EFFECT OF BERMUDA GRASS ROOTS ON THE SHEAR STRENGTH OF SOIL

Joenel Galupino
Faculty, Department of Civil Engineering, De La Salle University

Ram Voltaire Gonzaga
Department of Civil Engineering, De La Salle University

Geofferson Montemayor
Department of Civil Engineering, De La Salle University

Erica Elice Uy
Faculty, Department of Civil Engineering, De La Salle University

出版情報：Proceedings of International Exchange and Innovation Conference on Engineering & Sciences (IEICES). 11, pp.25-31, 2025-10-30. International Exchange and Innovation Conference on Engineering & Sciences
バージョン：

EFFECT OF BERMUDA GRASS ROOTS ON THE SHEAR STRENGTH OF SOIL

Joenel Galupino[1], Ram Voltaire Gonzaga[2], Geofferson Montemayor[2], and Erica Elice Uy[1]
[1] Faculty, Department of Civil Engineering, De La Salle University, Manila
[2] Student, Department of Civil Engineering, De La Salle University, Manila
Corresponding Author E-mail: joenel.galupino@dlsu.edu.ph

Abstract: *Through laboratory-based testing, this study investigates the effect of Bermuda grass (Cynodon dactylon) roots on the shear strength of silty sand soil. Unreinforced soil and soil reinforced with vertically and horizontally oriented roots were subjected to direct shear tests under normal stresses of 22.5, 45, and 90 kPa. The results indicated that the internal friction angle was significantly enhanced by roots that were vertically aligned, while horizontally aligned roots contributed to increased cohesion. The tensile strength of the roots was also examined, and it was found that the tensile capacity of the roots in the lower sections was higher due to their smaller diameter. The substantial reinforcement potential of Bermuda grass was underscored by the experimental shear strength values, which surpassed theoretical predictions. Specifically, these results endorse the utilization of locally accessible vegetation as a sustainable and cost-effective soil stabilization method, particularly for the purpose of erosion control and slope protection. The study emphasizes the significance of root orientation in shaping soil behavior and suggests that additional research be conducted in field conditions and with a variety of soil types.*

Keywords: Bermuda grass; shear strength; root reinforcement; soil stabilization; direct shear test;

1. INTRODUCTION

The Philippines' topographical complexity and climatic conditions continue to make soil erosion one of the most urgent environmental concerns [1]. The continuous removal of topsoil by water or wind is a significant issue in both rural agriculture and infrastructure development, as it undermines soil fertility and land stability [2]. Various strategies have been implemented to reinforce soil strength and mitigate erosion in response to these challenges [3-17]. Vegetation-based methods have gained popularity because of their cost-efficiency, environmental friendliness, and sustainability [18]. This investigation investigates one such method that involves the use of Bermuda grass (*Cynodon dactylon*) to improve the shear strength of soil.

In the global literature, the role of vegetation, particularly grasses, in soil stabilization is extensively documented [19]. Root systems have the ability to physically bind soil particles and enhance the overall structure of the soil, thereby providing resistance to displacement and degradation [20]. The fibrous roots of grasses penetrate the upper soil layers, thereby enhancing internal friction and cohesion. By interlocking soil masses, these biological reinforcements perform a similar function to mechanical soil nails [21]. *Cynodon dactylon*, which is more commonly referred to as Bermuda grass, is distinguished by its dense root network, rapid growth, and adaptability. Bermuda grass is a viable alternative that offers comparable mechanical benefits, despite the fact that vetiver grass has been extensively studied and implemented in slope protection and erosion control. Its fibrous root system, which is heart-shaped, exhibits exceptional adaptability to sandy and erosion-prone soils [22]. Furthermore, it is well-suited to the Philippine landscape due to its ability to endure severe conditions, including drought, salinity, and periodic flooding. Bermuda grass's geotechnical potential, particularly in terms of enhancing shear strength, remains largely unexplored, despite its extensive use in landscaping and ground cover.

The inclusion of Bermuda grass roots in soil matrices has the potential to significantly enhance shear resistance, according to preliminary findings from previous studies [22]. The internal friction angle is increased by the presence of roots, and the soil's cohesion is occasionally marginally increased. This interaction leads to a composite system in which the soil and root collaborate to withstand deformation under applied loads. In comparison to control samples, direct shear tests conducted on root-infused samples consistently produce higher peak shear stresses [23]. In hilly or disturbed terrains, such enhancements are essential for the prevention of shallow landslides and surface erosion. The prevalence of erosion-related disasters in the Philippine context renders this research of significant relevance. In regions such as Antipolo City, Lanao del Sur, and Cebu, instances of soil failure have been documented because of inadequate drainage management and heavy rainfall. These occurrences underscore the necessity of sustainable, scalable, and cost-effective soil stabilization solutions. A promising bioengineering strategy is the utilization of locally available plant species, such as Bermuda grass. Such vegetation has the potential to decrease the necessity for costly mechanical reinforcements by reinforcing the soil from within [21].

