iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 11 Issue: III Month of publication: March 2023

DOI: https://doi.org/10.22214/ijraset.2023.49065

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 11 Issue III Mar 2023- Available at www.ijraset.com

Evaluation of the Biomechanical Potential of *Pennisetum Purpureum* and *Mangifera Indica* Plant Roots for Sustainable Slope Stabilization

Patrick Usifo[1], Wu Li-Quan[2]
Zhejiang University of Science and Technology School of Science, No 318 Liuhe Road, Hangzhou, 310023, CHINA

Abstract: The potentials of the roots of Pennisetum purpureum and Mangifera indica for use in sustainable stabilization of slope were evaluted. The plant roots were sampled close to an erosion site in Nwonta Isuikwuato local government of Abia State Nigeria. The tensile strength of the roots segments was determined using the Universal Testing Machine (UTM) at the Michael Okpara University of Agriculture, Umudike. The effect of water content and dehydration due to adverse weather condition was studied by tensile testing the roots after different drying periods (30 minutes, 1 hour, and 24 hours). Laboratory experiments was performed to evaluate the engineering properties of the soil at the erosion site. The mean tensile strength of the Pennisetum purpureum obtained were 5.30 MPa (hydrated roots), 12.49 MPa (30 minutes dried) and 17.13 MPa (1 hour dried). After 24 hours drying the roots of Pennisetum purpureum which is a grass species was not strong enough to be tested for tensile strength. For the Mangifera indica the mean tensile strength obtained were 17.41 MPa (hydrated roots), 18.73 MPa (30 minutes dried) and 21.84 MPa (1 hour dried) and 34.10 (24 hours dried). The roots show that root tensile strength increased as the root moisture content reduces. The heightened rate of soil erosion in the study area could be due to the fact that the soils are predominantly sand with no cohesion as observed from the laboratory test. Hence, planting these vegetations can significantly lead to the improvement of the strength properties of the soil and minimise the rate of soil erosion and slope failure.

I. INTRODUCTION

One of the global threats that result in economic and social damages is slope failure and soil erosion (Fig. 1.1). This has both direct and indirect impact on the sustainable development of the society. The immediate costs associated with repairing slope failure-damaged roads, homes, and facilities, as well as the human lives lost, are referred to as the direct repercussions of slope failure and soil erosion. For example, it was reported by the total cost of stabilising the Pennan landslide was roughly six hundred thousand pounds (£600, 000) (BBC, 2009). Again, Highland (2012) stated that the direct damages due to landslides in Colorado, USA, in 2010 were USD 9 million. Petley (2012), reported that between 2004 and 2010, slope failure lead to the death of more than 32,322 persons globally.

Fig.1.1: Different technical methods used mitigate soil erosion and slope failures in the biggest gully site in South eastern (Nigeria): (a) sand bags (b) runoff breakers (Igwe and Una 2019).

Most of the slope failure in South east Nigeria mostly results from degradation of the soil due to erosion. In this regard, there are several gully sites in south east part of the Nigeria at varying stages of development (Okorafor et al. 2017). For instance, the number of gully site in the different states in South Eastern Nigeria area as follows Anambra (700), Enugu (600), Abia (300), Imo (400), and Ebonyi states (250) (Igbokwe et al. 2004; Egboka, 2004). The statistics on the gully erosion sites are not exhaustive, since new sites are being created every rainy season due to increased rainfall intensities and duration leading to flooding. According to estimates, among other environmental issues in Nigeria, slope erosion and landslides affects roughly 50 million persons and causes the largest GNP loss ($3 billion annually) (World Bank, 1990). This is one of the most existential dangers to the huge population of Southern Nigeria and certain areas of Northern Nigeria (Egboka et al., 2019). (Obaisi, 2018). These have resulted in the loss of life, agricultural land, and other priceless possessions (Egboka et al., 2019). On the other hand, a few of the indirect effects of landslides include the disruption of transportation networks, the interruption of agriculture production, reduction in the valuation of facilities in close proximity to slope failure-prone locations etc.

Slope instability may result from manmade and natural processes. Soil erosion, the slope angle of repose, torrent rainfall and flooding, and the engineering properties of the soil, etc. are some of the ecological factors that affect mass movement. According to Gibson et al. (2013), the UK saw a high rate of landslides in 2012 as a result of more rainfall. Once more, research has shown that soil physical characteristics including cohesion, bulk density, plasticity, and shear strength affects the stability of slopes (Zung et al., 2009; Ekeoma et al. 2021). Human activities like deforestation, farming, building, increased loads on roads and slopes, etc. can cause slope collapse in addition to natural processes. The uprooting of trees from a natural slope, according to Gray and Megahan (1981), is one of the key elements that enhances the susceptibility of slopes to failure.

Traditional (e.g., use of retaining walls, soil nailing, gibbon wall etc.) and non-traditional (animal and plant fibres etc.) stabilisation techniques are two categories of remedies to slope collapse that are now available. Prior to implementing a strategy to mitigate environmental deterioration, sustainability and environmental friendliness are important factors to consider in addition to safety. This is done to prevent the problem that was supposed to be remedied from getting worse. Bioengineering has been shown to be more effective and cost-effective than conventional slope improvement techniques in this regard (Stokes et al., 2009). Plant root enhancing soil strength against erosion, stream embankment collapse and slope failure through two mechanisms namely: hydrological and mechanical (Punetha et al. 2019). Although the use of plants to maintain environmental balance is a long-standing practise, research into its underlying mechanisms only began around 50 years ago (Ziemer, 1981).

