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Research Article

Engineering Properties of Fine-Grained Soil Stabilized with Plantain Peels Ash

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Abstract

The research investigated the influence of green ash on the engineering properties of fine-particle soils, with a focus on their suitability in construction and electronic industries. The soil underwent treatment with plantain peel ash (PPA) at varying concentrations of 2, 4, 6, 8, and 10% by mass of the dried soil, and was followed by a curing period of 21 days. Thereafter, the California Bearing Ratio (CBR), free swell index (FSI), dielectric constant (ε'), dielectric loss (ε''), and relaxation time (τ) values were measured following ASTM-approved guidelines. The results revealed that the PPA had substantial influence on the soil CBR and FSI parameters. The soil CBR increased from 4.39 to 16.62%, while the FSI declined from 15.27 to 8.77%, as the PPA quantity increased linearly from 0 to 10%. Regarding the soil dielectric parameters, the results depicted that the ε', ε'' and τ increased unevenly from 4.27 to 7.11, 1.01 to 1.85, and 4.18 to 4.6, respectively, when the concentration of the PPA was increased evenly from 0 to 10%. The improvements noted due to the PPA presence in the soil, impacting both its geotechnical characteristics and specific dielectric properties, indicate the potential for utilizing PPA in the production of eco-friendly electronic components.

Keywords	*Engineering Properties; Agricultural Residues; California Bearing Ratio; Capacitors; Computer Components; Dielectric Constant*
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Introduction

Soil is rich in materials and minerals used in the semiconductor industry, which produces integrated circuits, transistors, and other important electronic components. These components are vital for the development of computer systems and other essential electronic devices (Espadinha-Cruz *et al*., 2021; Pennisi *et al*., 2022). Soil plays an essential role in the infrastructural and socioeconomic development, contributing significantly to overall national progress. Soil possesses a multitude of engineering properties that dictate its suitability for diverse engineering applications (Ebuzoeme, 2015). Poor knowledge of the soil properties stands as one of the primary causes of structural failures (Igwe and Umbugadu, 2020). Soils are produced mainly through rocks weathering, and partially through decomposition of organic materials. The properties of soils are indeed influenced by the characteristics of the parent materials from which they are derived. Apart from soil formation, organic matter contributes immensely to soil fertility, and also influences various electrical and mechanical properties of soil (Gurmu, 2019; Aloni and Alexander, 2020; Sheng *et al*., 2023).

Soil geotechnical and electrical properties are among the most essential soil engineering properties. These properties are fundamental for several applications, including infrastructural development and crop production. Electrical properties of soil hold relevance in both electrical and civil engineering roles, given their substantial influence on the design and functionality of constructed or installed structures (Gustavo Fano, 2020). Soil particles sizes determined its water retention and permeability rate, which directly affects physical, geotechnical and electrical properties. Soil moisture facilitates electrical charges movement within the soil mass, thereby influencing its electrical conductivity and dielectric behaviors potential (Brevik *et al*., 2006; Peranić et al., 2022; Rasheed *et al*., 2022). Geotechnical characteristics of soil are basic factors considered during structures design and implementation. These parameters are structures specific, as California Bearing Ratio (CBR) is mainly considered in road pavement design while shear strength us widely considered during foundation design (Ashioba and Udom, 2023).

Naturally, some soils lack necessary properties to allow their sustainability for a specific application, which is a major challenge in the telecommunication, agriculture and construction industries. These challenges can be overcome through appropriate stabilization (treatment) of the soil. Soil stabilization is an effective technique of enhancing the soil properties; hence, overcoming the problems posed by the initial poor soil properties (Md Zahri and Zainorabidin, 2019; Verma *et al*., 2021). The stabilizing technique and agent adopted must yield positive outcome for the intended task, and should be environmentally friendly. Due to environmental sustainability, green stabilizing materials are usually chosen over inorganic materials; while physical stabilization method is widely used because of greenhouse gasses challenges (Maraveas, 2019; Bekkouche *et al*., 2022).

Despite the advancements in researches related to the soils geotechnical and electrical properties management (Buazar, 2019; Zada *et al*., 2022; Boaventur et al., 2023; Gidebo et al., 2023; Mezie *et al*., 2023), there is information gap on the effect of plantain peel ash (PPA) some prominent mechanical and dielectric parameters of the soil. Therefore, it is paramount to evaluate the impact of PPA on the dielectric and geotechnical properties of fine-grained soils. This study will bridge the existing information gap in soil stabilization. Information obtained from this study will promote sustainable practices in the telecommunications, agriculture and road construction sectors.

Materials and Methods

Materials

Soil Collection

The fine grained soil sample was collected from a flood basin in Ozoro community of Delta State, Nigeria. The wet sample was air-dried the laboratory for two weeks at a mean temperature of 28^{o}C.