The primary goal of this investigation is to ascertain the impact of Bermuda grass roots on the shear strength of soil. The study specifically examines the impact of roots on the soil's angle of internal friction and cohesion, which are two critical parameters in soil shear strength. The research also aims to quantify the distinctions between soil samples that are rootless and those that contain vertically and horizontally integrated roots. Roots are naturally grown in a variety of orientations in real-world applications, which are simulated by these conditions. The comparison will be based on data obtained from controlled laboratory tests.

Bermuda grass was procured from nearby farms, while soil samples were obtained from erosion-prone regions in Antipolo City for this investigation. The index properties of the soil, including grain size distribution, specific gravity, Atterberg limits, and compaction characteristics, were predetermined prior to testing [24]. This established a foundation for comprehending the soil's classification and its response to stress. The tensile strength of root samples was measured to assess their contribution to the integrity of the root-soil composite, and they were prepared uniformly. The resulting failure envelopes were compared by conducting standard direct shear tests on samples with and without roots.

The assessment of the impact of root orientation on shear strength was a critical component of this investigation. Based on prior research, it is hypothesized that vertically aligned roots make a more substantial contribution to shear resistance than horizontally aligned ones. This is since vertical roots are more effectively positioned to intercept potential failure planes and increase interparticle friction. Although beneficial, horizontally oriented roots may not effectively counteract vertical displacements or contribute to resistance across multiple failure surfaces. The empirical insights into the differential reinforcement effects of root orientation will be provided by the testing results. It is imperative to possess a thorough comprehension of the mechanics of the root-soil interface to interpret the findings of this investigation. The interaction between roots and soil is facilitated by mechanical interlocking, adhesion, and friction, which results in a synergistic effect that improves stability [25]. The diameter and moisture conditions of roots also significantly influence their tensile strength. The tensile strength of roots with a smaller diameter is generally higher, which is more effective in resisting soil deformation. These dynamics are essential for assessing the efficacy of Bermuda grass in geotechnical applications.

This research contributes to the expanding body of literature advocating for green infrastructure, given the global emphasis on sustainable engineering practices. Vegetation-based reinforcements are ecologically harmonious, self-replicating, and biodegradable, in contrast to synthetic materials. The principles of ecological engineering are well-suited to Bermuda grass, which is both resilient and abundant in the local area. It is appropriate for community-level applications in slope protection and erosion control due to its low maintenance requirements and rapid growth. Additionally, its application may serve as an adjunct to structural measures in integrated soil management systems.

This study also emphasizes the necessity of conducting research on plant-soil interactions at the local level. Although international studies offer valuable theoretical foundations, context-specific validation is required due to the regional soil characteristics, climate, and vegetation behavior. The findings of this study will be particularly pertinent to the soil conditions of the Philippines and can be used to inform policies and practices in civil engineering and environmental science. Furthermore, the data produced may be employed for educational purposes in geotechnical engineering courses and for practical applications in local slope stabilization projects. The objective of this paper is to establish a definitive correlation between the presence of Bermuda grass roots and enhanced soil shear strength. The research promotes the widespread implementation of vegetation-based stabilization methods by validating the efficacy of this bioengineering technique. It also provides opportunities for additional research that involves hybrid vegetative systems, other native grass species, and combined structural-biological stabilization models. The objective of this work is to provide a fundamental contribution to the sustainable soil engineering practices of the nation.

2. METHODOLOGY

The objective of this investigation is to ascertain the extent to which Bermuda grass (*Cynodon dactylon*) roots affect soil shear strength. The experimental approach is characterized by the quantification of changes in shear parameters as a result of the presence of roots, which is achieved through both field sampling and laboratory testing. Site selection, soil and root collection, sample preparation, root characterization, and direct shear testing comprise the research process. In order to guarantee consistency and dependability, conventional geotechnical laboratory protocols are implemented [24]. The methodology is designed to isolate the root effect by ensuring that all other variables are uniform. The study site was chosen in Antipolo City, Philippines, where Bermuda grass is naturally abundant and soil erosion is a frequent occurrence. This location offered soil samples of the same classification, both rooted and unrooted, shown in Fig. 1. The region was selected to minimize the potential impact of environmental factors, including climate and drainage, on root development. Rooted samples were obtained from patches that had Bermuda grass coverage that was well-established and in good health. Control samples were collected in close proximity to the rooted zones to guarantee that the parent soil material remained constant.