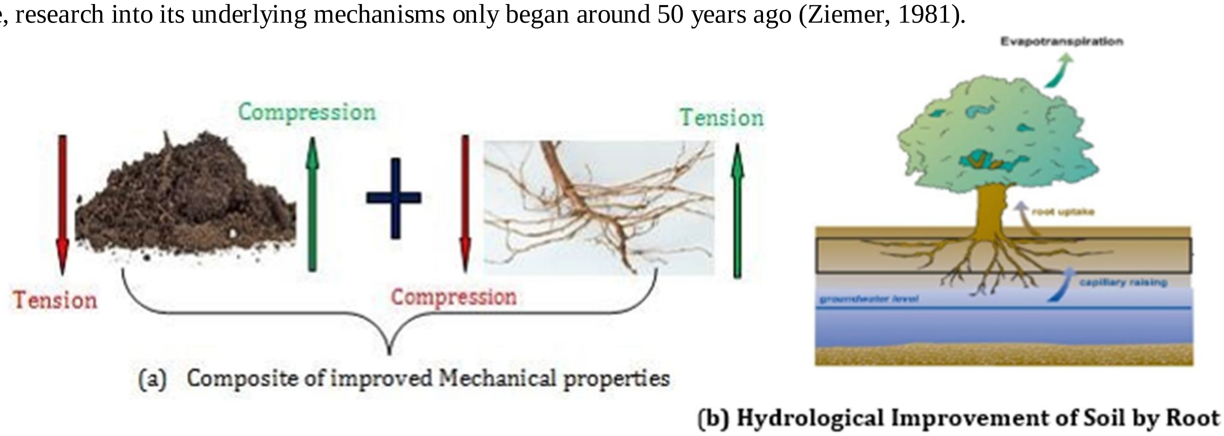


Fig. 1.2: Mechanical and hydrological reinforcement of the soil by vegetation. A) increase in soil strength due to root reinforcement (B). Increase in the soil effective stress due to evapotranspiration.

Several studies have shown that plant properties below and above the soil are crucial for strengthening the soil against deterioration and eventual collapse (De Baets et al. 2009; Ghestem et al. 2014). Roots are strong in tension but weak in compression under the soil, whereas soil is strong in tension but weak in compression; as a result, roots reinforced soil has enhanced mechanical characteristics (Fig. 1.2a), which is helpful for slope stability (Gyssels et al., 2005).

Plant root and its leaves improves the hydrological properties of the soil (Fig. 1.2b) in addition to its mechanical qualities. This is accomplished by roots boosting soil matric suction and evapotranspiration, which is the process of dissipating excess pore pressures (Mahannopkul and Jotisankasa, 2019). As was already established, both the roots and the leaves that are above the soil are necessary for hydrological the reinforcement of the soil (i.e., the reduction of the soil pore pressure which leads to increased effective stress).

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 11 Issue III Mar 2023- Available at www.ijraset.com

The issue of sustainability and climate change cannot be overemphasized as it has become a global trend. Hence, most of the engineering activities or solutions is now being tailored to meet a certain level of sustainability or climate change regulation. In this regard, soil bioengineering technology is widely being adopted as a better, more economical and environmentally friendly approach to slope stabilization against landslide and soil erosion (Stokes et al., 2009). One of the challenges with the use of vegetation for slope stabilization is that some plants survive only within a particular geographical and environmental conditions. Hence, the biomechanical properties of plant species need to be evaluated before they are used for slope remediation. Although previous studies have been performed on the impact of plant roots on slope stability, to the best of my knowledge studies focusing on the engineering properties of plants in regard to slope stability is rare performed in African context. Hence, this study seeks to make use of innovative Bio-shield for sustainable soil erosion mitigation.

II. CAUSES OF SLOPE FAILURE

Understanding factor contributing to the collapse is necessary for appropriate slope failure mitigation. Some of the common elements may be divided into internal and external categories. The external factors include: torrent rainfall and flooding, erosion, external loading, and anthropogenic activities; while the internal factors deal with the engineering properties of the soil, for instance, frictional angle, soil effective stress, slope steepness, cohesion, and groundwater table etc.

Rainfall intensity-related slope collapses frequently happen on moderately stable slopes. Rainfall of higher intensity frequently causes erosion as well as an increase in pore water pressure, which reduces the effective stresses in the soil. The soil matric suction is reduced as the soil becomes saturated due rainwater infiltration, this results to the removal of the top soil layer (erosion) and changes the geometry of a slope, leading to slope collapse. This lowers the soil's shear strength to the point where balance can no longer be maintained. As a result, there is a good likelihood that a large mass movement will take place following a downpour. According to Fig. 2.1, the UK had a high number of landslides in 2012 as a result of an increased rate of rainfall.

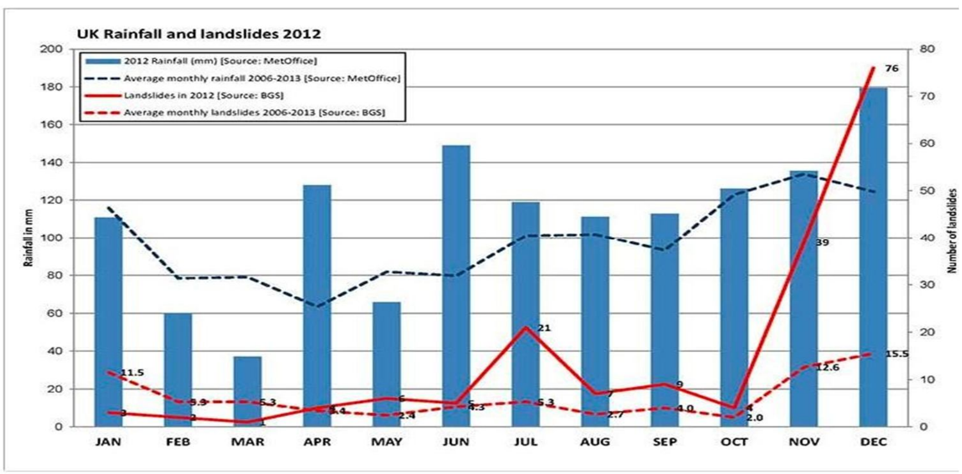


Fig. 2.1: Increased rainfall results to high rate of landslides in the UK (Source: Gibson et al., 2013).

