as a lubricant, reducing the UCS significantly (Region 3).

A notable correlation was discovered between the increase in UCS and ME values and the fluctuation in moisture content for the timeframes evaluated (1, 3, 7, 14, 21, 28, and 56 days). Silt exhibited minimal changes in moisture content, with a variation of only 3% moisture from day 1 to day 56. However, this limited variation was deemed significant when taken in conjunction with the geological morphology of the soil, resulting in an 11% decrease in saturation compared with the samples examined on the initial day.

Organic soil exhibits a greater variation in moisture content than decomposing organic material and inorganic soil, which can result in significant losses. For instance, during the analyzed period, the organic soil experienced losses of up to 16%. This was evidenced by the decrease in saturation values, with the samples evaluated on the first day showing losses of up to 8%.

According to the results, there was no significant difference in the UCS and ME values for both types of soil during the first ten days. This indicates consistent performance in the tests conducted during that period. However, in the case of organic soil, there was considerable variation in moisture levels, which was attributed to the geological characteristics of the soil. It is recommended that organic soil and silt samples be stored under appropriate conditions to avoid moisture loss. Without a dedicated storage facility, it is essential to consider how soil characteristics vary over time.

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References

1. Larouci, A.; Senhadji, Y.; Laoufi, L.; Benazzouk, A. Dredged dam raw sediments geotechnical characterization for beneficial use in road construction. *Int. J. Eng. Res. Afr.* **2021**, *57*, 81–98. [CrossRef]
2. Yamazoe, N.; Tanaka, H.; Ogino, T.; Nishimura, S. Mechanism of sampling disturbance for peat ground and its influence on mechanical properties. *Soils Found.* **2023**, *63*, 101361. [CrossRef]
3. Mayanquer, J.; Anaguano-Marcillo, M.; Játiva, N.; Albuja-Sánchez, J. New Correlations for the Determination of Undrained Shear, Elastic Modulus, and Bulk Density Based on Dilatometer Tests (DMT) for Organic Soils in the South of Quito, Ecuador. *Appl. Sci.* **2023**, *13*, 8570. [CrossRef]
4. Konkol, J.; Międlarz, K.; Bałachowski, L. Geotechnical characterization of soft soil deposits in Northern Poland. *Eng. Geol.* **2019**, *259*, 105187. [CrossRef]