Fig. 1. Collected soil samples from Sitio Calumpang, Antipolo City, along Marcos Highway.

Soil samples were meticulously excavated to a depth of 150 mm, which corresponds to the observed root zone depth of Bermuda grass. Index testing and compacted sample preparation were conducted using stainless steel cutting rings to extract undisturbed samples. Additionally, bulk samples were collected for compaction and classification tests. Additionally, soil particles were gently removed from grass roots without compromising the structure through gentle washing. Before testing, the materials were stored in sealed containers to prevent moisture loss.

Index testing was implemented initially to ascertain the soil's engineering and physical characteristics. These comprised particle size distribution, specific gravity, Atterberg limits, moisture content, and compaction characteristics. The ASTM and AASHTO standards were followed during the testing process. Baseline information regarding the soil type was obtained from the results, which was subsequently employed in the classification and interpretation of shear strength behavior. The Unified Soil Classification System (USCS) was implemented to conduct soil classification.

The roots of Bermuda grass were categorized and separated based on their diameter ranges: less than 0.5 mm, 0.5–1 mm, and greater than 1 mm. The below-ground biomass was characterized by measuring the root length, density, and distribution within the soil. A modified tensile test was employed to apply tension until failure in order to determine the root tensile strength. In order to prevent premature breakage, the samples were gently clamped. The mechanical contribution of roots to soil reinforcement was interpreted using the tensile strength data. Table 1 provides the number of root samples to be tested for tension.

Table 1. Quantity of Samples Per Trial

Trials	Quantity of Grass Samples
1	9
2	9
3	9
Total Amount of Roots	**27**

A series of direct shear tests were conducted on both rooted and unrooted samples to assess the shear strength of soil. The apparatus employed was a conventional direct shear device, which permits horizontal displacement under a constant normal stress. Each condition was subjected to three different magnitudes of normal stresses: 22.5 kPa, 45 kPa, and 90 kPa. These stresses were chosen based on the normal stresses associated with the height of soil embankments and the field density of the soil. The peak shear stress values were recorded, and shearing was conducted at a strain rate of 1 mm/min. The Mohr-Coulomb failure envelope was used to calculate the internal friction angle (φ) and cohesion (c). Sample preparation was essential to guarantee consistency among tests. Bermuda grass roots were reintroduced into the rooted soil in predetermined orientations: vertical, horizontal, and random. These orientations simulate the natural growth patterns and evaluate the directional influence of roots on shear strength. The root content was maintained at a consistent root-to-soil volume ratio, as determined by field measurements. The Standard Proctor method was employed to achieve uniform dry density across all samples during compaction.

The summary of direct shear strength tests conducted for this study is presented in Table 2, which is categorized based on soil conditions and root orientations. In order to assess the impact of Bermuda grass roots on the shear strength of the soil, a total of 29 shear tests were conducted. Nine trials were conducted on the control group, which represented soil that lacked any grassroots. 11 trials were conducted using soil with horizontally oriented roots and 9 trials with vertically oriented roots for the reinforced soil condition. The increased number of tests in the horizontally rooted category may indicate a heightened interest in the impact of lateral root distribution on shear resistance. The schematic diagram is shown in Figures 2 and 3.

Table 2. Quantity of Soil Samples per Trial

Variety of Direct Shear Strength Test	No. of Trials
Direct Shear Strength of Controlled Condition	
Controlled Soil Condition	9
Direct Shear Strength of Soil with Grassroots	
Soil with Horizontally Oriented Roots	11
Soil with Vertically Oriented Roots	9
Total	**29 Trials**

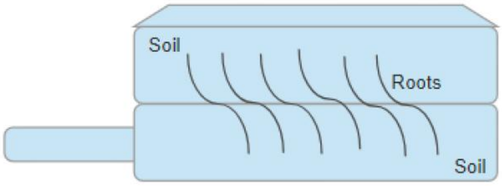

Fig. 2. Schematic Diagram of Vertical Root Direct Shear Test

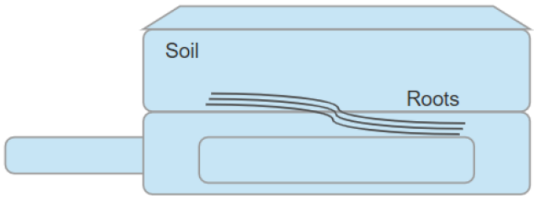

Fig. 3. Schematic Diagram of Horizontal Root Direct Shear Test

Tables and graphs were employed to display the test data, which included shear stress-displacement curves, Mohr-Coulomb envelopes, and models [26-33]. Each root orientation was analyzed independently, and comparisons were made between orientations and against control samples [34].

