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Soil Stabilization using Coffee Husk Ash and Lime

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Abstract: Paddy soils pose significant construction challenges due to their unique physical properties. High water content, low bearing capacity, and high compressibility make them prone to settlement and deformation issues. Additionally, paddy soils have low shear strength, high plasticity index, and low permeability, increasing the risk of landslides, foundation instability, and waterlogging. Hence, there exists a need of improving the engineering properties of soil before using for construction by soil stabilization techniques. Here we are going to use coffee husk ash and lime as stabilizer in various proportion. The main objective of this study is to investigate the effect of coffee husk ash and lime on the engineering properties of paddy soil such as strength, Atterberg's indices and CBR values. Coffee Husk Ash was added in two proportions, 10% and 20% with three proportions of lime, 4%, 5%, 6%.
Keywords: Soil Stabilization, Coffee Husk Ash, Lime, Atterberg Limits, UCC, CBR, MDD, OMC

I. INTRODUCTION

Problematic soils, influenced by climate, geology, and human activities, pose challenges for construction, agriculture, and sustainability. These include expansive, collapsible, soft, high-plasticity, saline, acid sulphate, peat, and paddy soils, which have low strength, high settlement, and erosion risks. Stabilization methods like chemical additives, compaction, overloading, and soil replacement improve soil properties. Recently, waste materials such as rice husk ash, fly ash, and lime kiln dust have been used as cost-effective stabilizers. Paddy soils, rich in silts and clays, have poor strength, low bearing capacity, and high instability, leading to structural issues. Stabilization blends materials to enhance soil strength, drainage, and durability. This study focuses on stabilizing paddy soil, which poses challenges due to its weak strength and high moisture sensitivity, making it unsuitable for construction. This study explores an innovative and sustainable approach to soil stabilization using Coffee Husk Ash (CHA) and lime. Coffee husk, an agricultural byproduct, has pozzolanic properties that can improve soil strength when combined with lime. The research investigates the geotechnical behaviour of CHA-lime-stabilized paddy soil through laboratory tests, including Atterberg limits, compaction, unconfined compressive strength, and California Bearing Ratio (CBR).

The findings of this study contribute to the development of eco-friendly soil stabilization methods, offering a cost-effective alternative to conventional stabilizers while addressing environmental concerns associated with agricultural waste disposal.

II. SPECIFIC OBJECTIVES

1) To analyse the impact of CHA-lime stabilization on the strength characteristics of soil.
2) To determine the influence of CHA-lime mixture on the index properties of soil, such as plasticity and liquid limits.
3) To establish the optimal proportion of Coffee Husk Ash and lime for effective soil stabilization.
4) To evaluate the effect CHA- lime mixture on Maximum Dry Density and Optimum Moisture Content.
5) To evaluate the effect of CHA-lime mixture on CBR value of soil.
6) To assess the environmental and economic benefits of using CHA as a sustainable soil stabilizer.

III. MATERIALS AND METHODS

Materials used for this study are paddy soil, coffee husk, and lime. Laboratory tests such as specific gravity test, hydrometer analysis, Atterberg's limit test, UCC strength test, heavy compaction test, and CBR test were conducted to determine the basic properties of collected soil sample.

A. Paddy Soil

Paddy soils are characterized by significant volume changes in response to moisture fluctuations, exhibiting high plasticity, water absorption capacity, and clay content. These soils swell when exposed to water and shrink upon drying, leading to cracks, low strength, and stability issues.

Typical problems associated with expansive soils include foundation damage, structural instability, pavement cracking, and soil settlement. Identification involves high liquid limits, plasticity indices, and shrinkage limits, as well as the presence of expansive minerals like montmorillonite and smectite. The soil used for this study is obtained from nearby locality.

B. Coffee Husk Ash

Coffee husks are industrial waste material from the coffee industry. The coffee husk used for this study is obtained from Paloor Kotta in Kadungapuram village of Malappuram district Kerala. The coffee husk ash (Fig 3.4) is obtained by burning the coffee husk in an uncontrolled condition.

