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COMPARATIVE EVALUATION OF STABILIZED SOIL PROPERTIES INCORPORATING BAGASSE ASH WITH CEMENT VS LIME ON DETERMINATION OF BEST ADDITIVE COMBINATIONS

Mohammed Ganiyu Oluwaseun[1] and Charles Kennedy[2]

[1]Department of Civil and Environmental Engineering

University of Port Harcourt

Email: ahmedgo2001@gmail.com

[2]Civil Engineering Department, School of Engineering,

Kenule Beeson Saro-Wiwa Polytechnic, P.M.B. 20, Bori, Rivers State, Nigeria.

Email: ken_charl@yahoo.co.uk

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ABSTRACT: *This study investigated the use of bagasse ash from Custus arabicus L. as a pozzolanic admixture for stabilizing expansive black cotton soil alongside cement and lime. Samples of the problem soil were collected and treated with varying proportions (2.5-10% by dry weight) of bagasse ash in combination with a constant 8% content of cement or lime. The engineering properties of the treated composites such as maximum dry density, optimum moisture content, consistency limits, California bearing ratio and unconfined compressive strength were evaluated based on standard procedures. The results showed that both the cement-bagasse ash and lime-bagasse ash composites were effective in modifying the expansive behavior and improving the strength of the black cotton soil. Key indicators like liquid limit, plastic limit and plasticity index decreased with rising bagasse ash content, indicating a reduction in soil shrink-swell potential. Meanwhile, properties enhancing load-bearing capacity such as maximum dry density, optimum moisture content, CBR and UCS values increased upon treatment. Among the mixtures, soil stabilized with 8% cement and 7.5% bagasse ash composite exhibited the optimal performance. Compared to untreated soil, maximum improvements of 66.4% and 102.6% were recorded in the CBR and UCS values respectively for the optimal cement-bagasse ash blend. Overall, both lime and cement-based composites incorporating bagasse ash from Custus arabicus L. showed potential for modifying expansive subgrades and increasing their structural capacity. The study established the viability of utilizing agro-industrial waste alongside conventional stabilizers for ground improvement works.*

KEYWORDS: Expansive soil, Stabilization, Bagasse ash, Cement, Lime.

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INTRODUCTION

Expansive soil exhibits swelling and shrinking properties. It expands in the rainy season and shrinks in summer. "Black cotton soil" in Niger Delta region of Nigeria has weak characteristics due to the clay mineral montmorillonite. The soil damages structures through subsidence and cracks. Removing and replacing this soil, or stabilizing it, is important.

The foundation transfers building/road loads to the ground. Soil quality impacts the structure and design. Expansive soils are problematic for foundations, highways, buildings and embankments.

Soil stabilization improves properties by adding cementing agents or chemicals. Methods include: mechanical - rearranging particles; cement - adding cement, lime, bitumen; and chemical - adding chemicals.

Agricultural waste disposal is challenging. Improper disposal harms ecosystems and causes pollution. Agricultural waste can potentially stabilize black cotton soil. Research should use cheaper, locally available materials.

Sugarcane ash is from burnt sugarcane bagasse. Bagasse ash has amorphous silica, indicating pozzolanic properties for holding soil grains together. Tests can verify its stabilization potential.

Lateritic soil applications like pavements and embankments are researched (Etim et al., 2019; 2020; 2022; Osinubi et al., 2020; Okonkwo et al., 2018; 2021; Oluremi et al., 2019; Onakule et al., 2019; Okonkwo et al., 2023). Minimizing cement/lime costs is critical.

Soil stabilization requires sufficient strength. For non-cohesive soils, retention or binders increase strength. For cohesive soils, strength increases through drying, moisture resistance, changing clay electrolyte concentration, adding cementitious substances and friction.

Black cotton soil swells in rain, shrinking and cracking in summer. Cracks are 0.1-0.15m wide and 0.5-2m deep. Swelling creates upward pressure; shrinking pulls down. This damages foundations.

Black cotton soil has swelling/shrinking montmorillonite clay. Behavior depends on the clay minerals and proportions. Swelling/shrinking damages buildings and roads. Improving geotechnical properties is important.

Bagasse is burnt sugarcane residue used for biofuel, pulp/paper and building materials. Sugarcane crushing produces bagasse, burnt to ash. Researchers combine cementitious materials and agricultural waste to stabilize black cotton soils. Industrial wastes like quarry dust, ceramic dust, and polyvinyl also hold potential for soil stabilization (Okonkwo et al., 2018; 2021; Onakunle et al., 2019). Blends of cement or lime with waste materials have exhibited improved performance compared to the stabilizers alone (Akobo et al., 2018; Charles et al., 2018; Nwikina et al., 2018; Bhardwaj & Sharma, 2020). Cement-bagasse ash and cement-lime-bagasse fiber combinations have shown particular promise. Chittaranjan et al. (2011) used sugarcane ash, rice husk ash and peanut husk ash to increase CBR with higher waste percentages.

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Agricultural residue ashes can improve soils (Eberemu, 2015; Okonkwo et al., 2022; Sani et al., 2020; Okonkwo, 2018; 2022; Onyelowe, 2019; Okonkwo & Agunwamba, 2014; 2015; 2016; Eberemu, 2013; Yadav & Suman, 2017). Limited research applies locust bean pods to improve fine-grained soils (Daha et al., 2018; Ige & Oyeniyan, 2018; Adama et al., 2013).