3. RESULTS AND DISCUSSIONS

The grain size distribution of the test soil sample, shown in Figure 4, indicated that it is primarily composed of sand and has a coarse grain size, with a fine content of 43.86%. The soil is classified as silty sand (SM) by the Unified Soil Classification System (USCS). This classification has implications for its behavior under shear stress, particularly in the absence of reinforcement. The classification was substantiated by the sieve analysis, which demonstrated a typical gradation for silty sand.

These soils are moderately robust; however, they frequently require reinforcement, such as vegetation. The Plasticity Index (PI) was 17 as a result of the Atterberg limits, which demonstrated an average Liquid Limit (LL) of 49% (shown in Fig. and a Plastic Limit (PL) of 33%.

The average value of 2.7 obtained during specific gravity testing is consistent with the anticipated range for silty sands. The analysis of root interaction with soil is also facilitated by the specific gravity data. The maximum dry density was 12.94 kN/m³, and the optimal moisture content was 25.33%, as determined by compaction testing. The regional soil conditions are likely the reason for the slight decrease in these values compared to the standard for silty sands. At 9.04% moisture, the compaction curve yielded a target density of 11.23 kN/m³, which was employed to prepare the shear test sample.

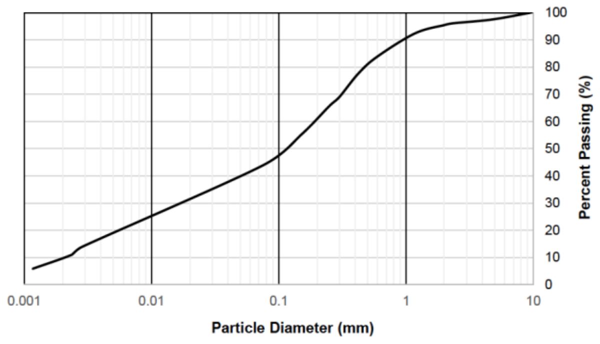

Fig. 4. Grain Size Distribution Chart of the Soil Sample

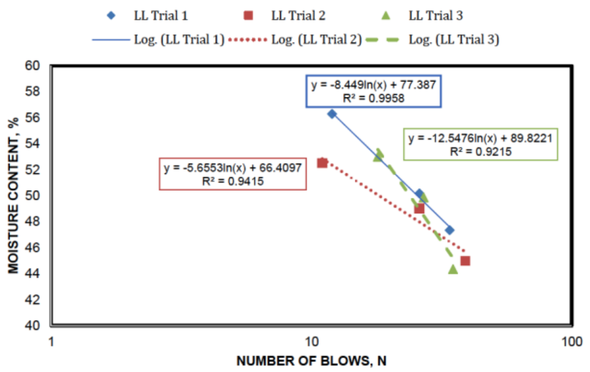

Fig. 5. Liquid Limit Flow Curve

The root tensile strength test of 27 Bermuda grass specimens revealed diameters ranging from 0.245 mm to 2.08 mm and lengths ranging from 9.6 cm to 22.3 cm. For the purpose of analysis, roots were divided into three categories: the top (25%), middle (50%), and bottom (75%). The tensile strength of the bottom section was the highest, with a value of 79.07 MPa. It is important to note that roots with a smaller diameter exhibited a higher tensile strength, as shown in Fig. 6. The inverse relationship between tensile strength and root diameter was a significant finding. The trend was most pronounced in the lower section of the roots, as evidenced by a power regression curve that displayed an R^2 of 0.88. These characteristics contribute to the resistance of soil to shear. The potential of Bermuda grass roots as natural reinforcement elements is substantiated by these findings [35].

Under normal stresses of 22.5, 45, and 90 kPa, direct shear tests in control soil samples yielded shear stress values of 28.65, 35.17, and 41.13 kPa at 15% strain. The angle of internal friction was 10.06°, and the derived cohesion was 25.67 kPa. Baseline mechanical performance of unreinforced soil is represented by these values. The results were in accordance with the anticipated outcomes for silty sand that lacked any root reinforcement.