C. Lime

Quicklime and hydrated lime are both used to stabilize soil, and both contain calcium, which is essential for soil modification and stabilization. Quicklime (CaO) is often preferred because it’s more effective and can develop greater strength in soil mixtures. Hydrated lime (Ca (OH)2) reacts with clay particles, making soil more friable and granular, which can improve mixing and compaction. For this study we are using Hydrated lime.

D. Mix proportion

Mix proportion adopted for this study is given in below (TABLE 1). Six set of soil samples was treated with various percentage of CHA and lime.

TABLE I

MIX PROPORTION

TRIAL 1		TRIAL 2		TRIAL 3	
CHA %	LIME %	CHA %	LIME %	CHA%	LIME %
10	4	10	5	10	6
20	4	20	5	20	6

IV. RESULTS AND DISCUSSION

A. The Basic Properties

Basic properties of the sample soil are given in TABLE 2.

TABLE 2

BASIC PROPERTIES OF SOIL

SL No.	Property	Value
1	Specific gravity	2.25
2	Liquid limit	45%
3	Plastic limit	34.44%
4	Shrinkage limit	23.16%
5	Plasticity index	10.56%
6	Optimum moisture content	20.8%
7	Maximum dry density	1.71 g/cc
8	UCC strength	3.16×10^{-3} Kg/cm^2
9	California bearing ratio	0.89%

B. Properties of Soil Treated with CHA and Lime

Atterberg’s limit test, unconfined compressive strength test, heavy compaction and California Bearing Ratio test were conducted to determine the change in properties of soil treated with various percentages of CHA and Lime.

C. Variation of Atterberg Limit Values with Varying Percentage of CHA and Lime

The liquid limit, plastic limit, shrinkage limit, and plasticity index of untreated soil and treated soil is given in Table 3. The variation in LL, PL, SL and PI of samples treated with CHA and lime are presented in Fig 1.

TABLE 3
SUMMARY OF INDEX PROPERTIES OF SOIL TREATED WITH CHA AND LIME

Atterberg limits	Liquid limit (%)	Plastic limit (%)	Shrinkage limit (%)	Plasticity index (%)
Untreated soil	45	34.44	23.16	10.56
Soil + 10% CHA + 4%LIME	45	36.68	25.54	8.32
Soil + 20% CHA + 4%LIME	47	37.89	26.74	9.11
Soil + 10% CHA + 5%LIME	42	34.72	28.03	7.28
Soil + 20% CHA + 5%LIME	40	35.5	25.21	4.5
Soil + 10% CHA + 6%LIME	39	36.96	20.59	2.04
Soil + 20% CHA + 6%LIME	40	37.83	16.62	2.17