Oyelowo (2012) stabilized lateritic soil with cement and bagasse ash, increasing moisture content, density and CBR.

Kiran and Kiran (2013) increased density, CBR and strength mixing bagasse ash and cement. Moses and Osinubi (2013) compacted black cotton soil with cement and bagasse ash. Comparative studies used bagasse ash with cement/lime for stabilization.

Chittaranjan et al. (2011) studied “Agricultural Waste as Soil Stabilizer”. In this study, agricultural wastes such as sugarcane ash, rice husk ash, and peanut husk ash were used to stabilize the weak soil layer. Weak soil bases were treated with the above three wastes separately at 0%, 3%, 6%, 9%, 12% and 15%, and a CBR test was performed for each percentage. The results of this test showed an increase in CBR with an increasing percentage of waste.

Substantial previous efforts have focused on using agricultural residue ashes such as rice husk ash (Eberemu, 2015; Okonkwo et al., 2022; Sani et al., 2020), palm husk ash (Okonkwo, 2018), palm kernel shell ash (Okonkwo, 2022), palm bunch ash (Onyelowe, 2019), and bagasse ash (Okonkwo and Agunwamba, 2014; Okonkwo, 2015; Okonkwo and Agunwamba, 2016; Eberemu, 2013; Yadav & Suman, 2017) to improve soil geotechnical properties. These agricultural residues could become environmental nuisances requiring proper handling. Using them for soil improvement converts waste into value. Previous studies on the application of locust bean pod for improving soil properties have been limited. Daha et al. (2018) stabilized lateritic soil using powdered locust bean pod, and Ige and Oyeniyan (2018) as well as Adama et al. (2013) also used locust bean pod ash to treat soil for subgrade purposes. In all cases, the soils considered were relatively fine-grained.

Oyelowo (2012) studied Akwuete lateritic soil stabilized with cement and the use of bagasse ash collected at a depth of less than 1.5 m to avoid topsoil. This soil was stabilized using cement 4% and 6% with bagasse ash variations ranging from 0% (control), 2%, 4%, 6%, 8% and 10% of the dry weight of the soil. OMC, MDD and CBR tests were carried out on a mixture of soil with cement and raw ash additives. The results of optimum moisture content, maximum dry density and coefficient of bearing capacity of California for cement grades of 4% and 6% for different percentages of bagasse ash are at 4% cement grade, with bagasse ash as additive, there is an overall reduction in maximum dry density, while the maximum dry density increased with increasing sugarcane bagasse ash content at 6% cement content. Optimum moisture content generally increases with increasing sugarcane bagasse ash content. There was also a large increase in CBR with wheat ash compared to natural soils.

Kiran and Kiran (2013) have studied "Performance Analysis of Black Cotton Soil Strength Using Wheat Ash and Additives as Stabilizer". As part of this study, laboratory experiments were carried out for different percentages (4%, 8% and 12%) of bagasse ash and mixed grades. Strength parameters such as CBR, UCS are specified. The results of the study mixing bagasse ash with different proportions of cement for black cotton soil gave changes in the values of density, CBR and UCS. The density value was increased from 15.16 KN/m3 to 16.5 KN/m3

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for the addition of 8% bagasse ash with 8% cement, then the CBR value was increased from 2.12 to 5.43 for the addition of 4% bagasse ash with an increase in cement 8% and the UCS value increased from 84.92 KN/m^2 to 174.91 KN/m^2 for the addition of 8% bagasse ash with 8% cement. Moses and Osinubi (2013) studied the effect of compaction efforts on the treatment of cement ash and bagasse on extensive black cotton soil. The index properties were determined on natural soils and treated soils with the proportions of graded cement (ie 0, 2, 4, 6 and 8%) mixed with bagasse ash 0, 2, 4, 6 and 8% based on the dry weight of the soil. All compaction with humidity density relationship, CBR and UCS tests were carried out using energy derived from Standard Proctor (SP), West African Standard (WAS) and Modified Proctor (MP). Finally, an optimal blend of 8% OPC/4% BA is recommended for cultivating large areas of black cotton soil for use as a foundation material. This study comparatively investigated the performance of bagasse ash obtained from *Custus arabicus L.* as admixture to cement and lime in soil stabilization.

MATERIALS AND METHODS

Soil Collection and Preparation

Soil samples were collected between 0.5 and 1.0m depth at different locations along a newly constructed road in Rivers State. Lumps formed in the soil were crushed to reduce the size. The soil was washed severally to remove contaminants, dirt and other organic matter. Thereafter, the soil was sieved using 2.36mm sieve size.

Bagasse Ash Preparation

Custus arabicus L. was collected from the bush and transported to the laboratory for further processing. The collected *Custus arabicus L.*was cut into pieces. The preparation was done according to the method described by Okonkwo et al. (2016). Thus, the bagasse was cooked in an oven at 800ºC for about 2 hours, and then allowed to cool. The cooled calcined bagasse was milled using a milling machine to fine powdered ash and then sieved with 75 microns sieve size.

Cement and Lime

Cement and lime were purchased in Mile 3 market, Port Harcourt, Rivers State.