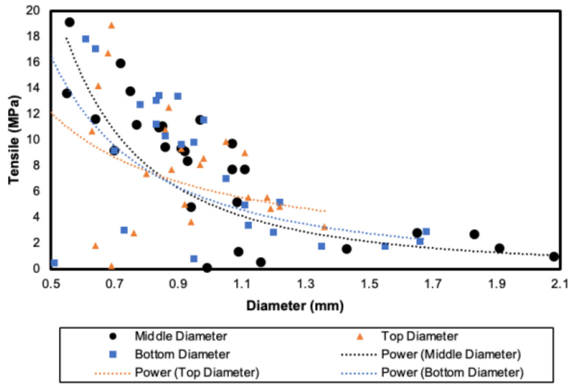

Fig. 6. Tensile strength at Top, Middle and Bottom of the roots tested.

A significant increase in shear strength was observed in soil samples that contained vertically aligned Bermuda roots. The shear stress values at 15% strain increased to 34.32, 45.95, and 72.33 kPa under the same loading conditions, shown in Fig. 7. The angle of internal friction increased significantly to 29.53°, while cohesion was calculated at 21.13 kPa. The significance of vertical root orientation is underscored by the substantial increase in friction angle. The samples that were horizontally rooted exhibited the highest cohesion at 39.29 kPa, but they had a significantly lower internal friction angle of 2.89°. The shear stress values at 15% strain were 39.43, 40.56, and 42.83 kPa, shown in Fig. 8, indicating moderate improvements. Full results are shown in Table 3. The increased root contact along the shear plane may be the cause of the elevated cohesion. Nevertheless, the low friction angle implies that there is only a minimal amount of resistance to lateral displacement. This orientation may be more effective for the control of shallow erosion than deep slope stabilization.

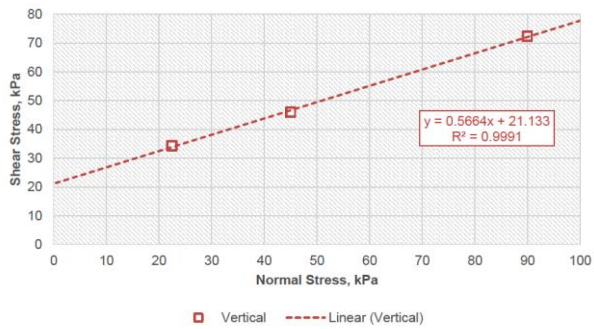

Fig. 7. The Failure Envelope of Soil with Vertically Oriented Roots

The behavior of volumetric strain varied among the samples. The control soil exhibited the typical compression behavior of loose sands, which is characterized by a reduction in volume during shear. Conversely, samples that were vertically rooted exhibited minimal volumetric change, which suggests that they exhibited improved structural cohesion. The slight expansion of horizontally rooted samples was likely the result of interference with shear box movement. This behavior may not accurately represent the interactions between roots and soil in their natural state.

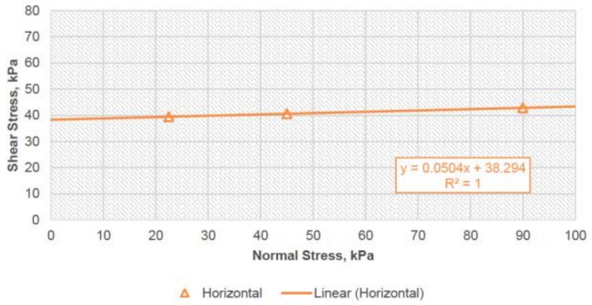

Fig. 8. The Failure Envelope of Soil with Horizontally Oriented Roots

Table 3. Comparison of Results between the Shear Stress of the Soil in Different Conditions.

Normal Loading (kPa)	Base Soil (kPa)	Soil with Vertical Roots (kPa)	Soil with Horizontal Roots (kPa)
22.5	28.65	34.32	39.43
45	35.17	45.95	40.56
90	41.13	72.33	42.83

4. CONCLUSIONS AND RECOMMENDATIONS

The shear strength of silty sand soil was examined in this study to determine the reinforcing effect of Bermuda grass (*Cynodon dactylon*) roots. The research demonstrated that the incorporation of grass roots, particularly in vertically aligned configurations, resulted in substantial enhancements in the internal friction angle. The potential of natural reinforcements in sustainable geotechnical engineering was underscored by the fact that the shear strength enhancements were achieved without the use of synthetic materials. The tested material was silty sand with moderate plasticity, which is classified as soil. Biological stabilization is a significant benefit of this material. The tensile properties of the roots and their capacity to interlock with the soil matrix are responsible for the increase in strength.