Plantain Peel Ash (PPA)

The plantain peels obtained from local restaurants were sun-dried, before they were burnt in the open air (Figure 1). The ash underwent sieving using a 150 µm mesh sieve to achieve a uniform particulate size of plantain peels ash (PPA)

Figure 1: PPA sample

Methods

Preparation of the stabilized soil samples

The fine grained soil was stabilized with PPA according to the treatment plans presented in Table 1, and cured for 21 days in room temperature (29±4°C).

Table 1: Stabilization plan of the soil samples

Code	PPA (% mass of the soil)
Control	0
SAM 1	2
SAM 2	4
SAM 3	6
SAM 4	8
SAM 5	10

Laboratory Analyses

Geotechnical Properties

Particle Size Distribution

The particle size grading of uncontaminated laterite was done in agreement with ASTM D6913-04 (2017) approved procedure.

California Bearing Ratio (CBR)

The CBR values of the soil samples were determined in accordance with ASTM D1883 (2021) guidelines for laboratory compacted soils.

Free Swell Index

The free swell index of the soil was measured in accordance with IS 2720 (Part-40) approved procedure.

Electrical Properties

Dielectric Constant (ε′) and Dielectric Loss (ε′′)

The soil ε′ and ε′′ were determined in harmony with ASTM D150 (2018) procedures, by using the microwave frequency of 9.0 GHz at a temperature of 28±2°C. At the end of each test, the ε′ was computed by using Equation 1.

$$\text{Dielectric constant} = \frac{C_a}{C_v} \quad (1)$$

Where: C_a = capacitance developed by the soil, and C_v = capacitance of the free air

Relaxation Time

The soil samples relaxation time (τ) was computed through the expression shown in Equation 2 (Odoh *et al*., 2024).

$$\tau = \frac{\varepsilon''}{\omega\varepsilon'} \quad (2)$$

Where $\omega = 2\pi f$

Statistical Analysis

The influence of PPA on the soil geotechnical and electrical properties was analyzed using one-way analysis of variance (ANOVA).

Results and Discussion

Geotechnical Properties

The ANOVA results of the effect of the PPA on the geotechnical properties are presented in Table 2. As shown in Table 2, it was noted that the PPA had no significant effect on the CBR and FSI values of the soil samples irrespective of eth PPA quantity.

Table 2: The effect of the PPA on the soil geotechnical properties

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.255	1	0.2552	0.0176	0.8971	4.9645
Within Groups	145.08	10	14.5083			
Total	145.34	11				

Soil Particle Size Grading

Figure 2 shows the sieve analysis results of the untreated soil (control). It can be seen from the chart that the soil contains a lot of fine particles (about 20%). Soil grain size and their distribution pattern are important factors that typically govern the engineering behaviors of the soil. Adequate knowledge of the soil grain size distribution enhances design of and development of civil and electrical engineering applications (Marin-Lopez *et al*., 2022; Ebisine and Okieke, 2023). Soils with large percentage of fines often exhibit high dielectric properties but may have low CBR and compaction degrees. The elevated dielectric properties of fine particles soils helps to facilitates electromagnetic waves propagation, especially in telecommunications, radar systems, and geophysical surveys (Olofinyo *et al*., 2019; Gustavo Fano, 2020).

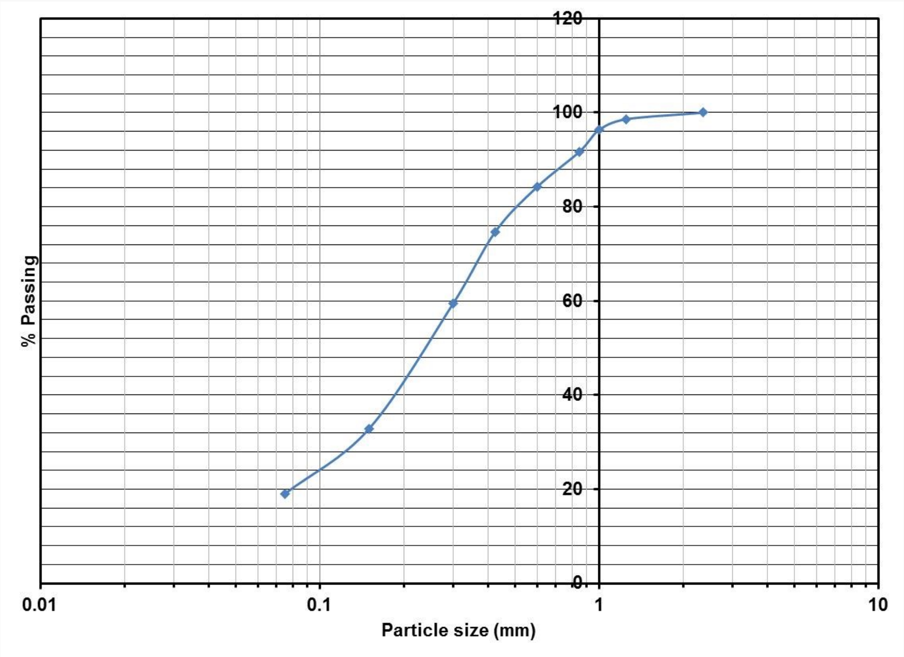

Figure 2: The sieve analysis curve

California Bearing Ratio (CBR)

