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ROOT TENSILE STRENGTH CHARACTERISTICS OF PHILIPPINE MURA GRASS FOR EROSION CONTROL

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ABSTRACT: This study examines the tensile characteristics of Mura Grass *(Vetiveria Nemoralis)* to evaluate its efficacy in stabilizing soil and preventing erosion. Soil erosion is an important concern in geotechnical engineering as it affects the stability of slopes and foundations and poses risks to infrastructure. Vegetation plays an essential role in mitigating these risks by reinforcing the soil using root systems. The research consisted of 27 trials, with each of the nine plants undergoing three trials, resulting in a comprehensive dataset. Contrary to the expectation that larger roots would require more force to break, the study reveals a weak correlation between Root Diameter and Maximum Force by analyzing the relationship between these two parameters. Even in relatively young plants with smaller root diameters, the root tensile strength was remarkable, consistent with values observed in previous studies. The most notable finding of this study is the inverse correlation between Root Diameter and Tensile Strength in Mura Grass, which aligns with observations in other plant species. The correlation between smaller root diameters and greater tensile strength can be attributed to an increase in cellulose and lignin content as the root diameter decreases. These findings have practical applications, especially in erosion control, where understanding the root strength of Mura Grass can help prevent soil erosion caused by natural forces such as water flow and wind. To improve accuracy and account for potential influencing variables, additional research and model refinement are recommended.

Keywords: Geotechnical Engineering, Regression, Vetiver, Tensile Strength, Bio-intervention, Philippine Mura Grass

1. INTRODUCTION

In the field of geotechnical engineering, soil erosion is a critical concern that has direct implications for the stability and safety of civil engineering projects [1]. The stability of foundations for buildings, bridges, and other infrastructures is a significant concern. Under these foundations, soil erosion can cause settlement, tilting, or structural failure. Geotechnical engineers play a crucial role in assessing erosion risks during the design phase and may need to implement preventative measures to combat erosion near critical structures [2].

Moreover, the stability of both natural and engineered slopes is a primary concern. Failures of slopes caused by erosion can result in landslides, posing significant threats to infrastructure and public safety [3]. Geotechnical engineers are responsible for conducting comprehensive analyses [4], research [8-13], and, when necessary, intervention [14].

Another crucial aspect of geotechnical engineering is designing and constructing erosion control structures, which include retaining walls, gabion baskets, and erosion control blankets, are intended to stabilize slopes and reduce soil erosion risks. In situations where erosion is a recurrent problem, geotechnical engineers may recommend soil stabilization techniques [15] that modify soil properties to increase erosion resistance.

Before beginning any construction project, geotechnical engineers conduct exhaustive site evaluations to assess soil conditions, including erosion risk. This vital information guides the design of suitable foundation systems and erosion control measures tailored to the specific project site.

To prevent soil erosion, geotechnical engineers employ a variety of interventions and strategies, tailoring their approach to the specific challenges presented by each project site. These measures are intended to stabilize soil, prevent erosion, and protect vital infrastructure. Engineers may recommend techniques such as terracing to reduce gradients and slow water flow, reinforced soil structures such as retaining walls, and the installation of drainage systems to manage runoff in the context of slope stabilization effectively. Erosion control blankets [16] and geotextiles [17] protect soil from wind and water erosion, whereas gabion baskets and ripraps provide structural reinforcement and absorb the energy of moving water. Sediment-laden runoff is captured using silt fences and sediment basins, minimizing downstream erosion. Hydroseeding accelerates plant growth for long-term soil stability, and soil stabilization measures, such as introducing chemical stabilizers or indigenous vegetation, strengthen soil cohesion and resistance to erosion. Also contributing to erosion prevention are channel stabilization techniques and well-designed stormwater management systems.

The role of vegetation in preventing soil erosion is essential. Its significance lies in its diverse erosion control contributions [18]. First, plant roots strengthen the soil by binding soil particles together, enhancing its stability. This reinforcement resembles a natural support system that prevents water and wind-caused erosion. Second, vegetation improves soil structure by increasing porosity and water infiltration, reducing surface runoff, and mitigating rainfall's erosive effect. Furthermore, vegetation acts as a protective shield, shielding the soil from the direct impact of raindrops and flowing water, minimizing soil detachment and surface erosion. It also slows water flow, making it less effective at transporting soil particles away. Even vegetation can trap sediment particles from runoff water, preserving water quality in nearby water bodies. As plants grow and their root systems become more effective at stabilizing the soil, established vegetation provides long-term erosion control as plants mature and their root systems become more powerful [19]. Furthermore, vegetation improves the aesthetics of landscapes and provides habitat for wildlife, making it an attractive option for erosion control in ecologically sensitive areas. It is also environmentally friendly and cost-effective in the long run, adhering to ecological restoration and conservation principles.