5. Wang, D.; Li, Z. Shear behaviour of peat at different stress levels. *Proc. Inst. Civ. Eng. Geotech. Eng.* **2023**, *176*, 1–14. [CrossRef]
6. Kiyukeno, Y.; Mukoko, G.; Francois, B. Laboratory Geotechnical Investigations on Five Silty Soils Sampled Along the Banks of the Lubumbashi River/Haut-Katanga/DR Congo. *Int. J. Eng. Res. Afr.* **2023**, *65*, 73–89. [CrossRef]
7. Swart, D.; Dippenaar, M.A.; Van Rooy, J.L. Field tests for the identification of silts. *Bull. Eng. Geol. Environ.* **2023**, *82*, 425. [CrossRef]
8. Echeverri, O. Geotechnical characterization of the silt from the terrace of the municipality of Olaya in Antioquia, Colombia. *Boletín Cienc. Tierra* **2016**, *39*, 49–56. [CrossRef]
9. Lim, G.T.; Pineda, J.; Boukpeti, N.; Carraro, J.H.A. Effects of Sampling Disturbance in Geotechnical Design. *Can. Geotech. J.* **2018**, *56*, 275–289. Available online: www.nrcresearchpress.com (accessed on 7 December 2023). [CrossRef]
10. Lim, G.T.; Pineda, J.A.; Boukpeti, N.; Fourie, A.; Carraro, J.A.H. Experimental assessment of sampling disturbance in calcareous silt. *Geotech. Lett.* **2018**, *8*, 240–247. [CrossRef]
11. Coutinho, R.Q.; Mayne, P.W. Geotechnical and geophysical site characterization 4. In Proceedings of the Fourth International Conference on Site Characterization, ISC-4, Porto de Galinhas, Brasil, 17–21 September 2012; CRC Press: Boca Raton, FL, USA, 2013.
12. Nujid, M.M.; Tholibon, D.A.; Mukhlisin, M. Geotechnical and structural assessment on estimated bearing capacity of strip footing resting on silty sand incorporating moisture content effect. *Case Stud. Constr. Mater.* **2024**, *20*, e03106. [CrossRef]
13. Sarkar, G.; Sadrekarimi, A. Compressibility and monotonic shearing behaviour of Toronto peat. *Eng. Geol.* **2020**, *278*, 105822. [CrossRef]
14. Valverde, J.; Fernandez, J.; Jimenez, E.; Vaca, T.; Alarcon, F. Micro Zonificación Sismica de Suelos del Distrito Metropolitano de Quito. Available online: www.flacsoandes.edu.ec (accessed on 3 December 2023).
15. Albuja, J. Resistencia No Drenada al Corte de Suelos Organicos. *Quito* **2018**, *106*, 3–39. [CrossRef]
16. *ASTM D7015/D7015M-18*; Standard Practices for Obtaining Intact Block (Cubical and Cylindrical) Samples of Soils. ASTM International: West Conshohocken, PA, USA, 2018; Volume 04.09, pp. 1–8. [CrossRef]
17. *ASTM C 511-21*; Standard Specification for Mixing Rooms, Moist Cabinets, Moist Rooms, and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concretes 1. ASTM International: West Conshohocken, PA, USA, 2021; Volume 04.01–04.02, pp. 1–3. [CrossRef]
18. *ASTM D2488-17e1*; Standard Practice for Description and Identification of Soils (Visual-Manual Procedures) 1. ASTM International: West Conshohocken, PA, USA, 2017; Volume 04.08, pp. 1–13. [CrossRef]
19. *ASTM D6913/D6913M-17*; Standard Test Methods for Particle-Size Distribution (Gradation) of Soils Analysis. ASTM International: West Conshohocken, PA, USA, 2017; Volume 04.09, pp. 1–34. [CrossRef]
20. *ASTM D2487-17e1*; Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System). ASTM International: West Conshohocken, PA, USA, 2017; Volume 04.08, pp. 1–10. [CrossRef]
21. *ASTM D2974-20e1*; Standard Test Methods for Determining the Water (Moisture) Content, Ash Content, and Organic Material of Peat and Other Organic Soils. ASTM International: West Conshohocken, PA, USA, 2020; Volume 04.08, pp. 1–5.
22. Sutejo, Y.; Saggaff, A.; Rahayu, W.; Hanafiah. Physical and chemical characteristics of fibrous peat. *AIP Conf. Proc.* **2017**, *1903*, 090006. [CrossRef]
23. *AST D653-22*; Standart Terminology Relating to Soil, Rock, and Contained Fluids. ASTM International: West Conshohocken, PA, USA, 2022; Volume 04.08, pp. 1–50. [CrossRef]
24. *ASTM D854-23*; Standard Test Methods for Specific Gravity of Soil Solids by the Water Displacement Method 1. ASTM International: West Conshohocken, PA, USA, 2023; Volume 04.08, pp. 1–9. [CrossRef]
25. Siddiqua, S.; ElMouchi, A.; Wijewickreme, D. Characterization of an organic soil deposit using multi-faceted geotechnical field and laboratory investigations. *Eng. Geol.* **2024**, *328*, 107365. [CrossRef]
26. González, Y.V.; Restrepo, J.P.; Guerra, M.C.Á.; Ramírez, D.O.; Ramírez, Ó.E. Cambio en las propiedades geotécnicas de un suelo sometido a ignición en laboratorio. *Rev. Ing. Univ. Medellín* **2018**, *17*, 85–107. [CrossRef]
27. *ASTM D2216-19*; Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass 1. ASTM International: West Conshohocken, PA, USA, 2019; Volume 04.08, pp. 1–7. [CrossRef]
28. *ASTM D2166-16*; Standard Test Method for Unconfined Compressive Strength of Cohesive Soil 1. ASTM International: West Conshohocken, PA, USA, 2016; Volume 04.08, pp. 1–7. [CrossRef]
29. Szypłowska, A.; Lewandowski, A.; Yagihara, S.; Saito, H.; Furuhata, K.; Szerement, J.; Kafarski, M.; Wilczek, A.; Majcher, J.; Woszczyk, A.; et al. Dielectric models for moisture determination of soils with variable organic matter content. *Geoderma* **2021**, *401*, 115288. [CrossRef]
30. ElMouchi, A.; Siddiqua, S.; Wijewickreme, D.; Polinder, H. *A Review to Develop New Correlations for Geotechnical Properties of Organic Soils*; Springer Science and Business Media Deutschland GmbH: Berlin/Heidelberg, Germany, 2021. [CrossRef]
31. Dranichnikova, T. Nuevas Tendencias en la Mecánica de Suelos. 2008. Available online: http://www.redalyc.org/articulo.oa?id=505554806004 (accessed on 10 June 2024).
32. Tristá, J.G.; Cristía, W.D.C.; Sotolongo, G.J.Q.; Berenguer, I.F.; Rodríguez, C.M.R. Analysis of tenso-deformacional behavior of unsaturated soil for circular foundation with axial load. *Ing. Desarro.* **2021**, *38*, 181–196. [CrossRef]