The results of the soaked CBR values are presented in Figure 3. It was noted that the PPA had significant effect on the soil CBR values, as the soil CBR values increased from 4.39 to 16.62% as the PPA quantity increases from 0 to 10%. Similar results were obtained by Akinwumi *et al*. (2023) in soil samples treated with PPA and coal ash. Furthermore, Alshawmar (2024) investigated the impact of plantain ash on the soil geotechnical properties, and reported that the ash initiated more than 100% increment in the soil CBR. CBR is one of the parameter used to assess soil samples load-bearing capacity and strength characteristics. Elevated CBR value is an indication that the soil had greater strength and resistance to deformation under vertical loading.

In this study, the maximum CBR level was observed at 10% PPA volume, which exceeded the findings reported by Ishola *et al*. (2019), wherein the maximum CBR value was observed at 6% PPA stabilization. The differences noted in the different research results could be attributed to the different plantain variety being studied, peels processing and storage methods. Crops varieties and field practices typically affect their chemical oxides compositions and physical properties, which may significantly, altered their studies results (Rajeev *et al*., 2022). CBR value plays a crucial role in designing the thickness of pavement subgrade and sub-base layers, and ultimately influences the integrity of the road. According to the recommendation from the Federal Ministry of Works and Housing (FMWH), the soils treated with PPA are suitable for use as subgrade material, and not sub-base material. Soil suitable for subgrade construction should possess a minimum soaked CBR value of 5%, while sub-base soil should have a minimum soaked CBR value of 25% (FMWH, 1997).

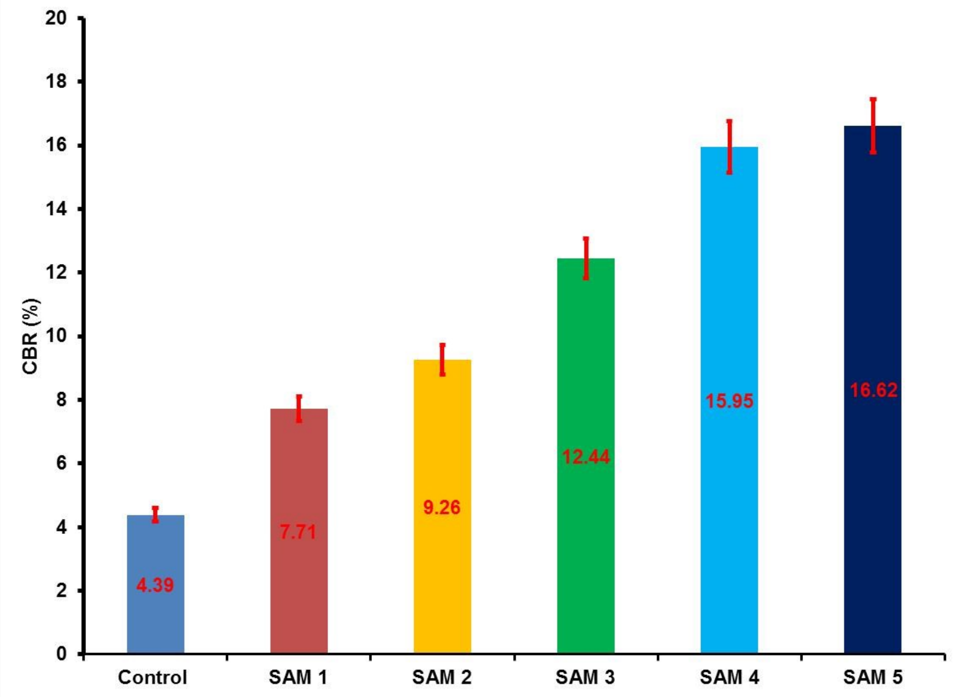

Figure 3: The soaked CBR values

Free Swell Index (FSI)

Figure 4 shows the mean results obtained for the free swell index of the soil specimens. Remarkably, the soil treated with 0, 2, 4, 6, 8 and 10% PPA developed FSI values of 15.27, 12.91, 11.53, 10.16, 9.48 and 8.77%, respectively, after the 21 days curing period. This is a strong indication that the PPA had substantial impact on the expansibility rate if the soil. Furthermore, the regression analysis depicted in Equation 3 confirms the existence of a strong positive correlation ($R^2 > 0.95$) between the soil FSI and the quantity of PPA in the soil. Interestingly, the highest depreciation in the swell rate (8.77%) was witnessed in the soil treated with 10% PPA after 21 days. Similar observations were made by Alshawmar (2024), when plant-based ash was used to control the swelling rate of expansive soil.