Various erosion-controlling plant species are commonly employed in the Philippines to prevent soil erosion and stabilize slopes. These species, including Napier Grass, Vetiver Grass, Mura Grass, Grass Leucaena, Bamboo, Talulot, Kakawate, Indigofera, Falcata, Ipil-ipil, and Pine, are carefully selected based on their adaptability to the local climate and terrain. They serve as natural erosion barriers, as their extensive root systems, nitrogen-fixing abilities, and rapid growth make them ideally suited for this function.

Vetiveria Nemoralis, also known as "Mura Grass," is a plant species that belongs to the same genus as Vetiver (Vetiveria Zizanioides) [20] and is renowned for its use in soil stabilization and erosion control. Mura Grass is typically found in natural forest environments, particularly in tropical and subtropical regions. Mura Grass (Vetiveria Nemoralis) may not be as well-known or studied in the Philippines as Vetiver (Vetiveria Zizanioides), but it can be significant for comparable reasons. The extensive and dense root system of Mura Grass makes it effective at stabilizing soil and preventing erosion. This plant's deep roots create a network that binds soil particles together, making them more resistant to wind and water erosion. Mura Grass is significant in the Philippines due to its ability to protect and stabilize natural forest ecosystems, especially in areas where soil erosion is a concern, they can help maintain the health and integrity of these ecosystems, which provide essential ecosystem services such as water regulation, wildlife habitat, and biodiversity support by preventing erosion.

In geotechnical engineering, determining the tensile properties of plant roots is essential for erosion control [21]. Engineers can assess how well roots can withstand forces such as water flow and wind using characteristics such as tensile strength, which aids in selecting suitable plant species for erosion control projects. This information guides the design of erosion control measures, helps predict the long-term effectiveness of vegetation, conducts slope stability analyses, and establishes maintenance guidelines. Thus, this study aims to characterize the tensile properties of Mura Grass, which can provide insights into the plant's ability to resist tensile forces. Furthermore, a regression model to predict roots' tensile strength was provided and validated.

2. RESEARCH SIGNIFICANCE

Understanding the tensile properties of Mura Grass is vital for its application in geotechnical engineering and erosion control. Its tensile strength plays a key role in determining its ability to anchor soil, preventing erosion caused by forces like wind and water. This insight allows engineers to select the most effective vegetation for soil stabilization and erosion prevention projects. Furthermore, investigating Mura Grass’s tensile characteristics contributes to the design of sustainable, eco-friendly erosion control solutions. By considering the plant's resistance to tensile stress, engineers can develop strategies that enhance ecological restoration and reduce the impact of soil erosion in vulnerable regions.

3. METHODOLOGY

3.1 Specimen Collection

Mura Grass (Vetiveria nemoralis) samples were collected from Calauan, Laguna, Philippines, shown in Fig. 1. The models focused on one-month-old plants representing the plant's early growth stages. The soil samples were carefully transferred to containers with their roots still intact.

3.2 Modified Tensile Test

A modified experimental approach was developed to assess the root tensile strength properties of Mura Grass, considering the unique constraints of the study. This method was inspired by the experiments conducted by Teerawattanasuk et al. (2014) [22], who utilized a Grass Root Tensile Test Machine, shown in Fig. 2a and 2b. Due to the limited availability of the plants, young plants (1-2 months age) were used in this study. The modified experiment adhered precisely to a series of steps. Nine plant samples were prepared and individually sealed in airtight zip-lock bags to preserve their integrity. Then, three distinct root strands were selected from the central region of each plant sample, where the roots exhibited the most incredible strength—these selected roots measured between 15 and 20 centimeters in length, the longest lengths available. As shown in Table 1, this procedure was repeated for each of the nine samples, resulting in a total of 27 tests to ensure the accuracy of the results.

Fig. 1 Mura Grass Farm un Calauan, Laguna, Philippines

As depicted in Figs. 2 and 3, the experimental apparatus consisted primarily of a metal clamp and a bucket. The metal clamp was firmly attached to a table and served as an anchor for the roots. The roots were attached and tied on the bucket's opposite end.