The hydraulic conductivity of the soil will also determine if a slope has a likelihood to collapse after a heavy downpour or not. High rainfall intensity rather than rainfall length is more likely to be the cause of slope failure in a soil with high permeability (Baeza and Corominas, 2001); whereas, slope with low permeable soils are more likely to fail if rainfall last for longer periods. Accordingly, depending on the type of soil and the existence of root systems, rainfall-induced slope failure may occur immediately or sometimes after the rainfall.

Slope instability may be caused by human activities such as agriculture, building, forestry, tourism, mining, etc. Construction operations frequently change an area's natural topography, which has an impact on the geomorphology and hydrological systems there and raises the risk of slope failure. Given that infrastructure growth is a major driver of economic expansion, it is crucial to comprehend how these variables hasten slope collapse. Building sustainable economic structures would be made possible as a result.

Another crucial element for determining the stability of slopes is the characteristics and composition of the soil. Clayey soil when saturated becomes heavier and more susceptible to mass movement, but cohesionless soil, such as loose sand and gravelly soil, can easily slip or move irrespective of the intensity or duration of the rainfall. As a result, depending on the soil's characteristics and classification, the cause of slope collapse may vary.

III. ROOT REINFORCEMENT OF SOIL

One technique to prevent slope failure is reinforcement using plant roots. According to Wu et al. (1979) and Ziemer (1981), the early quantitative studies on root-reinforcement of soil deals with the assessment of the shear strength properties of vegetated soil was. Research have also identified various factors influencing root biomechanical characteristics (Bischetti et al. 2005; Mickovski et al. 2009; Fan and Su 2008; Boldrin et al., 2018). In addition to determining the characteristics of roots, work has been done to develop models for the incorporation plant contribution to slope stability (Mao et al., 2012). However, discrepancies between these models shows that the fundamental reinforcing mechanisms controlling root reinforcement soil have not been clearly understood.

Finite element analysis and discrete element methods are highly complex computational approaches utilised in recent research to examine the interaction between the root and the soil, and to assess the stability of slopes stabilised with roots (Chok et al., 2015; Mao et al., 2014; Tiwari et al., 201; Likitlersuang et al., 2017). Finite element analysis has the advantage that it does not need prior information of the kind and location of the crucial slip surface, which is typically difficult to characterise when soil is vegetated (Chok et al., 2015). Conversely, the discrete element technique is suggested to show data consistency without challenges of convergence. However, the use of discrete element technique takes longer time during computation and it can be difficult locating the necessary parameters (Mao et al., 2014).

IV. ROOT CHARACTERISTIC NEEDED FOR SLOPE STABILITY

When measuring the soil's root reinforcement, the geometrical characteristics of roots are crucial (Bischetti et al. 2005). Consequently, it is crucial to understand root morphology. There are several varieties of roots (Gyssels et al., 2005). The capacity of the root system to anchor is also determined by adequate root characterisation, which is crucial for slope stabilisation. This allows for forecasts of potential root variability caused by environmental changes. According to Zobel and Waisel (2010), the classification of roots may be made based on the developmental origin of the roots, which enables the separation of roots based on tap root-dominated and shoot-borne root systems. Ziebel and Waisel (2010), reported four main categories of roots: tap root (root proceeding from the seed); lateral root (roots branches from other roots); Basal root (they are roots emanating from the hypocotyls), and short borne root (roots emanating from the stem).