According to Alshawmar (2024), organic matters help to improve soil microstructural pattern leading to reduction permeability degree; hence, lowering the swelling ability of the stabilized soil. Soils with high FSI pose significant threat to both agricultural and civil engineering projects; therefore, reduction in the swelling rate of active soils should be of paramount interest to civil engineers. This is to ensure the long-term stability and durability of the infrastructures (Emarah and Seleem, 2018; Kowalska *et al*., 2023).

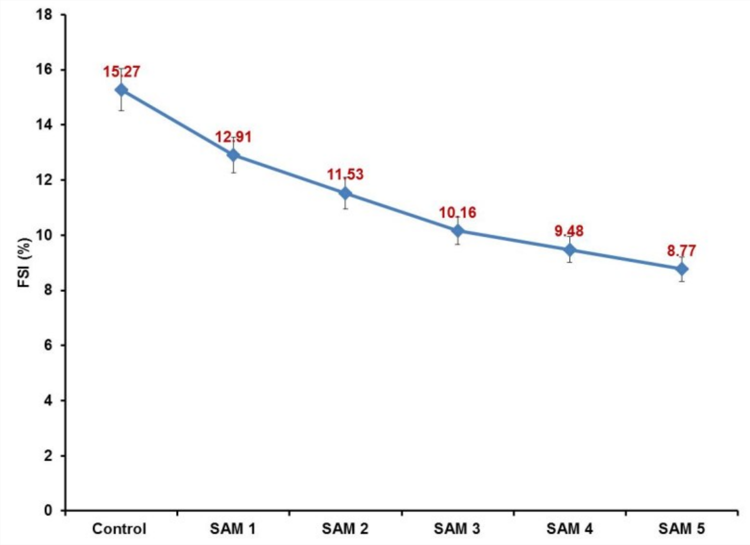

Figure 4: The FSI of the soil specimen

$y = -1.2617x + 15.769$ $R^2 = 0.9475$ 3

Dielectric Properties

The ANOVA findings regarding the impact of PPA on the soil dielectric characteristics are outlined in Table 3. According to the results presented, it was observed the PPA exhibited significant influence on the ε′, ε′′ and relaxation time of the soil samples.

Table 3: The influence of PPA on soil dielectric properties

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	62.582	2	31.2912	77.126	1.28E-08	3.682
Within Groups	6.085	15	0.4058			
Total	68.668	17				

Dielectric Constant

Figure 5 presents the dielectric constant results of the various amended soil samples. The results depicted that the PPA significantly influenced the ε′ values of the soil samples; as the ε′ values appreciated from 4.27 to 7.11 with 10% increment in the PPA content. It was observed that the Control, SAM 1, SAM 2, SAM 3, SAM 4 and SAM 5 soils developed ε′ of 4.27, 5.38, 5.91, 6.46, 6.83 and 7.11, respectively. This increment could be attributed to the hygroscopic and humus nature of PPA, that will facilitates moisture absorption and retention; thereby, leading to increment in the soil dielectric properties. Moreover, the regression analysis presented in Equation 4 validates a robust positive correlation ($R^2 > 0.90$) between the soil's ε′ values and the concentration of PPA within the soil. Chaudhari (2015) made similar findings of a situation where plant-based materials enhance the ε′ of soil samples.

Similarly, Muhammad *et al*. (2022) and Szypłowska *et al*. (2021) stated that integrating humus into soil facilitates its water absorption rate; hence, increasing its dielectric constant and loss potential. According to Zhang *et al*. (2021), dielectric constant reflects the moisture level and organic fertility of soil, therefore it values can be used to predict the suitability of a particular soil for agricultural purposes. Additionally, the increment facilitated by the organic ash presents a promising opportunity for utilizing PPA in the production of high-capacitance environmentally friendly capacitors, which hold potential for applications in the electrical and electronic industry.