Table 1 Quantity of samples required per trial

Trial	No. of Plant Samples
1	9
2	9
3	9
Total	27

The bucket was then gradually filled with sand from Ottawa until the point of root failure was reached. During the testing process, if a root snapped directly above the knot or snapped within the bottom or top 25%, the test was deemed invalid and repeated to ensure uniform stress distribution and avoid edge effects that could skew the accuracy and reliability of the tensile strength measurements.

In addition, the dimensions of the roots were determined by measuring their length and diameter at three distinct locations along their overall length. The measurements obtained at each site were averaged to determine the dimensions of the investigated roots. In addition, the bucket's weight and the sand it contained were measured and recorded to provide crucial data for subsequent analysis. Using this modified experimental method, the study successfully measured the root tensile strength of Mura Grass while adhering to the research's specific requirements and limitations.

Fig. 2a Modified Grass Root Tensile Test Machine

3.3 Regression Model and Validation

Lastly, a regression model was created with the independent and dependent parameters shown in Table 2.

This regression model was validated using an equality line, comparing the observed and predicted dependent variables.

Table 2 Parameters used in the regression model.

Parameters	
Independent	• Root Diameter (mm)
Dependent	• Force (N) • Tensile Strength (MPa)

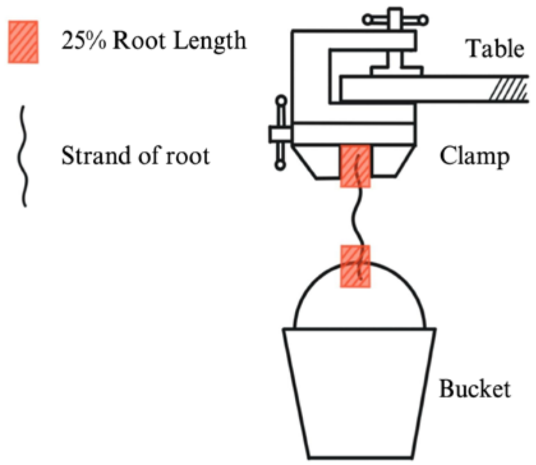

Fig. 2b Schematic Diagram of Modified Grass Root Tensile Machine

4. RESULTS AND DISCUSSIONS

4.1 Root Tensile Strength

Significant observations were made during the tensile strength tests, particularly regarding the average values of Root Diameter, maximum force, and root tensile strength. The averages were calculated for all plant specimens and are presented in Table 3 and illustrated in Fig. 4. The root diameters of the different plant specimens exhibited significant variation, ranging from 0.6 mm to 2.6 mm. However, when evaluating the average values, the root diameters ranged from 1.07 mm to 2.17 mm. Unexpectedly, the average values suggest that the plant samples analyzed in this study possessed thicker roots compared to those discussed in Noorasyikin and Zainab's [23] study. The variation in root diameter is important because thicker roots, with their larger cross-sectional area, are generally linked to higher tensile strength.

Considering the maximum force data, the recorded values in all trials varied significantly, ranging from 14.53 N to 39.52 N. The mean values varied between 18.10N and 34.61N. The observed variation in the maximum force suggests that there is significant variability in the root strength of the plant samples.

Table 3 presents a comprehensive analysis of the tensile characteristics of Mura Grass. Furthermore, the values for root tensile strength exhibit substantial differences among the different specimens. As an illustration, Plant No. 1 possesses a root diameter measuring 1.27 mm and exhibits a tensile strength of 34.28 MPa. On the contrary, Plant No. 9, with a root diameter of 2.17 mm, demonstrates a tensile strength of 9.73 MPa. The results of the investigation indicate a consistent inverse correlation between root diameter and tensile strength, suggesting that smaller root diameters correlate to higher tensile strength. This observation is consistent with the results presented by Teerawattanasuk et al. (2014) [22], where varying values were reported for each root diameter, confirming the consistency of this relationship in the tensile strength characteristics of Mura Grass.