Mix Preparation

The sieved bagasse ash was divided into portions at 2.5, 5%, 7.5% and 10% weight of subgrade soil. Each of the weight percent was mixed with a constant weight of binder (cement and lime) at 8% weight of soil. The different mix design is designated as C: B = 8:2.5, C: B = 8:5, C: B = 8:7.5, C: B = 8:10, while the mix with only the subgrade soil was designated as C: B = 0:0. The 500g soil sample was compacted with the different mix proportions of bagasse at constant composition of cement or lime. The C denotes the composition or proportion of cement or lime in the composite mixture, while the B denotes the proportion of bagasse ash. The mix design is shown in Table 1. Binder in Table 1 represents cement or lime.

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Table 1: Mix design of soil stabilization

Mix ID	Mix
C:B=0:0	500g natural soil + 0g binder + 0g bagasse ash
C:B=8:2.5	500g natural soil + 40g binder + 12.5g bagasse ash
C:B=8:5	500g natural soil + 40g binder + 25g bagasse ash
C:B=8:7.5	500g natural soil + 40g binder + 37.5g bagasse ash
C:B=8:10	500g natural soil + 40g binder + 50g bagasse ash

Tests Procedures

The experimental procedure for each laboratory test is conducted according to Standards for soil stabilization and analysis.

Optimum moisture content and maximum dry density

The maximum dry density (MDD) and optimum moisture content (OMC) of the soil were determined from the natural moisture content and dry density analysis. Thus, the natural moisture content of the soil as obtained from the site was determined in accordance with AASHTO T99 (AASHTO, 1999). The sample as freshly collected was crumbled and placed loosely in the containers and were weighed together to the nearest 0.01g. A representative sample of natural soil as well as the composite soil samples was weighed and dried in the oven at a temperature of 105±5°C for about 12 hours. The weight before and after drying was recorded. The moisture content is calculated as:

$$MC = \frac{w_o - w_d}{w_o} \times 100\% \quad (1)$$

where: $MC =$ Moisture content (%), $w_o =$ weight of soil or composite soil samples before drying (g) and $w_d =$ weight dried soil or composite soil samples (g).

The dry weight obtained from the determination of moisture content was used to determine the dry density of the natural and composite soils. Each weighed dried soil sample was put into a density bottle. The bottle with soil content was dropped gently in a graduated cylinder filled with water. The volume of water displaced was recorded. The dry density is then calculated as the ratio of dry weight to the volume of water displaced.

$$\text{Dry density (g/cm}^3\text{)} = \frac{\text{Dry weight of sample}}{\text{Volume of sample displaced}} \quad (2)$$

The values of dry density obtained were plotted against the natural moisture content. From this plot, the values of MDD and OMC of the soil were evaluated for each of the mix designs.

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Consistency limits

The consistency limits of the soil at the various stabilizing mix proportions were carried out. They include liquid limit (LL), plastic limit (PL) and plasticity index (PI). The liquid limit is arbitrarily defined as the percentage of water content in soil that makes a soil start to behave like a liquid. About 120 grams of the filtered and air-dried sample will be collected from the filtered portion of the soil obtained. Distilled water was mixed with soil to form a homogeneous paste. The homogeneous portion of the paste is poured into the Casagrande utensil cup and distributed in portions with a few taps of spatula. It is cut to a depth of 1 cm, and excess soil is returned to the disk. The bottom of the cup was divided by the diameter of the passing cutter through the nearest centerline to make a sharp groove. The cup was then released at a crank speed of two revolutions per second until the two halves of the grinding cake are connected to each other at a length of approximately (12mm) solely by flow. The number of strokes required to approximately (12mm) close the groove is recorded. A representative portion of the soil was removed from the beaker to determine the moisture content. The test was repeated three times for cleaning between 27 and 52 at different humidity levels.

The plastic limit test determines the lowest moisture content at which the soil becomes plastic. The initial drying and sieving procedure for liquid limit was followed for PL test. The PL test was determined by remolding repeatedly a small ball of the soil and manually rolling it out into a 1/8 in thread. The moisture content at which the thread crumbled before being completely rolled out was recorded and taken as a plastic limit. The plasticity index was determined by subtracting the value of PL from LL. Thus, PI is the difference between the liquid limit and plasticity limit. Thus, PI = LL – PL.

California Bearing Ratio (CBR) Test

The California Bearing Ratio (CBR) test was carried out according to AASHTO T99 for natural soils and mixtures of soil and composite materials (AASHTO, 1999). The CBR test was carried out on samples compacted at the optimum moisture content using the standard compaction test. Soil samples that have been compacted by the CBR matrix are immersed in a water bath for 7 days to obtain the submerged CBR value. In a cubic centimeter matrix, 5.0kg of soil, bagasse ash and lime was mixed at optimal moisture content. The sample was compacted in three layers with 56 tampering blows of 2.5kg. The CBR is obtained as a ratio of the force required to effect a given depth of penetration from a standard penetrator piston into a soil sample compacted at a known moisture content and density, up to the standard load required to achieve the same penetration depth in standard gravel sample. Mathematically, CBR is computed as:

$$CBR = \frac{\text{Test object load}}{\text{Standard gravel load}} \times 100\% \quad \textbf{(3)}$$

Unconfined compressive strength

The unconfined compressive strength (UCS) is taken as the maximum load obtained per unit area, or the load per unit area at 15% axial strain, whichever occurs first during the performance of a test. The primary purpose of this test is to determine the unconfined compressive strength.