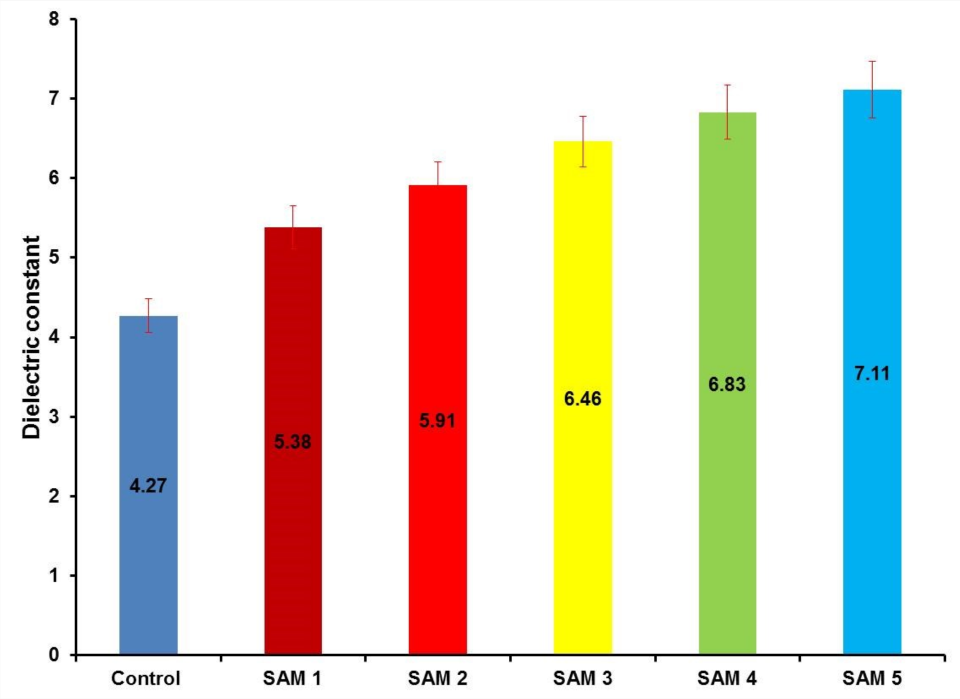

Figure 5: Dielectric constant of the samples

y = 0.5457x + 4.0833 R^2 = 0.9445
4

Dielectric Loss

Figure 6 displays the ε'' findings for the different soil specimen after stabilization. The findings illustrate a notable impact of PPA on the soil ε'' content, as the ε'' values increased from 1.01 to 1.85 with a 10% rise in PPA quantity. It was noted that the Control, SAM 1, SAM 2, SAM 3, SAM 4, and SAM 5 specimens exhibited ε'' values of 1.01, 1.32, 1.41, 1.59, 1.71 and 1.85, respectively. This is an indication that the PPA initiated a non-linear increment the soil ε'' as its (PPA) content in the sample increases, which is in confirmation of Navar khele *et al*. (2009) earlier reports that organic manure has the ability of increasing the ε'' of the soil. Furthermore, the linear regression given in Equation 5 affirmed a prefect linkage ($R^2 > 0.95$) between the soil ε'' value and the PPA volume.

These experimental outcomes are similar to the research findings of Chaudhari (2015) and Szypłowska *et al*. (2021) which stated that plant-based manure and moisture have the capacity of enhancing the ε'' value in the soil under normal conditions. Dielectric loss has direct impact capacitors performance, materials with lower ε'' display superior temperature stability and enable better transmission of signals. This characteristic contributes to the overall performance enhancement of electronic units and systems (You et al., 2023).

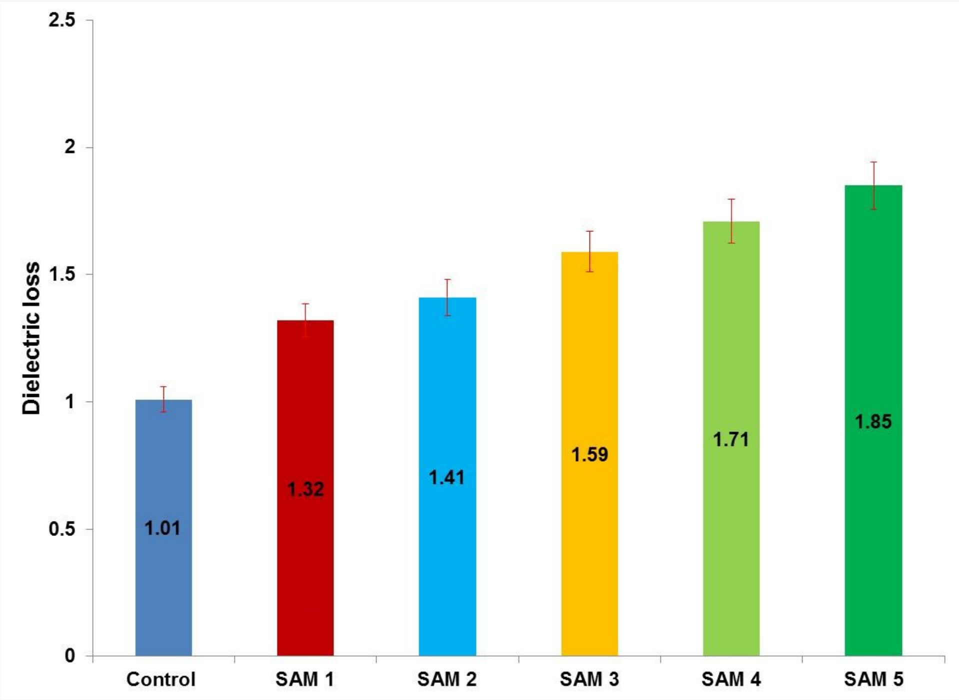

Figure 6: The dielectric loss

$y = 0.1586x + 0.9267$ $\qquad R^2 = 0.9708$ 5

Relaxation Time (τ)

The results of the soil samples relaxation time are presented in Figure 7. It was observed that the Control, SAMs 1 to 5 samples developed τ values of 4.18, 4.34, 4.22, 4.35, 4.43 and 4.6, respectively. This is an indication that the PPA initiated a non-linear increment in the soil τ values, as the PPA volume in the soil increased linearly from 0 to 10%. The first order linear regression represented with Equation 6 revealed that the PPA had a good positive relationship time (R^2 =0.7782) with the soil relaxation time. Relaxation time is the duration required for the dipoles within a soil to revert to their equilibrium state following disturbance by an external electric field, which is dependent on availability of water and organic materials (Syeda *et al*., 2020). Liu *et al*. (2013) reported that water and humus has the ability of increasing the dielectric properties of soil, and developed models that can predict the soils dielectric parameters based on their moisture and organic matter levels. The observed increases in soil dielectric properties following stabilization have significant positive implications across several engineering domains.