Table 3 Tensile Properties of Mura Grass

Plant No.	Diameter (mm)	Max Force (N)	Root Tensile Strength (MPa)
1	1.27	29.15	34.28
2	1.03	18.1	27.97
3	1.17	20.96	22.39
4	1.07	25.11	33.74
5	1.67	25.69	11.84
6	1.47	32.49	23.64
7	1.47	23.66	17.53
8	1.57	21.91	13.37
9	2.17	34.61	9.73

Lastly, the root tensile strength data provided valuable insight into the ability of plant samples to withstand tensile forces. Notably, the highest tensile strength recorded across all tests was 68.59 MPa, while the lowest was 6.85 MPa, as shown in Fig. 5. The tensile strength ranged from 9.73 to 34.20 MPa in terms of the average value. The distinction in tensile strength can be attributed to differences in root diameter, root age, and the composition of cellulose and lignin within the roots. Smaller roots with smaller diameters exhibit greater tensile strength as a result of the increased density of cellulose and lignin. These components play a crucial role in strengthening the cell walls and enhancing tensile strength.

Despite the relatively smaller root diameters and the plants' being only one month old, these results indicate that their root tensile strength remains remarkable. Although comparisons with other studies [23-24], may be limited due to the lack of information regarding the Mura Grasses' ages, it is essential to note that the values obtained in this study fall within the range of values [22]. This study, like the current one, examined the ages of the Mura Grass samples, including the testing of Mura Grass as young as two months old.

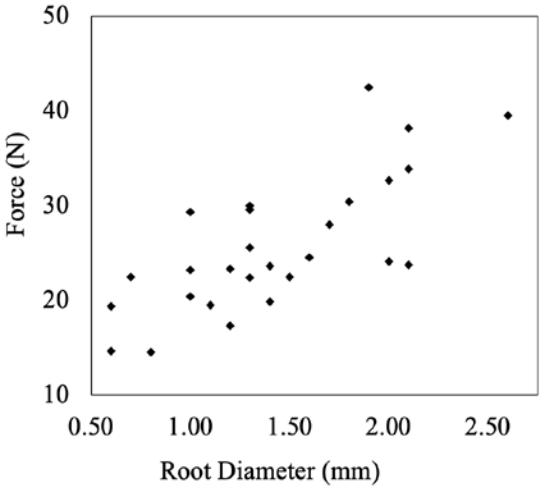

Fig. 4 Root Diameter and Force of Mura Grass

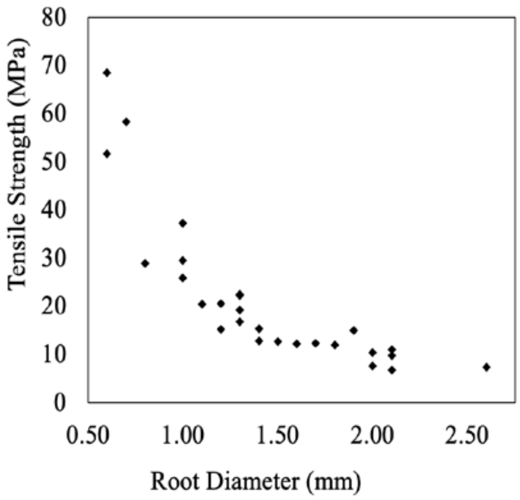

Fig. 5 Root Diameter and Tensile Strength of Mura Grass

As Root Diameter decreases, tensile strength increases. This result is consistent with previous studies. In addition, the inverse relationship is a well-established phenomenon in numerous plant species.

This relationship can be attributed to the increase in cellulose and lignin content as root diameter decreases. Lignin reinforces the cell wall, whereas cellulose imparts tensile strength to the plant's cell wall. Consequently, the observed increase in root tensile strength in smaller diameters can be attributed to the increased presence of cellulose and lignin, indicating that these roots contain a greater quantity of these strengthening components.

4.2 Root Tensile Strength Model

The relationship between Root Diameter (D) and Force (F) in Mura Grass exhibits exponential growth, as described by Eq. 1 and Fig. 6, where 'F' represents the Force and 'D' represents the Root Diameter. This equation demonstrates that as the Root Diameter increases, the required Force to break the root increases exponentially. The coefficient '0.3936' represents the rate at which the Force increases as the Root Diameter changes.

$$F = 14.141e^{0.3936D} \quad (1)$$

The coefficient of determination associated with this equation (R^2 = 0.5511) indicates that the trendline is well-fitting. With an R^2 value of 0.5511, the model explains approximately 55.1% of the observed variation in Force of Mura Grass root diameter changes. While this indicates a moderate fit, it is essential to recognize that other factors not accounted for in the model may contribute to the remaining variation.

The trendline demonstrates the positive correlation between Root Diameter and Force, demonstrating that as the Root Diameter of the Mura Grass increases, it requires a greater force to break, highlighting the root's tensile strength characteristics.