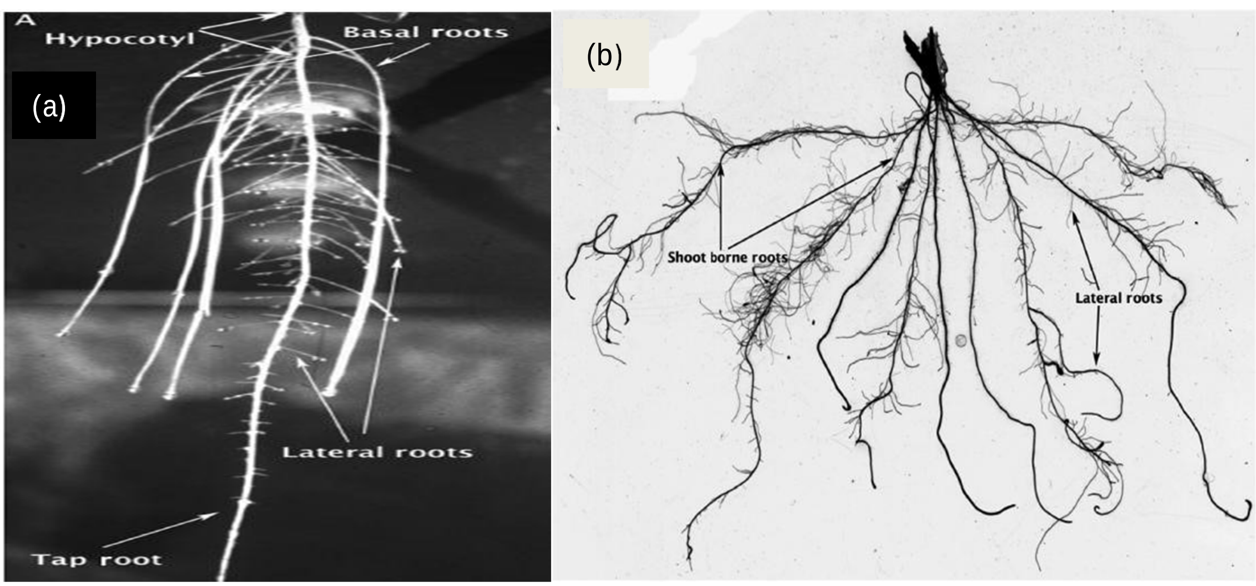


Fig. 2.2: Pictorial presentation of varying root classes (a) Soybean (b) Perennial ryegrass (Source: Zoebel and Waisel et al., 2010)

In addition to being categorised according to their pattern of development, plant roots are also categorised according to their diameters.

Root distribution in the soil affects root reinforcement. Schwarz et al. (2013) noted that root dispersion is inherently a result of root architecture. Trees with extensive taproots would have deeper roots but lower distribution or spread which will decrease rate of the amount of reinforcement offered at depth by the root. The architecture of the roots can be categorized into four namely heart root system, plate root system, tap root system, and fibrous or herbaceous root system (Stokes et al. 2009; Pohl et al. 2011).

V. BIOMECHANICAL PROPERTIES OF THE ROOTS

Biomechanical properties of the roots mostly reported and used in studies assessing slope stability are the tensile strength and elastic modulus (Loades et al. 2013; Stokes et al. 2009; Schwarz et al. 2010; Mickovski et al. 2009). Root tensile strength is regarded as the maximum force per unit area required to break the root (Genet et al., 2005). It is measured in Pascal Pa (N m^{-2}). Some investigations, however, simply quantified it as the force at failure (N) (Yang et al., 2016). A key root feature used to calculate its mechanical reinforcement in slopes is root rigidity. It is referred to as the roots stress-strain relationship. Perez-Harguindeguy et al. (2013) created approaches for identifying the qualities and characteristics of plants. Recent investigations used the universal testing equipment to assess the tensile strength of roots (Boldrin et al., 2018). The potential causes of inaccuracy for during the determination of tensile strength of the root includes the load cell, clamping mechanisms, and the rate of extension during the tensile testing of the roots. Hence, root tensile strength test is most times regarded as success whenever the roots fail within the midpoint of its length to prevent clamping system error. Root age, topological order, anatomy, moisture content, chemical composition, thickness, and soil characteristics are the properties of the root which affects it biomechanical properties (Loades et al. 2015; Mao et al. 2018; Mao et al. 2018; Boldrin et al. 2018; Genet et al., 2005; Stokes et al. 2009; De Baets et al. 2009; Mao et al. 2012; Loades et al., 2013).

The negative exponential relation is mostly used to explain the of the link between root diameter and tensile strength (Eqn. 2.1) (Mao et al., 2012)

$$T_r = aD^{-\beta} \qquad 2.1$$

Here, T_r is the root tensile strength,
D represents the root diameter,
and a and β stands for empirical constants.

The impact of root cellulose content and its diameter on the strength properties was assessed by Genet et al. (2005. Their findings (fig. 2.3) show that smaller diameter roots contain more cellulose, which enhances the root tensile strength. The relation between cellulose tensile strength and moisture content was studied using hybrid mechanics-molecular dynamics modelling techniques. The results showed that moisture content was related to cellular content. On the other hand, it was suggested that an increase in moisture content would boost water mobility since there would be less hydrogen connections between water molecules and cellulose crystals (Sahputra et al. 2019). Together, the cellulose content of the roots may affect the suction and tensile strength of the matrix, which may have an effect on the soil's hydrological and mechanical qualities.

According to Boldrin et al. (2018), the relationship between root tensile strength and moisture content suggests that a decrease in root moisture content causes an increase in root tensile strength. Because the saturated state represents the worst-case situation in slope stability analysis, the authors recommended that roots be evaluated at that condition. In addition, it would be helpful to comprehend how, in the worst-case situation, cellulose concentration may affect the dynamics of a slope stability study.