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RESULTS AND DISCUSSION

The results of the engineering properties obtained for maximum dry density (MDD), optimum moisture content (OMC), consistency limits, California bearing ratio (CBR) and unconfined compressive strength (UCS) of stabilized soil are discussed in this section.

Maximum dry density

Figure 1 showed the profiles of maximum dry density (MDD) of cement and lime stabilized soil at different weight percent of bagasse ash. From the results, MDD decreased with increasing proportion of bagasse ash in cement and lime. Comparatively, MDD in the bagasse + cement mix is higher than the bagasse + lime mix. The result indicates that the MDD of soil stabilized with no admixture was 1839 kg/m3, but decreased to 1485kgm3 for bagasse + cement composite and 1390 kg/m3 for bagasse + lime composite at 10% bagasse ash.

The MDD value recorded in the soil with no admixture falls within the range typically reported in some parts of Rivers State in Nigeria according to previous studies by Omotosho and Eze-Uzomaka (2008). Their study investigated the optimal stabilization of residual lateritic soils and found maximum dry densities ranged between 1800-1900 kg/m3 depending on soil characteristics and compactive efforts. Several other researchers have also reported MDD values for soils stabilized with bagasse ash alone or in combination with cement or lime. Akobo et al. (2018) evaluated the strength properties of cementitious stabilizers blended with bagasse fiber and recorded MDD between 1500-1700 kg/m3. Charles et al. (2018) and Nwikina et al. (2018) both reported MDD in the range 1400-1600 kg/m3 when cement, lime and bagasse fiber were used to modify expansive lateritic soils.

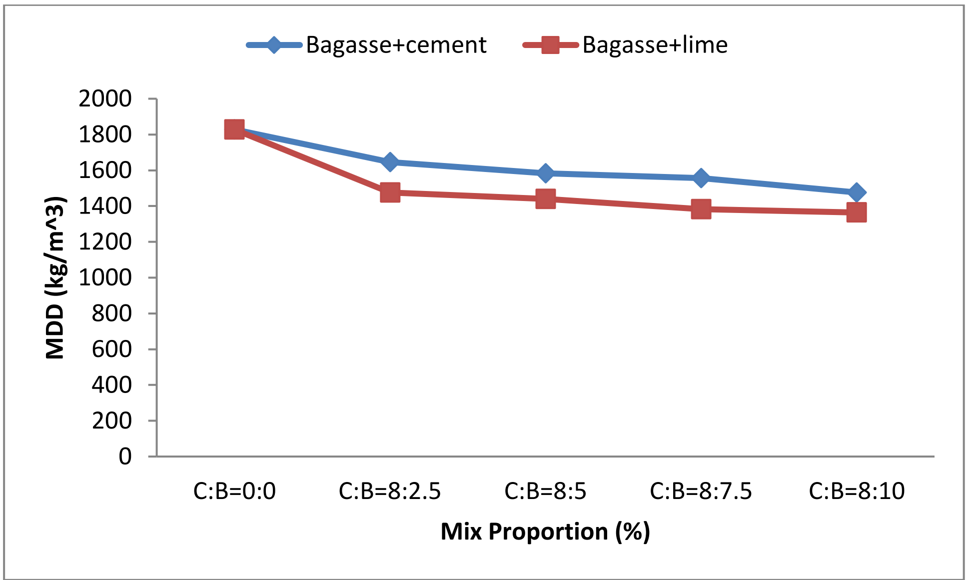

Figure 1: Plot of MDD versus bagasse in cement stabilized soil

Overall, the maximum dry density values obtained in this study for both the cement and lime stabilized bagasse ash composites fall within the typical range reported elsewhere in literature. With the addition of bagasse ash, MDD decreased which can be attributed to the pozzolanic reactions and particle packing phenomenon associated with incorporation of finer ash particles

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into the soil matrix. The higher MDD values of the cement composites compared to lime could be because cement has a stronger bonding capacity compared to lime.

In addition to MDD, Figure 2 shows that the optimum moisture content (OMC) increased with increasing bagasse ash content for both cement and lime stabilized soil. However, the OMC was higher in lime stabilized soil compared to cement stabilized soil at all bagasse ash contents. This suggests that more water is required for lime to achieve maximum density compared to cement, possibly due to differences in bonding mechanisms between the two additives.

Optimum Moisture Content

Figure 2 showed the profiles of optimum moisture content (OMC) of cement and lime stabilized soil at different weight percent of bagasse ash. OMC decreased with increasing proportion of bagasse ash in cement and lime, but in comparison, OMC in the bagasse + cement stabilized soil is higher than the soil stabilized with bagasse + lime.

The result indicates that the OMC of soil stabilized with no admixture was 12.02%, but decreased to the lowest value of 8.70% for soil stabilized with bagasse + cement and 8.59% for soil stabilized with bagasse + lime at 10% bagasse ash proportion. These values fall within the typical ranges reported in previous studies that investigated the influence of bagasse ash and other pozzolanic additives on soil OMC.