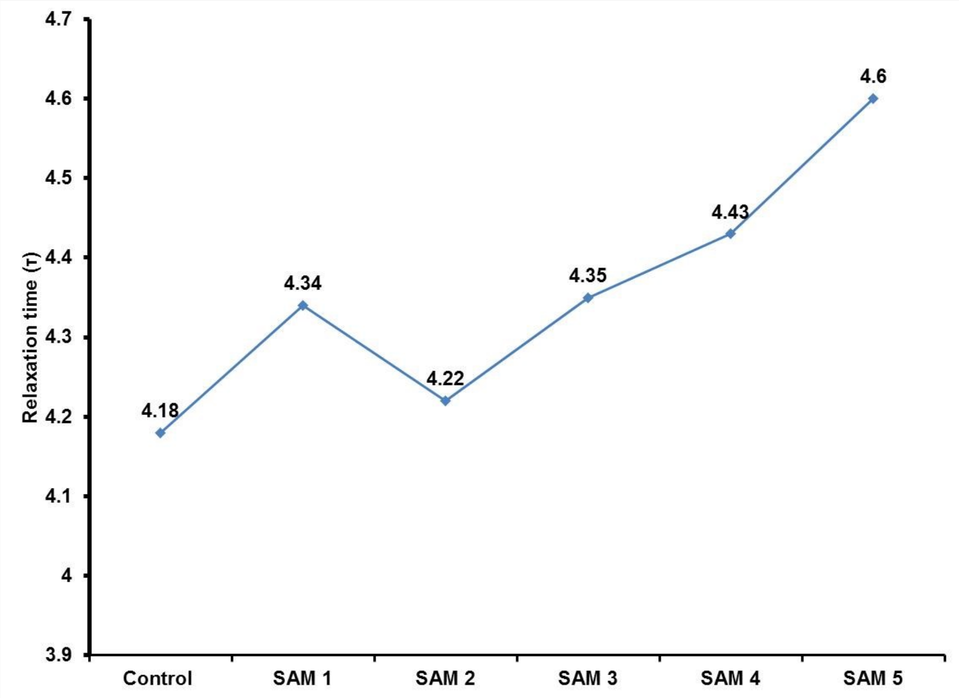

Figure 7: The Relaxation Time

y = 0.0714x + 4.1033 $R^2 = 0.7782$

6

Conclusion

The study was conducted to evaluate the possibility of enhancing the geotechnical and dielectric properties of natural soil through organic ash amendment. Fine-grained soil was stabilized with plantain peels ash (PPA), and their California Bearing Ratio (CBR), free swell index (FSI), dielectric constant (ε'), dielectric loss (ε'') and relation time (τ) were measured in accordance with ASTM approved guidelines. The results revealed that the PPA has a positive and significant impact on several soil properties, including the CBR, FSI, ε' and relaxation time. However, it's noted that the addition of PPA did not provide an advantage in terms of dielectric loss. The observed enhancements resulting from the inclusion of PPA in the soil, both in terms of its geotechnical behavior and certain dielectric properties, suggest the prospect of employing PPA in the manufacturing of environmentally friendly electronic components.

References

Alshawmar, F. (2024). Utilization of Nano Silica and Plantain Leaf Ash for Improving Strength Properties of Expansive Soil. *Sustainability, 16*, 2157. https://doi.org/10.3390/su16052157

Aloni, C., & Alexander, C. B. (2020). Environmental impact of weathering and soil formation in geomorphological research. *World Journal of Advanced Research and Reviews, 8*(3), 047–051. https://doi.org/10.30574/wjarr.2020.8.3.0399

Akinwumi, I., Onyeiwu, M., Epelle, P., & Ajayi, V. (2023). Soil Improvement Using Blends of Coal Ash and Plantain Peel Ash as Road Pavement Layer Materials. *Resources, 12*, 41. https://doi.org/10.3390/resources12030041

Ashioba, C., & Udom, G. J. (2023). Geotechnical Properties of Soil for Design and Construction of Foundation from Elebele Town, Bayelsa State, Nigeria. *J. Appl. Sci. Environ. Manage., 27*(6), 1177–1183.