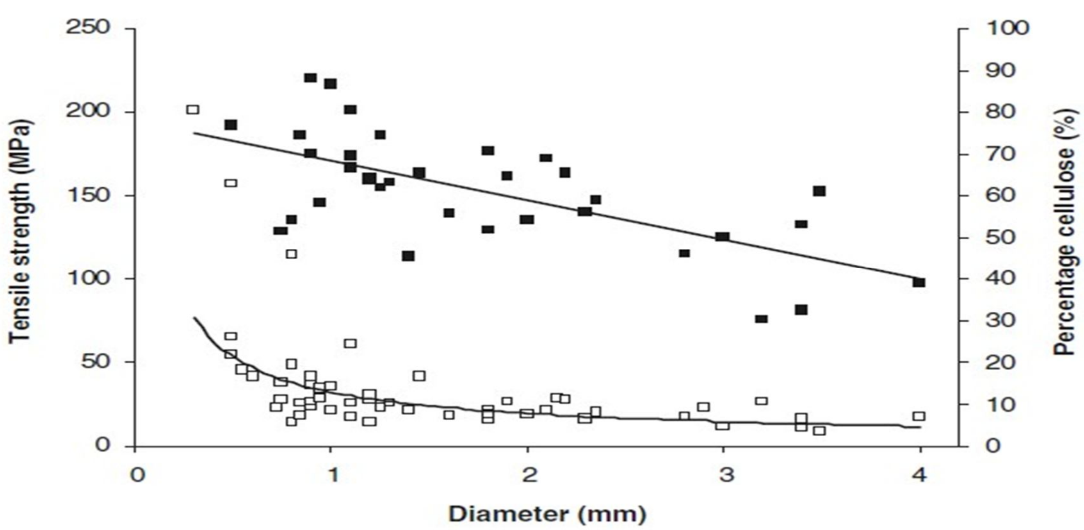


Fig.2.3: Relation between root tensile strength and diameter with the cellulose percentage on of the roots of Sweet Chestnut (Diameter is represented by white squares; while cellulose is represented by the black squares) (Genet et al., 2007)

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 11 Issue III Mar 2023- Available at www.ijraset.com

Although most studies have opined that the relation between root diameter and tensile strength is explained by the negative power law and has used it to model root-soil interaction (Bischetti et al. 2005; Schwarz et al. 2010), other studies have reported that some plant species only adhere weakly to the negative power law, and in some cases do not adhere at all (Hales and Miniat 2017; Boldrin et al. 2017b; Hales et al. 2013; Ghestem et al. 2014). In order to precisely determine the impacts of root diameter on the tensile strength of roots and to understand the causes of specific plant species' non-adherence to the negative power law, more study is urgently needed. Better root contribution to slope stability estimation will result from this.

VI. MODELLING ROOT-SOIL INTERACTION

It's crucial to analyse the role of roots to slope stability in addition to figuring out their strength capability. The models for root reinforcement of soil are classified based on the root breakage pattern during shear. In this regard, we have the Simple Perpendicular Root Model (Wu et al., 1976; Waldron, 1977) based on simultaneous breakage of the roots; the progressive root breakage model such as Fibre Bundle Model (FBM) (Pollen and Simon, 2005), and the Root Bundle Model (RBM) are a few models that have been created in this area (Schwarz et al., 2010).

This model considers how to root reinforcement affects soil cohesion and shear strength (Wu et al., 1976). It is founded on the Mohr-Coulomb soil failure envelope equation (Eqn. 2.2), which makes the assumptions that the roots are elastic, perpendicular to the slope and that the frictional angle is constant regardless of the location of the roots in the soil. The roots transmit the tension as a laterally loaded pile that resembles a pair of soil shears.

$$S_{r-s} = C + \sigma \tan \emptyset + C_r \qquad 2.2$$

where, S_{r-s} is the shear strength of the root-soil composite;
C_r is the additional cohesion from the roots
σ is effective stress of the soil,
C is soil cohesion and $\emptyset$ is the frictional angle.

$$C_r = t_r(\cos\theta \tan \emptyset + \sin\theta) \qquad 2.3$$

t_r (Root tensile strength per unit area of soil) is given by

$$t_r = \sum_{i=1}^{n} T_{ri} \left(\frac{A_r}{A_s}\right) \qquad 2.4$$

Where, $\frac{A_r}{A_s}$ is the roots area ratio RAR.

VII. PLANT SPECIES SELECTED FOR THIS STUDY

The grass species tested in this study are the Napier grass (*Pennisetum purpureum*) and vetiver grass (*vetiveria zizanioides (l.) nash*). These grasses were selected because of the vast abundance in study area.

Napier grass (*Pennisetum purpureum*) extremely useful for preventing soil erosion in sand rivers because, because to its unique characteristics, it can grow in sand with low nutritional status, sprouts fast, and swiftly covers the region. Studies have shown that elephant grass can be effectively used for erosion control (Singh, 2010).

Vetiveria zizanioides (l.) nash., a grass, is a multipurpose plant that has been used in several nations for a variety of uses. It is a perennial, tufted plant of Indian origins, yet it is also frequently seen in West Africa. West Africa is home to a common African equivalent (*V. nigritananigritana (Benth.) Stapf*) (Dalton et al. 1996). It can effectively withstand hard conditions because of its deep, thick roots, which extend vertically rather than horizontally (Maneecharoen et al., 2013). According to reports, V. zizanioides can minimise soil loss from 11 to 3 t ha1 (Greenfield, 1989). In other cases, it was claimed that planting vetiver decreased soil loss from 143 tonnes to 1.3 tonnes per ha immediately and permanently (Suarau et al. 2017). According to Maneecharoen et al. (2013), short-term yield gains in India have led to projected Benefit Cost ratios of greater than 2:1.

The ability of vetiver to reduce runoff and increase the likelihood that rainwater will soak into the soil rather than rushing down a slope makes it a good erosion and sediment control agent. The ability of vetiver to grow and perform well in a variety of soil types, depths, and structures, the fact that it doesn't compete with nearby crops, and the fact that it is neither invasive nor serves as a secondary host for pests and diseases are just a few of the qualities that make it superior for controlling erosion.

When planted in a single or many rows on contours, vetiver grass develops to produce sturdy protective barriers that can span slopes, impede erosive runoff water, and result in sediment deposition.

ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 11 Issue III Mar 2023- Available at www.ijraset.com

VIII. SAMPLING

Through visual inspection a healthy grass with chances of having large number of roots is selected for sampling. This is to guarantee that when the soil is washed off the roots, sufficient samples can be collected. A spade was employed dig out the plant from the soil after the grass had been identified. To do this, a square hole is cut around the grass, and before lifting the soil core, care must be taken to ensure that the depth from the plant is excavation is little beyond the root depth. Following excavation of the soil, the soil is collected in a plastic bag and carried to the laboratory where it is cleaned and prepared for tensile testing. The roots were carefully excavated so as not to harm or pre-stress them.

Fig. 3.1: Picture of the sampled Napier grass

With the use of water and a sieve, the roots were removed from the soil. Due of the softness of the grass root, cold water is utilised to wash the root away from the soil. Use of hot water may cause root damage.

Roots that are broken or have a length that is too short were rejected during the washing process. The roots were chopped into 60mm lengths after being cleansed.

This will provide uniformity when determining the impact of drying on the characteristics of the roots. To avoid pre-stressing the roots, this will be done extremely cautiously. Each root was properly saturated for 24 hours before tensile testing. This is to ensure that all the root have the same moisture regime prior to testing. According to Perez-Harguindeguy et al. (2013), it is extremely illuminating to segregate roots based on time and depth while sampling roots.

No particular number of root samples is suggested in the literature for assessing and comparing root strength characteristics. Additionally, few writers provide an explanation of the reasoning behind the choice of sample size. According to Perez-Harguindeguy et al. (2013), the sample size should be determined by the inherent diversity of plants and the likelihood that the materials would work when tested. In light of this, a preliminary investigation of the roots was conducted to observe the root diameters' wide range of variability. Preliminary inspection revealed that the majority of roots have a diameter spread between 0.9mm and 1.5mm, with only a small number of roots exceeding this range but not by more than 2mm.

IX. ASSESSMENT OF THE ROOT CLAMPING

The pneumatic clamp is evaluated to ensure that it was able to grip the grass roots firmly with minimal damages. For the test, roots with equal diameters were employed.

This helps to isolate the variation in the outcome caused by variations in the root diameter to the clamping mechanism. At clamping pressures of 20 kPa, 40 kPa, 100 kPa, and 200 kPa, a total of 10 root segments measuring 35 mm in length are evaluated. It shall be indicated whatever sort of root failure was really experienced (slippage, clamp failure, or root failure). The test will be considered successful if the failure type is "root failure," as observed.

To ensure the effect of the root tensile testing is not affected by the clamping pressure, the test is only assumed to be successful if the root fail around the midpoint of its length. Therefore, the clamping pressure with the highest number of successful test outcomes will be chosen as the clamping pressure to be applied. The pressure dial of the compressors employed by the pneumatic clamp is shown in Fig. 3.3.

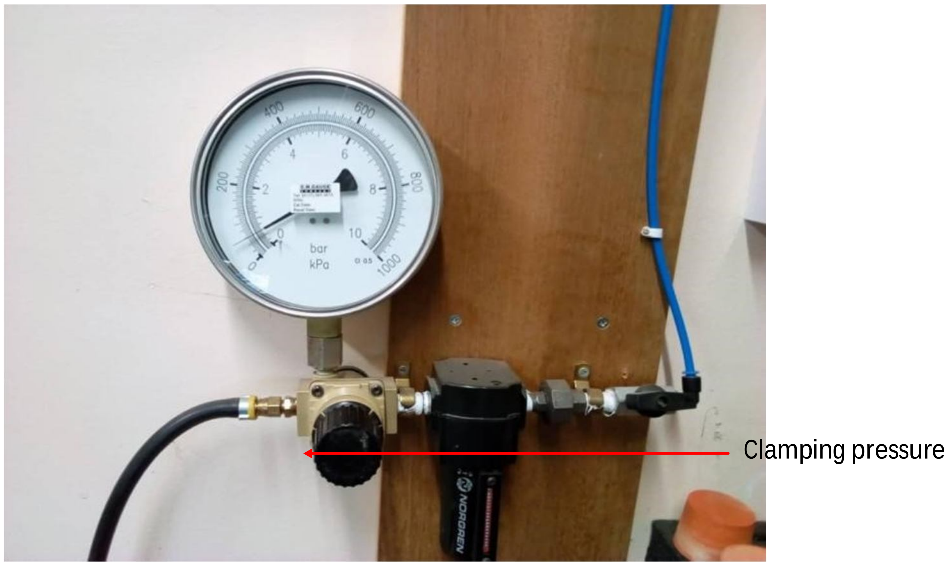


Fig. 3.3: The clamping pressure regulator. The gauge is scaled from 0kPa to 1000kPa and has 0.5% accuracy.

X. DETERMINATION OF ROOT BIOMECHANICAL PROPERTIES

The Universal Testing Machine (UTM), was used to determine the tensile strength and the Young's modulus of the roots (fig. 3.4). This device has software (Instons' Bluehill 3), which facilitates a variety of test options that ensures better control of the analysis, and data gathering. CSV files containing the output data from Instrons' Bluehill 3 are made available. The CSV file makes the data easily transferred to other software application such as Minitab or SPSS for statistical evaluation and analysis. The test will involve the use of a 500N load cell. The precision offered by the Instron Universal Testing Machine is 0.025% of the maximum output load or 0.25% of the applied load. Therefore, the accuracy for a 500N load cell will be 0.125. Instron 5966 supports a variety of gripping mechanisms, such as pneumatic or mechanical grips. Due to the fragile nature of the roots that will be put to the test, consistent clamping pressure application is necessary, pneumatic clamps were selected for the study. The 1kN model of the pneumatic clamp is the one that will be utilised. The clamps will be coupled to an air compressor with a maximum output pressure of 2.5bar. A protection device will be installed on the Instron cross head during the test to avoid unintentional contact between the different section of the clamps which could lead to injuries (fig. 3.4).