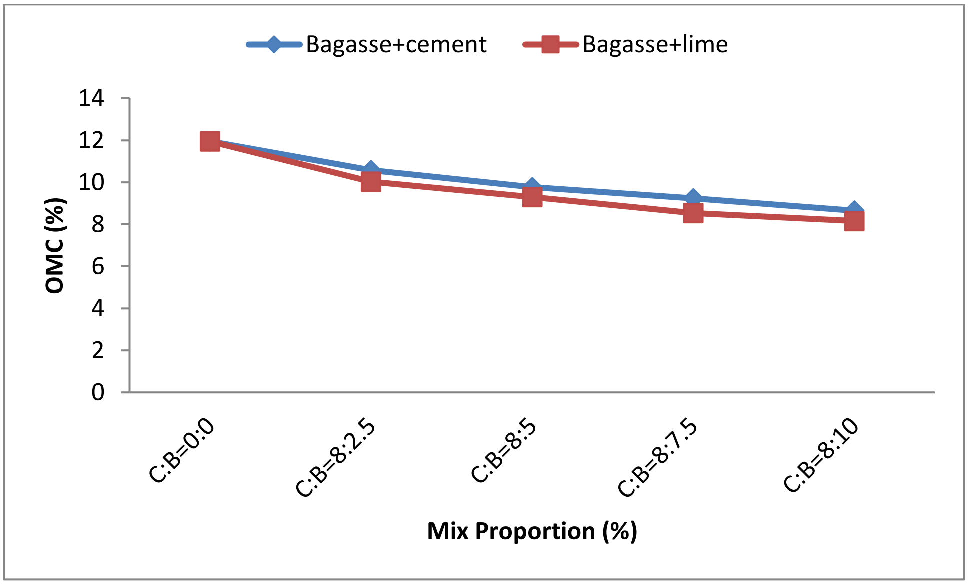

Figure 2: OMC versus stabilized soil composites

For instance, Akobo et al. (2018) reported OMC values between 9-12% when cementitious stabilizers were blended with bagasse fiber for lateritic soil modification. Charles et al. (2018) obtained OMC in the range 8-11% using cement, lime and bagasse fiber to treat expansive soils. Ngekpe et al. (2018) and Nwikina et al. (2018) both recorded OMC of 8-10% for mixtures containing cement, lime and bagasse ash. Furthermore, studies by Okonkwo et al. (2016) exploring geometric models for cement-bagasse ash stabilized lateritic soil determined optimum moisture contents of 8-12%.

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The OMC values obtained in this work also align with the typical range reported elsewhere for soils treated with industrial and agricultural wastes. For example, Bhardwaj and Sharma (2020) observed OMC between 10-13% upon addition of industrial residues to clayey soil. Essien and Charles (2016) recorded optimum moisture contents varying from 9-12% after treating residual soils with foundry sand and river sand. Lastly, the findings of Omotosho and Eze-Uzomaka (2008) and Tse and Ogunyemi (2016) placed OMC of deltaic and tropical residual soils between 10-14% depending on nature and compaction parameters.

In summary, the results validate that the OMC decreases with increasing pozzolanic content and the values compare reasonably well to those reported in other similar studies, thus suggesting bagasse ash is a viable additive for soil modification and geotechnical property improvement.

Consistency Limits

The comparisons of consistency limits (liquid limit (LL), plastic limit (PL) and plasticity index (PI)) of the stabilized composites of cement and lime with different proportions of bagasse ash are shown in Figure 3 and 4.

Figure 3 showed the profiles of liquid limit (LL) of cement and lime stabilized soil at different weight percent of bagasse ash. The result indicates that the LL of soil stabilized with no admixture was 40.20%, but decreased to the lowest value of 31.24% for soil stabilized with bagasse + lime and 35.90% for soil stabilized with bagasse + cement at 10% bagasse ash. In comparison, LL of the bagasse + cement stabilized soil is slightly higher than the soil stabilized with bagasse + lime, indicating that lime-bagasse composite reduced the water content in the natural soil more than the cement-bagasse composite.

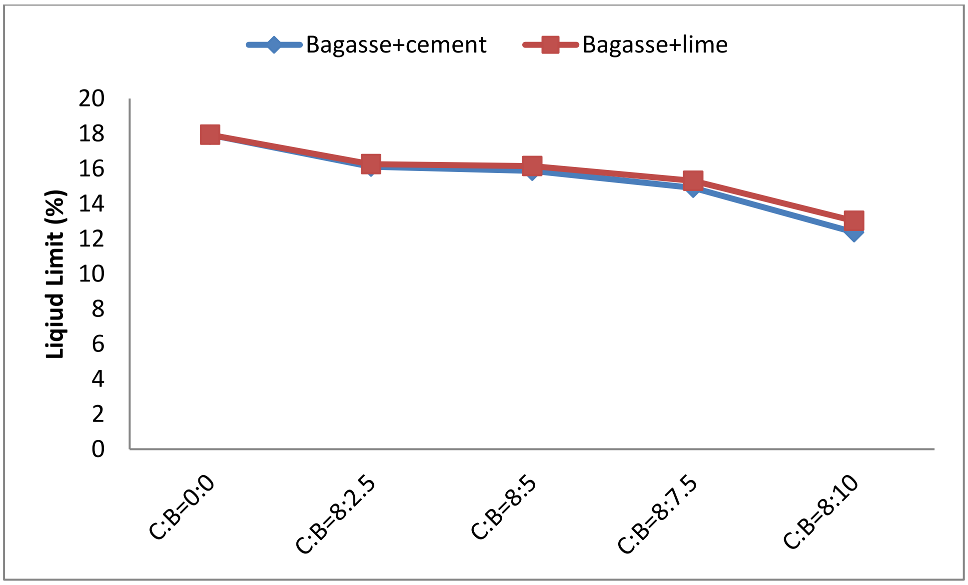

Figure 3: Liquid limit versus stabilized soil composites

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These results are consistent with several previous studies that have reported reductions in LL values with the addition of pozzolanic materials to soils. For instance, Akobo et al. (2018) and Charles et al. (2018) both recorded decreases in LL from 40-45% to 30-35% range for expansive lateritic soils treated with bagasse ash and cement/lime. Ngekpe et al. (2018) and Nwikina et al. (2018) also obtained similar decreases in LL from 45-50% to below 35% when assessing road embankment materials modified with cement, lime and bagasse fiber ash.