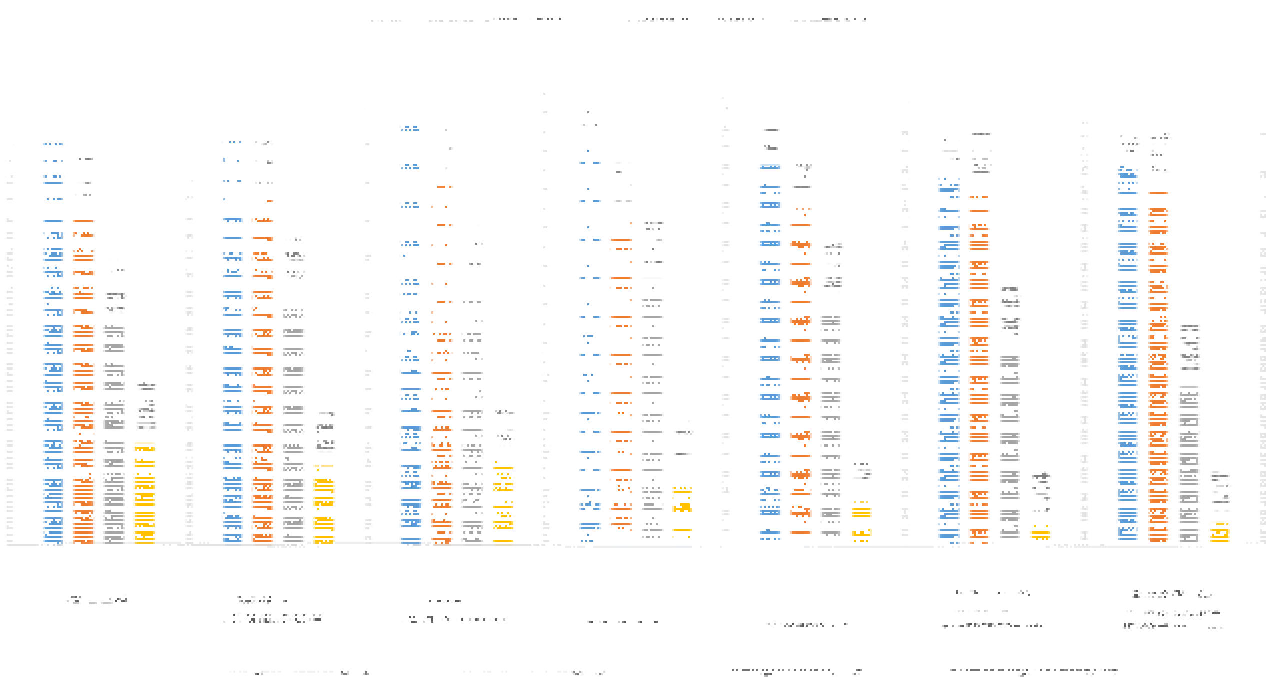

FIG. 1 variation in LL, PL, SL and PI of samples treated with CHA and lime

It can be observed that with addition of CHA-lime mixture index properties of soil changed. It can be observed that with addition of CHA & lime an increase in LL was noticed. With the increase in lime content the LL decreased. Liquid limit of untreated soil was

45% and it decreased into 39%. A lower liquid limit means the soil can hold less water before it starts to behave like a liquid. 10% CHA and 6% lime shows a better reduction in LL. The PL of the samples increased on the addition of CHA and lime. As the lime content increased plastic limit decreased.
Plastic limit of untreated soil was 34.44% after treating with CHA and lime it increased into 37.89%. 20% CHA and 4% lime shows a better result. Plasticity index gradually decreased to 2.04% from 10.56% when 10% CHA and 6% lime was added. A PI of 2.04% indicates the soil is now less prone to becoming sticky and malleable when wet. The soil exhibits very low plasticity, which means it has become more like a sandy or silty soil with low clay content.

D. Variation of UCC Strength Value with Varying Percentage of CHA and Lime

The Unconfined Compressive Strength of untreated soil and CHA-lime treated soil is given in Table 4

TABLE 4
SUMMARY OF UCC STRENGTH OF SOIL TREATED WITH CHA AND LIME

Sample	UCC strength (Kg/cm^2)
Untreated soil	3.2 x 10^{-3}
Soil + 10% CHA + 4%LIME	3.5 x 10^{-3}
Soil + 20% CHA + 4%LIME	4.2 x 10^{-3}
Soil + 10% CHA + 5%LIME	5.2 x 10^{-3}
Soil + 20% CHA + 5%LIME	5.5 x 10^{-3}
Soil +10% CHA + 6%LIME	7.2 x 10^{-3}
Soil +20% CHA + 6%LIME	6.2 x 10^{-3}

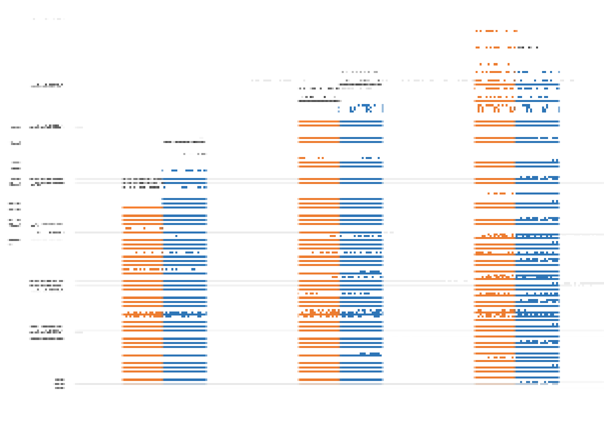

FIG. 2 Variation of UCC strength with varying percentage of CHA and Lime

The unconfined compressive strength of soil was improved after treating with CHA- lime mixture. The UCC strength of untreated soil was 3.5 x 10-3 Kg/cm2, the UCC strength increased up to 7.2 x 10-3 Kg/cm2 when treated with 10% CHA and 6% lime. Up on the addition of 20% CHA and 6% lime strength decreased. The optimal CHA content for strength improvement in this case is 10% CHA with 6% lime. Increasing CHA to 20% without increasing lime disrupts the stabilization balance, leading to poor pozzolanic reactions, weaker bonds, and reduced soil strength.