To ensure correct results, the load cell was properly calibrated before starting the tensile testing. Before calibrating the load cell, every load and clamp must be taken out of the cell. The Bluehill programme will be used to calibrate the load cell. The clamps are fixed to the load cell once the load cells have been calibrated. The Bluehill programme is then used to specify test procedures. It is important to choose test and sample settings that are suitable for the test being run. The needed test output will also be listed in the methodology file.

Elastic Modulus, Breaking Tensile Stress, Maximum Load, and Extension (mm) will be the main outputs for the current investigation.

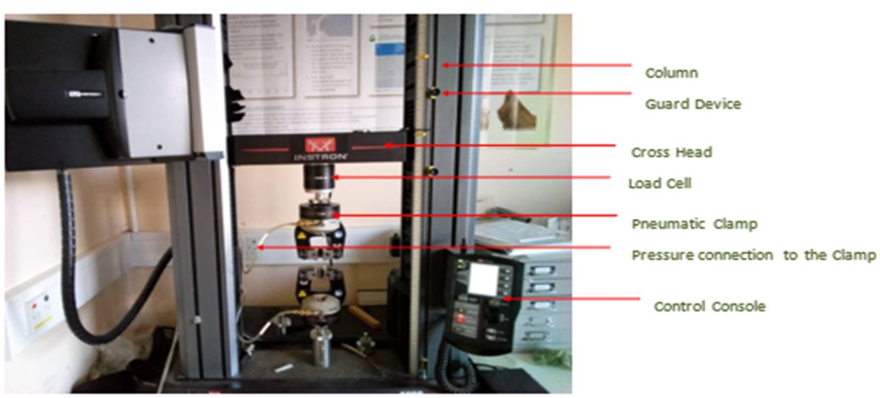


Fig. 3.4: Universal Testing Machine (UTM)

The Universal Testing Machine (UTM) crosshead is relocated to a place where the clamps are 35mm apart after the Instron has been set up and the root samples have been prepared. Next, a vertical position for the root sample is established between the bottom and top clamps. The root sample will be carefully positioned in the rubber pads so that they won't fall out throughout the test. The root will initially be forceps-inserted into the bottom clamp. In order to avoid crushing the hand and injuries under the clamps, pre-stressing the roots, and reducing water content of the roots due to manual handling, forceps are utilised in placing the roots between the clamps. All the experiments for this study was performed at the civil engineering laboratory of Michael Okpara University of Agriculture, Umudike.

XI. DETERMINATION OF THE SOIL PROPERTIES

All laboratory tests carried out which included determination of natural moisture content of the laterite, particle size distribution of laterite, and direct shear test was performed in accordance with BS 1377:1975.

XII. RESULTS AND DISCUSSION

To ascertain if the observed difference were significant, a paired sample t-test was performed with the null hypothesis that the instrument used in measuring the root diameter (i.e., microscope and digital calliper) does not affect the mean of the diameters obtained. The values of the root diameter of *Pennisetum purpureum* (grass) root obtained using microscope was significantly different compared to the values obtained when digital callipers [$t\ (18) = 4.40$, and $p\text{-value} < 0.001$]. Hence the equal mean null hypothesis was rejected. However, for the tree roots (*Mangifera indica*) the difference between the diameters of the roots measured with microscope compared with the digital calliper was not significant, [$t\ (26) = 1.178$, and $p\text{-value} < 0.249$]

XIII. CONCLUSION

The following conclusions were drawn from the result obtained in this study:

1) Greater tensile strength values were obtained for the tree roots (Mangifera indica) compared to the grass roots (Pennisetum purpureum).
2) Dehydrated roots have more tensile strength compared to the hydrated roots. Hence, this study hypothesizes that as the soil get drier, there is an opportunity for the tensile strength of the roots to increase.
3) The grass root species loses moisture faster compared to the tree roots. This is because, the tree roots have less surface area compared to the grass roots.
4) The soil in the study area has poor engineering quality this exacerbated the rate of soil erosion in the area.

REFERENCES

[1] ARNONE, E., CARACCIOLO, D., NOTO, L. V., PRETI, F. & BRAS, R. L. 2016. Modeling the hydrological and mechanical effect of roots on shallow landslides. Water Resources Research, 52, 8590-8612.
[2] BAEZA, C. & COROMINAS, J. 2001. Assessment of shallow landslide susceptibility by means of multivariate statistical techniques. Earth Surface Processes and Landforms, 26, 1251-1263.
[3] BISCHETTI, G. B., CHIARADIA, E. A., SIMONATO, T., SPEZIALI, B., VITALI, B., VULLO, P. & ZOCCO, A. 2005. Root strength and root area ratio of forest species in Lombardy (Northern Italy). Plant and Soil, 278, 11-22.
[4] BOLDRIN, D., LEUNG, A. K. & BENGOUGH, A. G. 2017b. Root biomechanical properties during establishment of woody perennials. Ecological Engineering, 109, 196-206.
[5] BOLDRIN, D., LEUNG, A. K. & BENGOUGH, A. G. 2018. Effects of root dehydration on biomechanical properties of woody roots of Ulex europaeus. Plant and Soil, 431, 347-369.
[6] BRANSBY, M. F., DAVIES, M. C. R., MICKOVSKI, S. B., SONNENBERG, R., BENGOUGH, A. G. & HALLETT, P. D. 2006. Stabilisation of slopes by vegetation reinforcement. In: Physical modelling in geotechnics, two volume set. Proceedings of the sixth international conference on physical modeling in geotechnics. 6th ICPMG'06, 4–6 August 2006. CRC Press, Hong Kong.
[7] CHOK, Y. H., JAKSA, M. B., KAGGWA, W. S. & GRIFFITHS, D. V. 2015. Assessing the influence of root reinforcement on slope stability by finite elements. International Journal of Geo-Engineering, 6, 13.
[8] COPPIN N.J., RICHARDS I.G. 2007. Use of vegetation in civil engineering. Construction Industry Research and Information Association, London.
[9] DE BAETS S., POESEN J., KNAPEN A., BARBERA G.G., NAVARRO J.A. 2008. Root characteristics of representative Mediterranean plant species and their erosion-reducing potential during concentrated runoff. Plant and Soil 294: 169-283.
[10] DE BAETS, S., POESEN, J., REUBENS, B., MUYS, B., DE BAERDEMAEKER, J. & MEERSMANS, J. 2009. Methodological framework to select plant species for controlling rill and gully erosion: application to a Mediterranean ecosystem. Earth Surface Processes and Landforms, 34, 1374-1392.
[11] GENET, M., STOKES, A., SALIN, F., MICKOVSKI, S., FOURCAUD, T., DUMAIL, J. F. & VAN BEEK, R. 2005. The influence of cellulose content on tensile strength in tree roots. Plant and Soil, 278, 1-9.