The tensile strength of Bermuda grass roots was found to vary depending on the root diameter and location within the root system. The lowest section of the root system contained the thinnest roots, which exhibited the highest values. This supports the hypothesis that soil reinforcement is more effectively facilitated by roots with a smaller diameter, as they are more flexible and dense. The shear testing phase demonstrated the root-soil interface's strength, as samples with roots exhibited altered failure envelopes and improved peak shear stress. In particular, the internal friction angle was significantly enhanced from 10.06° in control samples to 29.53° by vertically oriented roots. This significant increase validates the potential of Bermuda grass to stabilize slopes. The overall shear strength improvement was significant, despite the slight reduction in cohesion in vertical-root samples. The soil strength was also influenced by the orientation of the horizontal roots, albeit in a unique manner. The soil samples with horizontal roots exhibited the highest cohesion at 39.29 kPa, but there was only a slight increase in shear stress as the normal loads increased. The roots' orientation parallel to the direction of shear suggests that the interlocking capacity is limited, as the internal friction angle decreased to a mere 2.89°. Although the horizontal roots were successful in enhancing cohesion, they provided less resistance to lateral displacement under shear stress. This suggests that horizontal roots may be more advantageous for the prevention of surface erosion than for the enhancement of deep-seated stability.

The volumetric behavior of the soil samples also offered a glimpse into the role of roots in the preservation of soil integrity. Vertically rooted samples maintained a relatively consistent volume throughout the shear process, indicating that the roots prevented excessive dilation or compression. Conversely, control samples experienced substantial compression during shear, while horizontally rooted samples experienced slight expansion. This phenomenon is likely attributable to interference with the test setup or inadequate reinforcement. These discrepancies serve as additional evidence that the deformation characteristics of a material are influenced by its root structure, in addition to its strength. When comparing the test results to the theoretical predictions, the observed strength gains exceeded the expectations. The average experimental increase in shear strength due to Bermuda grass roots was 15.86 kPa, which exceeded the theoretical estimate of 7.09 kPa based on established models. This discrepancy implies that the current reinforcement models may not fully account for the contribution of root architecture and distribution. It underscores the necessity of predictive tools that are either updated or region-specific and that take into account the unique characteristics of local vegetation.

The results bolster the broader application of Bermuda grass in bioengineering projects, particularly for the stabilization of shallow slopes, the control of roadside erosion, and the rehabilitation of degraded lands. It is a practical choice for widespread implementation due to its adaptability and availability in the Philippines. The results also indicate that the benefits of reinforcement are contingent upon the orientation of the roots. Consequently, it is essential to conduct site-specific assessments in order to ascertain the most effective planting and maintenance strategies. Engineering designs that incorporate biological components must, therefore, incorporate root architecture and growth behavior during the planning phase. This study offers quantitative support for the integration of vegetation into geotechnical designs, thereby reconciling environmental and structural factors. Vegetation is no longer solely aesthetic; it can be utilized to enhance structural functionality.

Additionally, it is imperative to acknowledge the study's constraints. The experiments were conducted in controlled laboratory environments, which may not accurately reflect the complex field conditions. Performance in actual applications may be influenced by natural variability in soil moisture, root growth, and external loading. Moreover, the results were restricted to Bermuda grass and silty sand, which restricted their generalizability. Nevertheless, these limitations do not diminish the fundamental discoveries; rather, they emphasize the necessity of additional research. Laboratory insights can be combined with field trials to validate and refine these findings in real-world settings. Furthermore, it is imperative to investigate the impact of seasonal fluctuations on the strength of roots and the patterns of growth. The case for plant-based reinforcement would be further bolstered by the expansion of the range of vegetation types and soil classes. This study establishes a strong foundation, despite its limitations.

Bermuda grass is highly recommended for use as a natural soil reinforcement material in civil engineering projects, particularly in regions susceptible to shallow landslides, surface erosion, and embankment failures, in accordance with the results of this study. The internal friction angle of the soil was significantly increased by this configuration, which is why future projects should prioritize vertical planting strategies that promote root growth in the downward direction. It is recommended that the Philippines update its engineering design manuals and slope stabilization guidelines to include vegetation-based reinforcement strategies, with a particular focus on locally available grasses such as Bermuda.