E. Variation of MDD, OMC and CBR Value with Varying Percentage of CHA and Lime

The effect of CHA and lime on the compaction characteristics and CBR was determined. The maximum dry density, optimum moisture content and CBR value of untreated soil and CHA-lime treated soil is given in Table 5. The variation in MDD, OMC and CBR value upon the addition of different percentages of CHA and lime is given in FIG. 3

TABLE 5

SUMMARY OF MDD, OMC AND CBR VALUE OF SOIL TREATED WITH CHA AND LIME

Sample	MDD (g/cc)	OMC (%)	CBR value (%)
Untreated soil	1.74	20.8	0.89
Soil + 10% CHA + 4%LIME	1.75	19.72	12.99
Soil + 20% CHA + 4%LIME	1.77	19.2	16.72
Soil + 10% CHA + 5%LIME	1.79	18.6	17.91
Soil + 20% CHA + 5%LIME	1.82	17.96	21.75
Soil + 10% CHA + 6%LIME	1.79	18.76	7.39
Soil + 20% CHA + 6%LIME	1.76	19.95	6.57

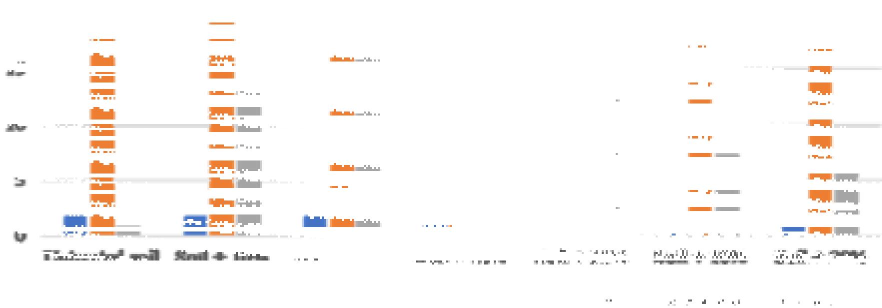

FIG. 3 Variation of MDD, OMC and CBR Value with Varying Percentage of CHA and Lime

After treating the soil with 20% coffee husk ash (CHA) and 5% lime, the maximum dry density (MDD) increased from 1.74 g/cc to 1.82 g/cc, while the optimum moisture content (OMC) decreased from 20.8% to 17.96%. This improvement is due to better soil bonding, reduced voids, and enhanced particle packing from pozzolanic reactions. However, when lime increased to 6%, excessive flocculation reduced compaction efficiency, leading to lower MDD and higher OMC. The California Bearing Ratio (CBR) value also increased significantly, from 0.89% to 21.75%, due to pozzolanic reactions forming cementitious compounds like CSH and CAH. Cation exchange improved flocculation, reduced plasticity, and filled voids, enhancing compaction and strength. Increasing lime beyond 5% reduced CBR due to excess flocculation and moisture retention.

V. CONCLUSIONS

Soil stabilization improves strength, durability, and load-bearing capacity. This study examined the effects of Coffee Husk Ash (CHA) and lime on soil properties. The liquid limit decreased from 45% to 39% with 10% CHA and 6% lime, while the plastic limit increased from 34.44% to 37.89% with 20% CHA and 4% lime. The plasticity index dropped from 10.56% to 2.04% with 10% CHA and 6% lime, making the soil less sticky.

UCC strength improved from 3.5×10^{-3} Kg/cm² to 7.2×10^{-3} Kg/cm² with 10% CHA and 6% lime, but excess CHA (20%) reduced strength. MDD increased from 1.74 g/cc to 1.82 g/cc with 20% CHA and 5% lime, while OMC decreased from 20.8% to 17.96%. However, more lime increased OMC and reduced MDD due to excessive flocculation. The CBR value increased significantly from 0.89% to 21.75% with 20% CHA and 5% lime but decreased with higher lime content. CHA-lime treatment improved soil stability, reduced plasticity, and enhanced strength, with 10% CHA and 6% lime as the optimal mix. Future research should optimize mix ratios, explore other stabilizers, and assess long-term durability. CHA-lime stabilization is a sustainable, cost-effective method for improving soil in construction projects.