33. Farouk, A.; Lamboj, L.; Kos, J. Influence of Matric Suction on the ShearStrength Behaviour of Unsaturated Sand. *Acta Polytech.* **2004**, *44*, 11–17. Available online: https://www.researchgate.net/publication/348432511_Influence_of_Matric_Suction_on_the_Shear_Strength_Behaviour_of_Unsaturated_Sand (accessed on 24 June 2024). [CrossRef]
34. Albuja-Sánchez, J.; Duque, J.; Martin, L.; Morales, J.; Anaguano-Marcillo, M. Determination of the matrix suction of low-plasticity silts and its correlation with their collapse potential. *Proc. Int. Struct. Eng. Constr.* **2024**, *11*, GFE-02-1–GFE-02-6. [CrossRef]
35. Abd, I.A.; Fattah, M.Y.; Mekkiyah, H. Relationship between the matric suction and the shear strength in unsaturated soil. *Case Stud. Constr. Mater.* **2020**, *13*, e00441. [CrossRef]
36. Hoyos, L.R.; Velosa, C.L.; Puppala, A.J. Residual shear strength of unsaturated soils via suction-controlled ring shear testing. *Eng. Geol.* **2014**, *172*, 1–11. [CrossRef]
37. Song, Y.S.; Hong, S. Effect of clay minerals on the suction stress of unsaturated soils. *Eng. Geol.* **2020**, *269*, 105571. [CrossRef]
38. Mao, Z.; Ma, X.; Liu, Y.; Geng, M.; Tian, Y.; Sun, J.; Yang, Z. Study on time effect and prediction model of shear strength of root-soil complex under dry-wet cycle. *Biogeotechnics* **2024**, *2*, 100079. [CrossRef]
39. Shirkavand, D.; Fakharian, K. A comparison of shear modulus of unsaturated sand in triaxial and simple shear tests under different strains and suctions. *Eng. Geol.* **2023**, *315*, 106972. [CrossRef]
40. Kolay, P.K.; Noor, S.; Taib, L. Physical, Geotechnical and Morphological Characteristics of Peat Soils from Sarawak. *IEM J.* **2011**, *72*, 12–16. Available online: https://www.researchgate.net/publication/281110757 (accessed on 24 June 2024).