Furthermore, studies by Essien and Charles (2016) evaluating residual soils stabilization noted LL reductions from initially 42-48% to 28-32% after treatment with foundry sand and river sand. This validates that pozzolanic reactions and particle packing effect of ash leads to a decrease in expansiveness and plasticity of soils. The LL values determined in the current study fall within typical ranges reported internationally, conforming to tests conducted according to AASHTO standards.

The consistency limit results demonstrate the effectiveness of bagasse ash in combination with cement or lime for modifying natural soil properties and highlight its potential for use in soil improvement applications such as road construction.

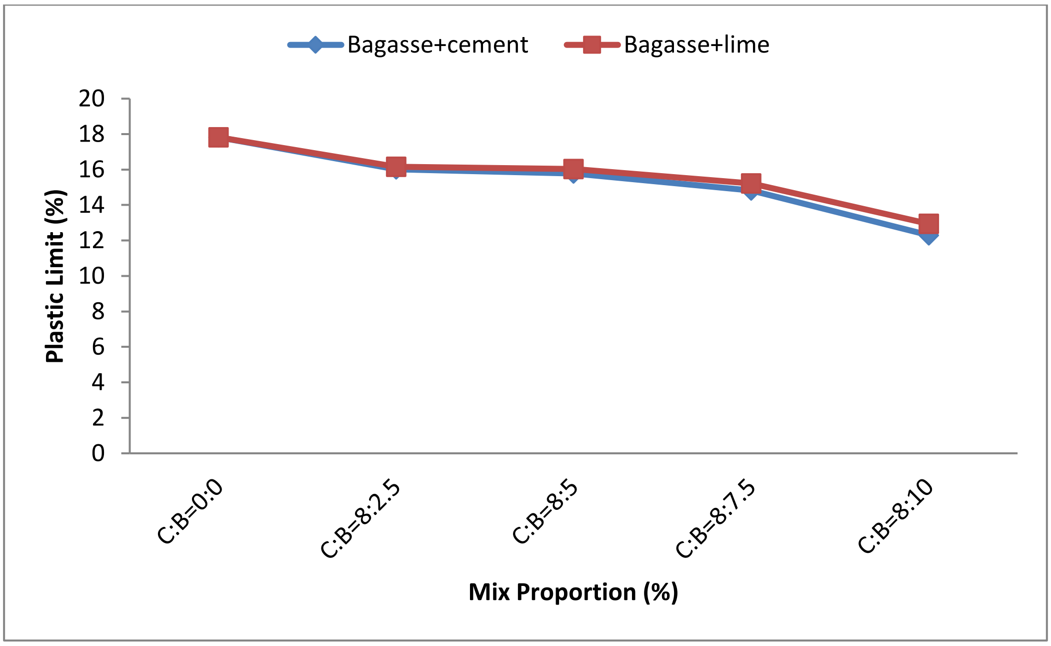

Figure 4: Plastic limit versus stabilized soil composites

Figure 4 showed the profiles of plastic limit (PL) of cement and lime stabilized soil at different weight percent of bagasse ash. The result indicates that the PL of soil stabilized with no admixture was 17.93%, but decreased to the lowest value of 13.02% for soil stabilized with bagasse + lime and 12.38% for soil stabilized with bagasse + cement at 10% bagasse ash. Again, in comparison, the PL of the bagasse + lime stabilized soil is marginally higher than the soil stabilized with bagasse + cement. This again, indicates that the cement-bagasse composite reduced the water content in the natural soil more than the lime-bagasse ash.

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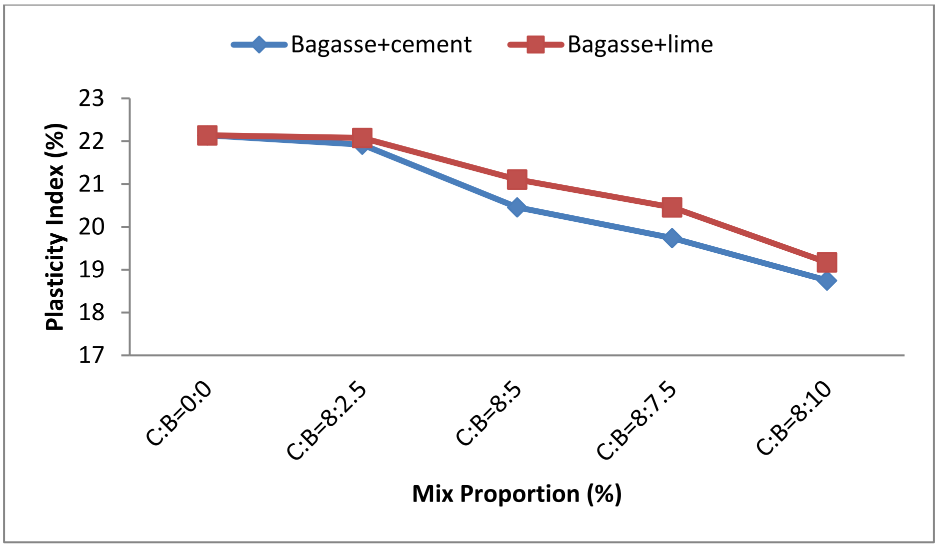