The results of this study are encouraged to be validated and expanded upon through additional research in real-world field conditions. The evolution of root strength and distribution over time and under varying climatic conditions will be determined through long-term monitoring of actual slopes planted with Bermuda grass. In order to evaluate the compatibility and constraints of Bermuda grass in various geotechnical environments, these field studies should encompass a broader spectrum of soil types, including clay, loam, and gravel. Studies should also investigate the optimization of soil reinforcement performance by examining the combination of various root orientations and densities. In addition, the comprehension of the mechanisms of root-soil interaction could be improved through the application of numerical modeling tools, root scanning technologies, and image analysis. This supplementary research will facilitate the refinement of predictive models for bio-reinforced soils and facilitate their wider implementation in the field of engineering.

Urban planners and policymakers should contemplate the integration of bioengineering solutions that utilize Bermuda grass into the infrastructure of city drainage, greenbelts, and flood control. The adaptability, low maintenance, and proven reinforcing capacity of Bermudagrass render it an ideal choice for large-scale environmental rehabilitation initiatives. Funding for research-based vegetative solutions should be included in budget allocations for slope management and erosion control. Academic institutions and government agencies may collaborate to establish pilot projects that illustrate the environmental advantages and cost-effectiveness of grass-reinforced soils. Additionally, these initiatives may be eligible for funding from national or international organizations that specialize in disaster risk reduction or climate resilience. In conclusion, the implementation of vegetative soil reinforcement methods not only meets technical requirements but also fosters environmental sustainability and community engagement in infrastructure protection initiatives.

5. REFERENCES

[1] Asio, V., Jahn, R., Perez, F., Navarrete, I., & Abit, S. (2009). A review of soil degradation in the Philippines. Annals of Tropical Research, 69–94.

[2] Evans, B. (2000). Soil Erosion at Multiple Scales—Principles and Methods for Assessing Causes and Impacts. Journal of Environmental Quality, 29(6), 2047–2047.

[3] Galupino, Joenel, et al.. Performance of concrete mixed with fly ash and plastic when exposed to fire. International Journal of GEOMATE, 19, 44–51.

[4] Uy, Erica Elice Saloma, et al.. Utilization of Philippine gold mine tailings as a material for geopolymerization. International Journal of GEOMATE, 21, 28–35.

[5] Elevado, Kenneth Jae T., et al.. Compressive strength optimization of concrete mixed with waste ceramics and fly ash. International Journal of GEOMATE, 16, 135–140.

[6] Elevado, Kenneth Jae T., et al.. Compressive strength modelling of concrete mixed with fly ash and waste ceramics using K-Nearest Neighbor Algorithm. International Journal of GEOMATE, 15, 169–174.

[7] Elevado, Kenneth Jae T., et al.. Artificial Neural Network modelling of concrete mixed with waste ceramic tiles and fly ash. International Journal of GEOMATE, 15, 154–159.

[8] Dungca, Jonathan, et al. Linear optimization of soil mixes in the design of vertical cut-off walls. International Journal of GEOMATE, 14, 159–165.

[9] Dungca, Jonathan R., et al.. Hydraulic conductivity characteristics of road base materials blended with fly ash and bottom ash. International Journal of GEOMATE, 14, 121–127.

[10] Dungca, Jonathan R., & Galupino, Joenel G.. Modelling of permeability characteristics of soil-fly ash-bentonite cut-off wall using response surface method. International Journal of GEOMATE, 10, 2018–2024.

[11] Dimalanta, Julia Beatriz, et al.. Investigation of the Effects of Waste Stone Powder as an Additive for Alluvial Soil. International Exchange and Innovation Conference on Engineering and Sciences, 10, 99–104.

[12] Ubay-Anongphouth, Irene Olivia, & Alfaro, Marolo (2022). Delayed instabilities of water-retaining earth structures. Frontiers in Built Environment, 8.

[13] Chuyaco, Francis Matthew, et al.. Influence of Temperature on Ignition Loss and Morphology of Horsetail Ash. International Exchange and Innovation Conference on Engineering and Sciences, 10, 353–358.

[14] Chuyaco, Francis Matthew, et al.. Assessing the potential of horsetail ash as a sustainable additive in infrastructure materials through ignition testing. Journal of Infrastructure, Policy and Development, 8.

[15] Ann Adajar, Mary, et al.. COMPRESSIVE STRENGTH AND DURABILITY OF CONCRETE WITH COCONUT SHELL ASH AS CEMENT REPLACEMENT. International Journal of GEOMATE, 17, 183–190.