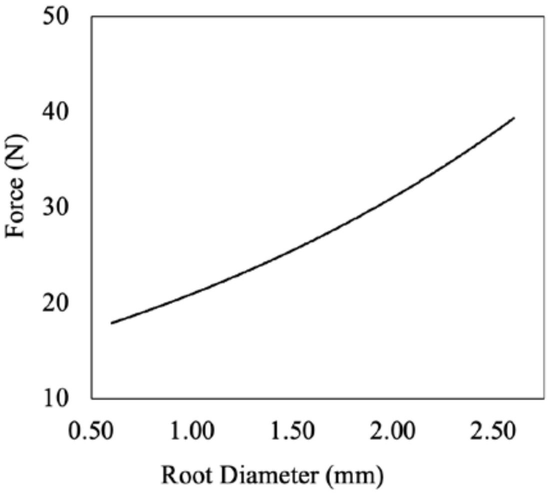

Fig. 6 Model for Root Diameter and Force of Mura Grass Relationship

Validation of the model describing the relationship between Root Diameter and Force of Mura Grass involves determining the degree to which the predicted values of the model correspond to the observed values, shown in Figure 7. Observed values in this context represent the actual Force measurements (N) obtained during the experiments. In contrast, predicted values are those generated by the model based on the values of Root Diameter, shown in Fig. 7.

It is evident from the provided data that there are significant differences between the observed and predicted Force values. For instance, the model predicts Force values considerably lower than the observed values for many data points. This discrepancy is evident when the observed Force is 42.49 N, but the predicted Force is only 17.91 N. These disparities are also reflected in additional data points where the predicted Force consistently underestimates the observed Force values.

The relationship between Root Diameter (D) and Tensile Strength (T) in Mura Grass follows the inverse power function pattern described by Eq. 2, where 'T' represents Tensile Strength (in MPa) and 'D' represents Root Diameter (in mm). This equation's exponent '-1.485' represents the inverse relationship between Root Diameter and Tensile Strength. It indicates that as the Root Diameter of Mura Grass grows, Tensile Strength decreases, and an inverse power function governs this relationship. This equation illustrates the nonlinear relationship between root diameter and Tensile Strength, where smaller root diameters result in significantly higher Tensile Strength values.

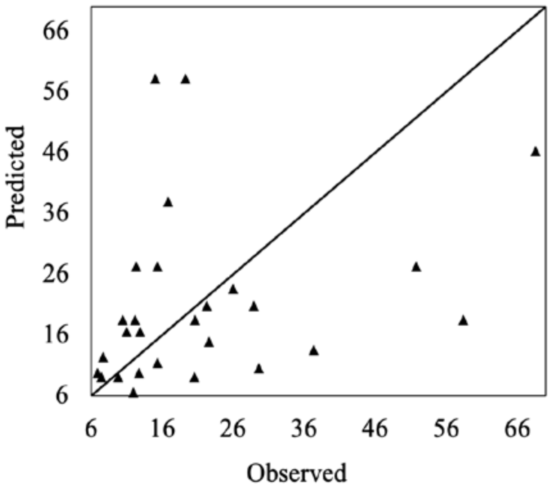

Fig. 7 Validation for the Model for Root Diameter and Force of Mura Grass Relationship

$$T = 27.248D^{-1.485} \quad (2)$$

Particularly notable is the coefficient of determination (R^2 = 0.9081) associated with this equation. With an R^2 value of 0.9081, the model adequately explains 90.81 % of the observed variation in Tensile Strength due to changes in Root Diameter. Despite the non-linear nature of the relationship, the high R^2 value indicates a strong fit for the inverse power trendline, thereby strengthening the model's ability to explain the relationship between Root Diameter and Tensile Strength in Mura Grass. It indicates that the inverse power function is an appropriate representation of the observed data, emphasizing the significant influence of Root Diameter on Tensile Strength in this plant species.

The dataset provides insightful information regarding the relationship between the Root Diameter and Tensile Strength of Mura Grass, shown in Fig. 9. Nonetheless, some obstacles and observations must be addressed. There is a notable disparity between the observed and predicted Tensile Strength values, with the model consistently overestimating Tensile Strength across the entire dataset. This discrepancy calls into question the model's ability to accurately represent the true relationship between these variables.