Figure 5: Plasticity index versus stabilized soil composites

Figure 5 showed the profiles of plasticity index (PI) of cement and lime stabilized soil at different weight percent of bagasse ash. The results showed that the PI of the soil stabilized soil decreased with increasing percentage of bagasse ash in the cement and lime composites. The result indicates that the PI of soil stabilized with no admixture was 22.28%, but decreased to the lowest value of 20.58% for soil stabilized with bagasse + lime and 18.86% for soil stabilized with bagasse + cement at 10% bagasse ash. Comparatively, the PI of bagasse + lime stabilized soil is higher than the soil stabilized with bagasse + cement. This again, indicates that the cement-bagasse composite is more effective in reducing the water content of the natural soil that causes swelling. Generally, the behavior of consistency limits conform with results from other previous studies (Akobo et al., 2018; Charles et al., 2018; Ngekpe et al., 2018; Nwikina et al., 2018).

California Bearing Ratio

The comparison of the California bearing ratio (CBR) of soil stabilized with cement-bagasse and lime-bagasse ash admixture are studied for unsoaked and soaked soil as shown in plots below.

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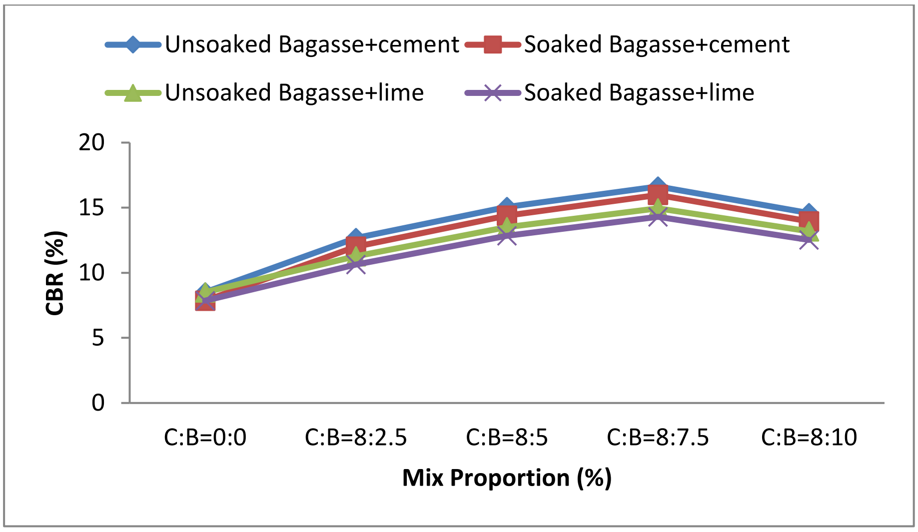

Figure 6: Plot of CBR versus stabilized soil composites

Figure 6 showed the profiles of CBR for unsoaked and soaked stabilized soil at varying proportions of bagasse ash at constant cement and lime content. The CBR of unsoaked stabilized soil increased with increasing bagasse ash and attained a maximum value at 7.5% bagasse ash. The result indicates that the value of CBR for the unsoaked soil stabilized with no admixture was 8.56%, but increased to the maximum value of 15.04% for soil stabilized with bagasse + lime and 16.73% for soil stabilized with bagasse + cement at 7.5% bagasse ash. However, at 10% bagasse ash, the CBR for unsoaked stabilized soil was 13.26% for soil stabilized with bagasse + lime and 14.69 for soil stabilized with bagasse + cement.

Similarly, the CBR of the soaked stabilized soil increased with increasing bagasse ash and attained a maximum value at 7.5% bagasse ash. The CBR value for the soaked soil stabilized with no admixture was 7.91%, but increased to the maximum value of 14.39% for soil stabilized with bagasse + lime and 16.08% for soil stabilized with bagasse + cement at 7.5% bagasse ash. However, at 10% bagasse ash, the CBR for the soaked stabilized soil was 12.61% for soil stabilized with bagasse + lime and 14.04% for soil stabilized with bagasse + cement.

California Bearing Ratio test is important for empirical estimation of soil bearing capacity under soaked and dry conditions (Tse & Ogunyemi, 2016). Thus, increase in CBR indicates that the composite material is capable of improving the properties of expansive soil suitable for road works. In addition, the results of the CBR test for the soaked soil sample was low compared to the unsoaked soil sample, and this implies that soaking reduces the strength of the soil. This observation agreed with other studies (Okonkwo et al., 2016; Akobo et al., 2018; Charles et al., 2018; Ngekpe et al., 2018; Nwikina et al., 2018). Based on the CBR results, the soil stabilized with cement and bagasse ash performed better than soil stabilized with lime and bagasse ash.

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Unconfined Compressive Strength of Stabilized Soil

The unconfined compressive strength obtained from the stabilization of subgrade soil with admixture of cement and bagasse ash as well as lime and bagasse are as shown below**.** The unconfined compressive strength (UCS) analysis was only studied for 7 days curing.