ASTM D6913-04. (2017). *Standard Test Methods for Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis*. Available online at: https://www.astm.org/d6913-04r09e01.html

ASTM D150. (2018). *Standard Test Methods for AC Loss Characteristics and Permittivity (Dielectric Constant) of Solid Electrical Insulation*. Available online at: https://www.astm.org/d0150-18.html

ASTM D1883. (2021). *Standard Test Method for California Bearing Ratio (CBR) of Laboratory-Compacted Soils*. Available online at: https://www.astm.org/d1883-21.html

Boaventura, N. F., Sousa, T. F. P., & Casagrande, M. D. T. (2023). The Application of an Eco-Friendly Synthetic Polymer as a Sandy Soil Stabilizer. *Polymers, 15*(24), 4626. https://doi.org/10.3390/polym15244626

Chaudhari, H. C. (2015). Dielectric properties of soils with organic and inorganic matter at J-band microwave frequency. *International Journal of Remote Sensing & Geoscience, 4*(2), 15–19.

Ebisine, E. E., & Okieke, U. J. (2023). Soil Electrical and Geotechnical Property Measurements: A Case Study of Oleh, Delta State, Nigeria. *Engineering Research Journal, 3*(5), 27–36.

Ebuzoeme, O. D. (2015). Evaluating the significance of poor road design as a factor of road failure: A study of Onitsha–Enugu Expressway, Southeastern Nigeria. *Civ Environ Res, 7*(2), 180–195.

Bekkouche, S. R., Benzerara, M., Zada, U., Muhammad, G., & Ali, Z. (2022). Use of Eco-Friendly Materials in the Stabilization of Expansive Soils. *Buildings, 12*(10), 1770. https://doi.org/10.3390/buildings12101770

Brevik, E. C., Fenton, T. E., & Lazari, A. (2006). Soil electrical conductivity as a function of soil water content and implications for soil mapping. *Precision Agriculture, 7*(6), 393–404. https://doi.org/10.1007/s11119-006-9021-x

Espadinha-Cruz, P., Godina, R., & Rodrigues, E. M. G. (2021). A Review of Data Mining Applications in Semiconductor Manufacturing. *Processes, 9*(2), 305. https://doi.org/10.3390/pr9020305

Buazar, F. (2019). Impact of Biocompatible Nanosilica on Green Stabilization of Subgrade Soil. *Scientific Reports, 9*(1), 15147. https://doi.org/10.1038/s41598-019-51663-2

Emarah, D. A., & Seleem, S. A. (2018). Swelling soils treatment using lime and sea water for roads construction. *Alexandria Engineering Journal, 57*(4), 2357–2365.

Gidebo, F. A., Yasuhara, H., & Kinoshita, N. (2023). Stabilization of expansive soil with agricultural waste additives: A review. *International Journal of Geo-Engineering, 14*(1). https://doi.org/10.1186/s40703-023-00194-x

Gurmu, G. (2019). Soil Organic Matter and its Role in Soil Health and Crop Productivity Improvement. *Academic Research Journal of Agricultural Science and Research, 7*(7), 475–483.

Gustavo Fano, W. (2020). The Electrical Properties of Soils with Their Applications to Agriculture, Geophysics, and Engineering. *Electromagnetic Field Radiation in Matter*. https://doi.org/10.5772/intechopen.88989

Igwe, O., & Umbugadu, A. A. (2020). Characterization of structural failures founded on soils in Panyam and some parts of Mangu, Central Nigeria. *Geoenvironmental Disasters, 7*(1). https://doi.org/10.1186/s40677-020-0141-9

IS 2720 (Part-40): 1977 (Reaffirmed 2021). *Method of test for soils: Determination of Free swell Index of soils*.

Ishola, K., Olawuyi, O. A., Bello, A. A., & Yohanna, P. (2019). Effect of plantain peel ash on the strength properties of tropical red soil. *Nigerian Research Journal of Engineering and Environmental Sciences, 4*(1), 447–459.

Kowalska, M., Grzesik, B., Adamczyk, Z., Nowak, J., & Konsek, A. (2023). Swelling of sulfate-bearing soil: A case study of A1 highway pavement failure. *Case Studies in Construction Materials, 18*, e02081.

Liu, J., Zhao, S., Jiang, L., Chai, L., & Wu, F. (2013). The influence of organic matter on soil dielectric constant at microwave frequencies (0.5–40 GHz). In *2013 IEEE International Geoscience and Remote Sensing Symposium - IGARSS*. https://doi.org/10.1109/igarss.2013.6721080

Maraveas, C. (2019). Environmental Sustainability of Greenhouse Covering Materials. *Sustainability, 11*(21), 6129. https://doi.org/10.3390/su11216129

Marin-Lopez, C., Lopez-Lara, T., Hernandez-Zaragoza, J. B., Horta-Rangel, J., Rojas-Gonzalez, E., Perez-Rea, M. L., Salgado-Delgado, R., Salgado-Delgado, A. M., & Castano, V. M. (2022). The Effect of the Grain-Size Distribution on Expansion and Collapse Behavior of Expansive Soils and Their Implications. *International Journal of Geosynthetics and Ground Engineering, 8*(1). https://doi.org/10.1007/s40891-022-00356-4

Mezie, E. O., Nwaiwu, C. M. O., & Nwakaire, C. M. (2023). Effects of Partial Replacement of Cement and Lime with some Agrowaste Ashes on the Geotechnical Behaviour of Lateritic Soil. *Saudi J Civ Eng, 7*(4), 115–126.