There are instances within the dataset in which the predicted values deviate significantly from the observed values, indicating the presence of potential outliers or errors in the model's predictions. For example, the third row of the data set demonstrates a significant disparity between the observed and predicted Tensile Strength values, highlighting the model's variability and limitations. This variation necessitates closer examination of the model's robustness and ability to account for the factors that influence Tensile Strength accurately.

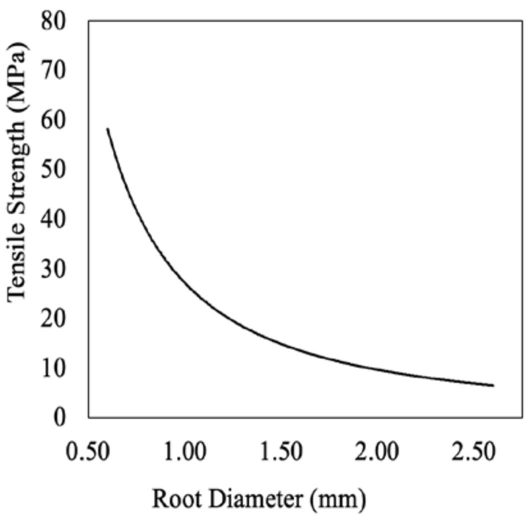

Fig. 8 Model for Root Diameter and Tensile Strength of Mura Grass Relationship

In addition, the dataset highlights the need for additional refinement of the predictive model. Although Root Diameter is unquestionably a significant variable, the observed discrepancies suggest that other variables or nonlinear relationships may also influence Tensile Strength. Consequently, there is room for model improvement, which may involve incorporating additional variables, investigating nonlinear relationships, or applying more advanced modeling techniques.

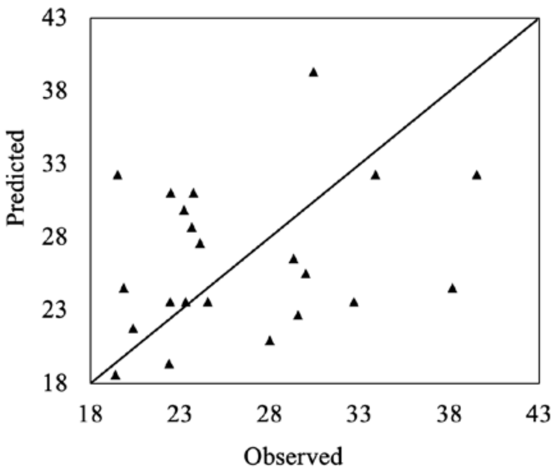

Fig. 9 Validation for the Model for Root Diameter and Tensile Strength of Mura Grass Relationship

5. CONCLUSIONS AND RECOMMENDATIONS

The results, as illustrated in Table 3 and Figs. 4 and 5, reveal crucial observations. First, the root diameters of the Mura Grass samples varied significantly, ranging from 0.6 mm to 2.6 mm, with average values falling between 1.07 mm and 2.20 mm. These average values indicate that the plant samples examined in this study had thicker roots than those analyzed in a previous study. This variation in root diameter is significant because thicker roots typically associated with larger cross-sectional areas have a greater tensile strength.

The weak correlation between maximum force and root diameter suggests that maximum force varies independently of root diameter.

Even with relatively smaller root diameters and the young age of the plants (only one month), the observed root tensile strengths are impressive, according to the data. The lack of information on the ages of the Mura Grass samples in other studies makes direct comparisons difficult. Still, these results fall within the range of values reported in the previous studies, who also considered the ages of the Mura Grass samples, including those as young as two months old.

This study's key conclusion is the inverse relationship between root diameter and tensile strength in Mura Grass, consistent with findings from other plant species. There was a correlation between smaller root diameters and greater tensile strength. This inverse relationship is well-established in the field of bioengineering and can be attributed to a rise in cellulose and lignin content as root diameter decreases. Lignin reinforces the plant cell wall, whereas cellulose imparts tensile strength to the plant cell wall. This provides a comprehensive understanding of the relationship between root diameter and tensile strength in Mura Grass.

This study has contributed to our understanding of the tensile properties of Mura Grass by highlighting the importance of root diameter and its inverse relationship to tensile strength. In erosion control, where understanding the root strength of Mura Grass can be crucial in preventing soil erosion caused by natural forces such as water flow and wind, these findings have numerous practical applications. However, additional research and model refinement are required to improve the predictive model's accuracy and account for other potentially influential variables.

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