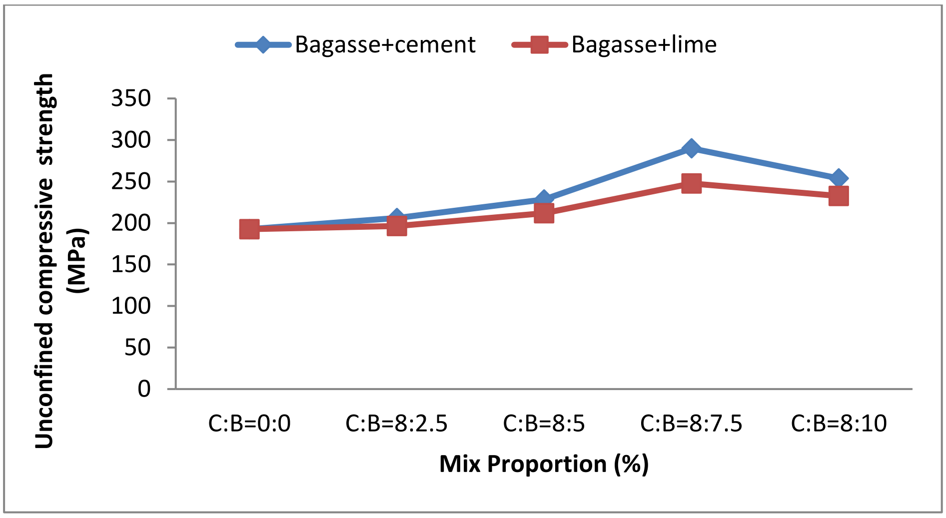

Figure 8: Plot of unconfined compressive strength versus soil composites

Figure 8 showed the profiles of unconfined compressive strength (UCS) of cement and lime stabilized soil at 2.5 to 10% weight percent of bagasse ash. The UCS value for soil stabilized with no admixture was 193.81, but increased to a maximum value of 249.10MPa for soil stabilized with bagasse + lime and 291.59MPa for soil stabilized with bagasse + cement at 7.5% bagasse ash. However, at 10% bagasse ash, the UCS for the stabilized soil was 233.98MPa for soil stabilized with bagasse + lime and 255.28MPa for soil stabilized with bagasse + cement. Comparatively, the UCS of bagasse + cement stabilized soil is higher than the soil stabilized with bagasse + lime. This indicates that the expansive soil gained more strength with the cement-bagasse composite compared to lime-bagasse composite. The increase in UCS agreed with previously reported studies (Okonkwo et al., 2016; Akobo et al., 2018; Charles et al., 2018; Ngekpe et al., 2018; Nwikina et al., 2018). Increase in UCS of stabilized soil was attributed to the transition of smaller size particles into large size particles that leads to more compact structure and densification (Kumar et al., 2016; Bhardwaj & Sharma, 2020).

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CONCLUSION

This study sought to compare the effectiveness of cement and lime as binders for stabilizing expansive black cotton soil, with the inclusion of bagasse ash obtained from Custus arabicus L. as a supplementary cementitious material. Through a series of laboratory experiments, the engineering properties of the treated soil specimens were evaluated to understand the influence of varying the bagasse ash content between 2.5-10% at a fixed 8% dosage of cement or lime. The results indicate that both the cement-bagasse ash and lime-bagasse ash composite mixtures were able to successfully modify the problematic behavior of the expansive soil. Key indicators of swelling such as liquid limit, plastic limit and plasticity index witnessed a reduction with rising ash proportions. There was also a notable improvement in strength-related parameters like maximum dry density, optimum moisture content, CBR and UCS values upon treatment. Of the combinations tested, soil stabilized with 8% cement and 7.5% bagasse ash achieved the most desirable geotechnical properties.

Based on the findings, it can be concluded that bagasse ash from Custus arabicus L. performs effectively as a supplementary cementitious material for soil modification applications. Both cement and lime-based blends incorporating the agro-waste ash were found suitable for improving expansive subgrade conditions. However, the cement composite formulations consistently outperformed the lime variants, confirming cement's stronger cementation ability. Overall, the study establishes the viability of utilizing locally available agricultural residues alongside conventional stabilizers for ground engineering works.

RECOMMENDATION AND BENEFITS

The findings of this study provide valuable recommendations for the stabilization and improvement of expansive subgrade soils. Based on the results, a mix design of 8% cement and 7.5% bagasse ash is proposed as the optimal combination for treating expansive black cotton soils. The use of this composite mixture would offer engineering and economic benefits for construction projects located in areas with such problematic soils.

From an engineering perspective, the proposed blend is effective at mitigating the shrink-swell behavior of expansive soils which can damage infrastructure. It enhances the load bearing capacity as indicated by the significant increases in CBR and UCS values. This has implications for more robust road and building foundation designs using less material.

The utilization of bagasse ash, an agricultural waste product, additionally provides environmental benefits. It offers a means to dispose of this residue while extracting economic value. The study also demonstrates the feasibility of partially replacing expensive cement with a locally available pozzolan. This can reduce construction material costs, especially for large-scale civil works in developing regions.

Overall, the outcomes support the potential application of the studied soil stabilization technique in ground modification activities. Further field validation and large-scale testing is recommended to fully optimize mix designs and verify performance benefits.

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