Md Zahri, A., & Zainorabidin, A. (2019). An overview of traditional and non-traditional stabilizer for soft soil. *IOP Conference Series: Materials Science and Engineering, 527*(1), 012015. https://doi.org/10.1088/1757-899x/527/1/012015

Muhammad, A., Zangina, T., Suleiman, A. B., Mohammed, J., & Hafeez, H. Y. (2022). Determination of dielectric properties of cultivated and uncultivated land at Kafin Hausa LGA, Jigawa State, Nigeria. *Dutse Journal of Pure and Applied Sciences, 8*(2b), 98–104.

Odoh, F. E., Igbologe, O., Idama, O., & Uguru, H. (2024). Assessment of the dielectric properties of soil around Delta State University Of Science And Technology, Ozoro, Nigeria. *Irish International Journal of Engineering and Scientific Studies, 7*(2), 1–9.

Olofinyo, O. O., Olabode, O. F., & Fatoyinbo, I. O. (2019). Engineering properties of residual soils in part of Southwestern Nigeria: Implication for road foundation. *SN Applied Sciences, 1*(5). https://doi.org/10.1007/s42452-019-0515-3

Pennisi, S. (2022). The Integrated Circuit Industry at a Crossroads: Threats and Opportunities. *Chips, 1*(3), 150–171. https://doi.org/10.3390/chips1030010

Peranić, J., Čeh, N., & Arbanas, Ž. (2022). The Use of Soil Moisture and Pore-Water Pressure Sensors for the Interpretation of Landslide Behavior in Small-Scale Physical Models. *Sensors, 22*(19), 7337. https://doi.org/10.3390/s22197337

Rajeev, R. T., Shukadev, M., Adinath, E. K., Rokayya, S., Al-Mushhin, A. A. M., Mahmoud, F. M., Uguru, H., & Mahmoud, H. (2022). Effect of harvesting stages and storage temperature on quality attributes and post-harvest shelf-life of mango (*Mangifera indica*). *Journal of Biobased Materials and Bioenergy, 16*, 770–782.

Rasheed, M. W., Tang, J., Sarwar, A., Shah, S., Saddique, N., Khan, M. U., Imran Khan, M., Nawaz, S., Shamshiri, R. R., Aziz, M., & Sultan, M. (2022). Soil Moisture Measuring Techniques and Factors Affecting the Moisture Dynamics: A Comprehensive Review. *Sustainability, 14*(18), 11538. https://doi.org/10.3390/su141811538

Verma, H., Ray, A., Rai, R., Gupta, T., & Mehta, N. (2021). Ground improvement using chemical methods: A review. *Heliyon, 7*(7), e07678. https://doi.org/10.1016/j.heliyon.2021.e07678

Sheng, R., Xu, H., Xing, X., Zhang, W., Hou, H., Qin, H., Liu, Y., Zhang, L., Fang, Y., Shen, J., Pernthaler, J., Wei, W., & Zhu, B. (2023). The role of inherited characteristics from parent materials in shaping bacterial communities in agricultural soils. *Geoderma, 433*, 116455. https://doi.org/10.1016/j.geoderma.2023.116455

Syeda, R. N., Basheer, M. A., Khan, A. R., & Shaikh, Y. H. (2020). Study of effect of potassium nitrate and ammonium sulphate on dielectric properties of soil at X and J-Band microwave frequencies. *Journal of Physics: Conference Series, 1644*, 012041.

Szypłowska, A., Lewandowski, A., Yagihara, S., Saito, H., Furuhata, K., Szerement, J., Kafarski, M., Wilczek, A., Majcher, J., Woszczyk, A., & Skierucha, W. (2021). Dielectric models for moisture determination of soils with variable organic matter content. *Geoderma, 401*, 115288. https://doi.org/10.1016/j.geoderma.2021.115288

You, L., Liu, B., Hua, H., Jiang, H., Yin, C., & Wen, F. (2023). Energy Storage Performance of Polymer-Based Dielectric Composites with Two-Dimensional Fillers. *Nanomaterials (Basel, Switzerland), 13*(21), 2842. https://doi.org/10.3390/nano13212842

Zada, U., Haleem, K., Saqlain, M., Abbas, A., & Khan, A. U. (2022). Reutilization of Eggshell Powder for Improvement of Expansive Clayey Soil. *Iran. J. Sci. Technol. Trans. Civ. Eng. 2022*, 1–8.

Zhang, Y. W., Wang, K. B., Wang, J., Liu, C., & Shangguan, Z. P. (2021). Changes in soil water holding capacity and water availability following vegetation restoration on the Chinese Loess Plateau. *Scientific Reports, 11*(1), 9692–9702.