[16] Galupino, Joenel, & Adajar, Mary Ann. RESPONSE SURFACE MODELLING OF PERFORMANCE OF CONCRETE WITH BAUXITE LATERITE SOIL AND FLY ASH. International Journal of GEOMATE, 25, 9–16.
[17] Galupino, Joenel G., & Dungca, Jonathan R.. Permeability characteristics of soil-fly ash mix. ARPN Journal of Engineering and Applied Sciences, 10, 6440–6447.
[18] Pérès, G., Cluzeau, D., Menasseri, S., Soussana, J. F., Bessler, H., Engels, C., … Eisenhauer, N. (2013). Mechanisms linking plant community properties to soil aggregate stability in an experimental grassland plant diversity gradient. Plant and Soil, 373(1–2), 285–299.
[19] Boldrin, D., Knappett, J. A., Leung, A. K., Brown, J. L., Loades, K. W., & Bengough, A. G. (2022). Modifying soil properties with herbaceous plants for natural flood risk-reduction. Ecological Engineering, 180.
[20] Stokes, A., Douglas, G. B., Fourcaud, T., Giadrossich, F., Gillies, C., Hubble, T., … Walker, L. R. (2014). Ecological mitigation of hillslope instability: Ten key issues facing researchers and practitioners. Plant and Soil. Kluwer Academic Publishers.
[21] Tsige, D., Senadheera, S., & Talema, A. (2020). Stability analysis of plant-root-reinforced shallow slopes along mountainous road corridors based on numerical modeling. Geosciences (Switzerland), 10(1).
[22] Ma, Q., Li, Z., Xiao, H., Hu, Z., & Pung, L. (2021). Mechanical properties of clay reinforced with Bermuda grass root under drying–wetting cycles. Environmental Earth Sciences, 80(1).
[23] Tan, H., Chen, F., Chen, J., & Gao, Y. (2019). Direct shear tests of shear strength of soils reinforced by geomats and plant roots. Geotextiles and Geomembranes, 47(6), 780–791.
[24] Jamshidi Chenari, R., Tizpa, P., Ghorbani Rad, M. R., Machado, S. L., & Karimpour Fard, M. (2015). The use of index parameters to predict soil geotechnical properties. Arabian Journal of Geosciences, 8(7), 4907–4919.
[25] Martinez, A., DeJong, J., Akin, I., Aleali, A., Arson, C., Atkinson, J., … Zheng, J. (2022). Bio-inspired geotechnical engineering: Principles, current work, opportunities and challenges. Geotechnique, 72(8), 687–705.
[26] Galupino, Joenel, & Dungca, Jonathan. Estimating Ground Elevation using Borehole Information: A Case of Metro Manila, Philippines. International Exchange and Innovation Conference on Engineering and Sciences, , 25–30.
[27] Angelo Fernandez, Cris, et al.. Evaluating Seismic Vulnerability and Enhancing Resilience of Road Infrastructure: A Comprehensive Bibliometric Analysis. International Exchange and Innovation Conference on Engineering and Sciences, 10, 525–531
[28] Co, Sean Cavan C., et al.. Estimation of Compression Index using Genetic Algorithm Approach. International Exchange and Innovation Conference on Engineering and Sciences, 10, 379–384.
[29] Dungca, Jonathan R., & Galupino, Joenel G.. Artificial neural network permeability modeling of soil blended with fly ash. International Journal of GEOMATE, 12, 76–83.
[30] Dungca, Jonathan R., & Galupino, Joenel G.. Modelling of permeability characteristics of soil-fly ash-bentonite cut-off wall using response surface method. International Journal of GEOMATE, 10, 2018–2024.
[31] Dungca, Jonathan, & Galupino, Joenel. Developing Nomographs for the Unit Weight of Soils. Buildings, 13.
[32] Galupino, Joenel, & Dungca, Jonathan. Estimation of Permeability of Soil-Fly Ash Mix using Machine Learning Algorithms. International Exchange and Innovation Conference on Engineering and Sciences, 9, 28–33.
[33] Uy, Erica Elice S., et al.. Characterization of Cebu Province Municipalities using Probabilistic Seismic Hazard Assessment and Geographic Information System. IOP Conference Series: Earth and Environmental Science, 479.
[34] Tomobe, H., Fujisawa, K., & Murakami, A. (2021). A Mohr-Coulomb-Vilar model for constitutive relationship in root-soil interface under changing suction. Soils and Foundations, 61(3), 815–835.
[35] Noorasyikin, M. N., & Zainab, M. (2016). A Tensile Strength of Bermuda Grass and Vetiver Grass in Terms of Root Reinforcement Ability Toward Soil Slope Stabilization. In IOP Conference Series: Materials Science and Engineering (Vol. 136). Institute of Physics Publishing.