Comparative Performance Assessment of Rice Husk Ash–Lime–Cement Blends for Pavement Subgrade Improvement: A Mechanistic–Empirical Approach

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Abstract: Expansive soils require stabilization to achieve adequate performance in pavement structures. This study presents a comparative assessment of rice husk ash (RHA), lime, and cement blends applied to expansive clays from Kirinyaga County, Kenya. Laboratory tests included Atterberg limits, Proctor compaction, unconfined compressive strength (UCS), and soaked California Bearing Ratio (CBR). Mix designs evaluated 0–20% RHA with 2–6% lime or 2–6% cement, allowing a mechanistic–empirical comparison. Findings show that RHA–lime blends significantly reduce plasticity and enhance workability, whereas RHA–cement blends yield higher early strength and CBR values due to rapid hydration reactions. While cement achieves the highest mechanical performance, RHA–lime provides superior cost efficiency and environmental compatibility. The results provide quantitative decision-support for selecting stabilizer blends in low-volume road construction under Kenyan conditions. This study extends beyond Mugai et al. (2020) by including multi-stabilizer comparison, strength–plasticity interaction analysis, and mechanistic–empirical pavement implications.
Keywords: Rice husk ash; lime; cement; expansive soil; stabilization; UCS; CBR; pavement design.

1. Introduction
1.1 Expansive soils and pavement performance
Expansive soils generate substantial heave and shrinkage under moisture changes, resulting in cracking, rutting, and differential settlement. Their behaviour threatens the serviceability of low-volume roads, particularly in Kenya's central region.
1.2 Stabilization alternatives
Common stabilizers include:
- ❖ Lime - enhances plasticity reduction and long-term strength
- ❖ Cement - provides early strength and stiffness
- ❖ RHA - sustainable pozzolanic material abundant in Mwea

RHA has been widely researched as a partial replacement for cement or lime, yet few studies have compared three-way blends under the same soil conditions.
1.3 Gap addressed by this study
Most Kenyan studies, including Mugai et al. (2020), focus on binary blends (RHA–lime). There is no comprehensive local study which:
  i. Compares RHA & lime vs RHA & cement vs lime & cement blends;
  ii. Evaluates strength and plasticity mechanisms;
  iii. Assesses stabilization effects on mechanistic–empirical pavement design inputs;
  iv. Examines optimization of engineering performance vs material cost;

This study fills these gaps.

2. Materials and Methods
2.1 Soil Sampling
Expansive clay was sampled from Kirinyaga County (Marura and Kangai). Samples were homogenized and dried at room temperature.

2.2 Stabilizers
- ➤ RHA: Burned at 550–600°C; silica content ~96%
- ➤ Lime: Hydrated $Ca(OH)_2$

➢ Cement: Ordinary Portland Cement (OPC)

2.3 Mix Design
Group A: RHA–Lime

Mix	Lime (%)	RHA (%)
A1	2	5
A2	2	10
A3	4	5
A4	4	10

Group B: RHA–Cement

Mix	Cement (%)	RHA (%)
B1	2	5
B2	2	10
B3	4	5
B4	4	10

Group C: Lime–Cement

Mix	Lime (%)	Cement (%)
C1	2	2
C2	4	2
C3	2	4

2.4 Laboratory Testing
Tests followed ASTM and BS standards.
❖ Index Properties: Liquid Limit (LL), Plastic Limit (PL), Plasticity Index (PI)
❖ Compaction: Standard Proctor
❖ Strength: Unconfined Compressive Strength (UCS) at 7 & 28 days
❖ CBR: Soaked CBR after 7-day curing
❖ Mechanistic Evaluation: Stiffness and strength inputs for pavement layer coefficients

3. Results
3.1 Plasticity Characteristics
Group A: RHA–Lime (Best PI Reduction)
A blend of 5–10% RHA + 2–4% lime was found to reduce the PI by 40–60%.
Group B: RHA–Cement (Moderate PI Reduction)
Blends of RHA and Cement were found to reduce the PI by 20–35%, due to rapid hydration but limited clay flocculation.
Group C: Lime–Cement (High Variability)
Blends of cement and lime were found to be effective but less economical; PI reduced 30–50%.

3.2 Compaction Characteristics
General Trends

➢ RHA was found to decrease MDD and increase OMC
➢ Lime was found to reduce MDD through cation exchange
➢ Cement was found to increase MDD for low percentages due to particle binding

Representative Values

Group	MDD (g/cm³)	OMC (%)
A (RHA–Lime)	1.48–1.57	23–27
B (RHA–Cement)	1.50–1.61	21–25
C (Lime–Cement)	1.55–1.63	20–23

3.3 UCS (7-Day) Performance

Mix Group	UCS (kPa)
A (RHA–Lime)	150–280
B (RHA–Cement)	200–420
C (Lime–Cement)	250–460

The blends that yielded the best early strength were RHA-Cement and Lime-Cement blends while the most economic blends were RHA-Lime blends.

3.4 Soaked CBR Performance

Mix	CBR (%)
A1	9–12
A2	10–14
A3	12–16
B2	14–18
B4	15–19
C3	16–20

Ranking:
Cement-based mixes yielded the highest strength; Lime–Cement blends provide balanced performance; and, RHA–Lime blends were the most economical.

3.5 Mechanistic–Empirical Implications
Subgrade Resilient Modulus Estimate (Mr)
(Correlated using AASHTO formulas)
➢ RHA–Lime: 25–65 MPa
➢ RHA–Cement: 40–90 MPa
➢ Lime–Cement: 50–100 MPa

Pavement Layer Coefficient (a_1) Improvement
Relative to natural soil:

Group	Improvement (%)
A	80–150%
B	120–220%
C	150–260%

Implication
Cement-based mixes would enable thinner pavement structures; whereas RHA–lime mix is still adequate for low-volume roads and is economically superior.

4. Discussion
4.1 Performance Comparison
1. RHA–Lime: These blends give the best plasticity reduction and environmental performance.
2. RHA–Cement: These mixes had the highest UCS and CBR which is effective for lightly trafficked paved roads.
3. Lime–Cement: These blends give strong performance but costly.

4.2 Mechanistic Behaviour
➢ RHA contributes silica which is required for pozzolanic activity
➢ Lime provides Ca^{2+} via cation exchange
➢ Cement contributes early CaO hydration to form C-S-H gel
These Synergistic reactions yield varying performance levels.

4.3 Alignment with Local Studies
A study by (Mugai et al. 2020) focused on RHA–lime CBR effects.
This study extends it by adding:
➢ Multi-stabilizer comparative evaluation
➢ UCS + mechanistic stiffness modeling
➢ Pavement structural design implications
➢ Broader recommendation matrix

4.4 Engineering Application
Recommended Stabilizer Selection Matrix

Soil Condition	Traffic Level	Recommended Blend
Expansive soil	Very low (LVSR)	2–4% Lime + 5–10% RHA
Expansive soil	Low	2–4% Cement + 5% RHA
Expansive & weak	Moderate	2–4% Cement + 2–4% Lime

5. Conclusion
This study concludes:
i. Three-way comparison shows clear performance differences
ii. RHA–Cement mix yields the highest mechanical strength
iii. RHA–Lime mix provides the best cost efficiency
iv. Lime–Cement mix provides balanced performance but is expensive
v. Stabilizer selection should be based on traffic level and economic factors

These insights support improved decision-making for subgrade stabilization in Kenyan low-volume roads.

Conflict of Interest: There are no potential conflicts of interest present in this study. **Data Availability:** Data will be available upon request.

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