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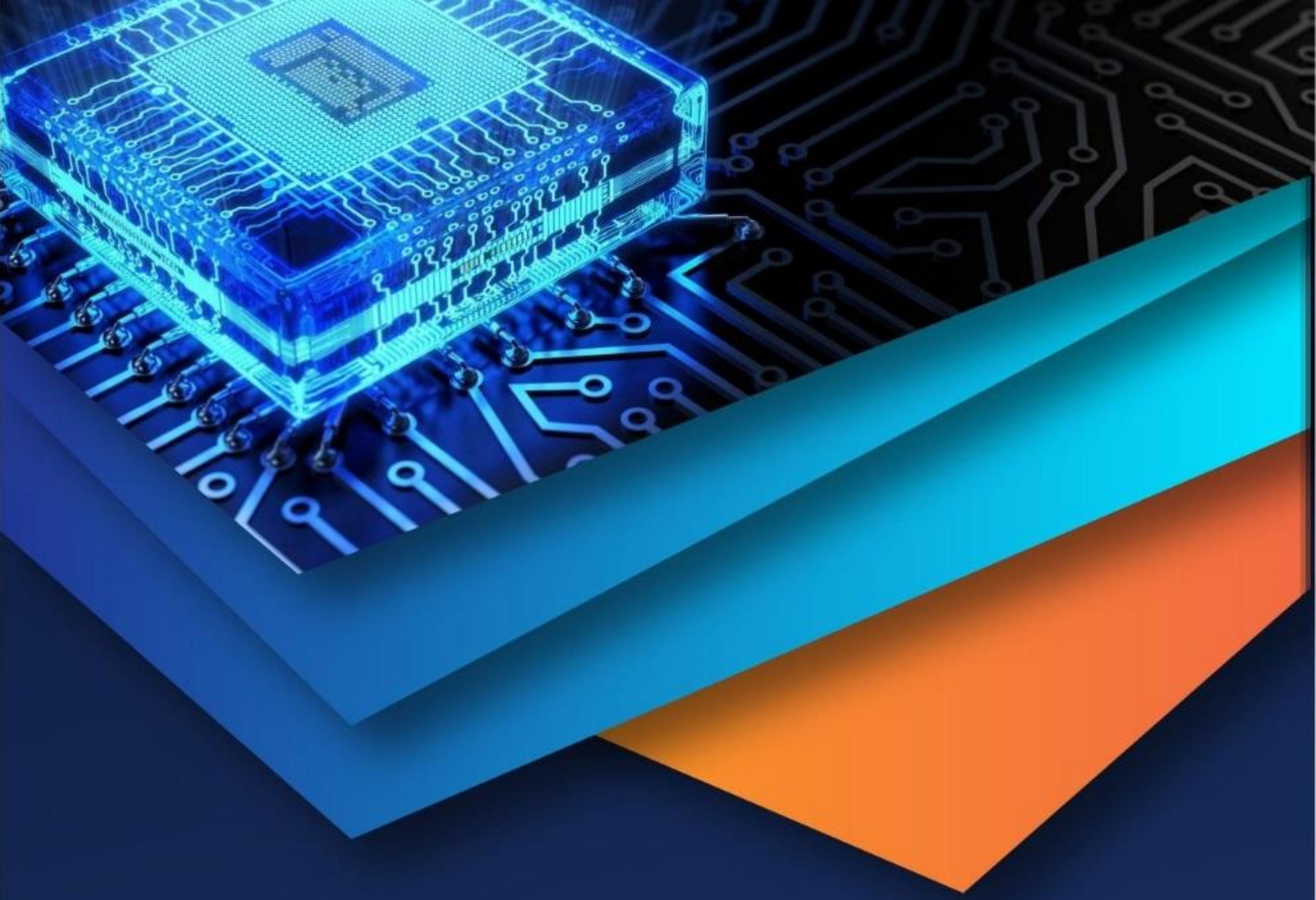

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