[12] GHESTEM, M., SIDLE, R. C. & STOKES, A. 2011. The Influence of Plant Root Systems on Subsurface Flow: Implications for Slope Stability. Bioscience, 61, 869-879.

[13] GHESTEM, M., VEYLON, G., BERNARD, A., VANEL, Q. & STOKES, A. 2014. Influence of plant root system morphology and architectural traits on soil shear resistance. Plant and Soil, 377, 43-61.

[14] GIBSON, A. D., CULSHAW, M. G., DASHWOOD, C. & PENNINGTON, C. V. L. 2013. Landslide management in the UK-the problem of managing hazards in a 'low-risk' environment.Landslides, 10, 599-610.

[15] GRAY, D. H., MEGAHAN, W. F. 1981. Forest vegetation removal and slope stability in the Idaho Batholith. USDA Forest Serv., Research Paper INT-271, 23.

[16] GYSSELS, G., POESEN, J., BOCHET, E. & LI, Y. 2005. Impact of plant roots on the resistance of soils to erosion by water: a review. Progress in Physical Geography, 29, 189-217.

[17] HALES, T. C. & MINIAT, C. F. 2017. Soil moisture causes dynamic adjustments to root reinforcement that reduce slope stability. Earth Surface Processes and Landforms, 42, 803-813.

[18] HALES, T. C., COLE-HAWTHORNE, C., LOVELL, L. & EVANS, S. L. 2013. Assessing the accuracy of simple field-based root strength measurements. Plant and Soil, 372, 553-565.

[19] HIGHLAND, L.M 2012. Landslides in Colorado, USA: Impacts and loss estimation for 2010, Open-File Report 2012–1204. U.S. Geological Survey, Reston

[20] LEUNG A.K., GARG A., COO J.L., NG C.W.W., & HAU B.C.H. 2015. Effects of the roots of Cynodon dactylon and Schefflera heptaphylla on water infiltration rate and soil hydraulic conductivity. Hydrological Processes 29: 3342-3354.

[21] LOADES, K.W., BENGOUGH, A.G., BRANSBY, M.F., HALLETT, P.D., 2013. Biomechanics of nodal, seminal and lateral roots of barley: effects of diameter, water logging and mechanical impedance. Plant Soil 370, 407–418.

[22] MAO, Z., SAINT-ANDRE, L., GENET, M., MINE, F. X., JOURDAN, C., REY, H., COURBAUD, B. & STOKES, A. 2012. Engineering ecological protection against landslides in diverse mountain forests: Choosing cohesion models. Ecological Engineering, 45, 55-69.

[23] MAO, Z., YANG, M., BOURRIER, F. & FOURCAUD, T. 2014. Evaluation of root reinforcement models using numerical modelling approaches. Plant and Soil, 381, 249-270.

[24] MICKOVSKI S.B., VAN BEEK L.P.H. 2009. Root morphology and effects on soil reinforcement and slope stability of young vetiver (Vetiveria Zizanioides) plants grown in semiarid climate. Plant and Soil 324: 43-56.

[25] MICKOVSKI, S. B., HALLETT, P. D., BRANSBY, M. F., DAVIES, M. C. R., SONNENBERG, R. & BENGOUGH, A. G. 2009. Mechanical Reinforcement of Soil by Willow Roots: Impacts of Root Properties and Root Failure Mechanism. Soil Science Society of America Journal, 73, 1276-1285.

[26] NI J.J., LEUNG A.K., NG C.W.W., SHAO W. 2017. Modelling hydro-mechanical reinforcements of plants to slope stability. Computers and Geotechnics 95: 99-109

[27] NORRIS J.E, & GREENWOOD J. R. 2006. Assessing the role of vegetation on soil slopes in urban areas. In: Proceedings of the 10th IAEG International Congress, Nottingham, September 2006.

[28] PEREZ-HARGUINDEGUY, N., DIAZ, S., GARNIER, E., LAVOREL, S., POORTER, H., JAUREGUIBERRY, P., BRET-HARTE, M. S., CORNWELL, W. K., CRAINE, J. M., GURVICH, D. E., URCELAY, C., VENEKLAAS, E. J., REICH, P. B., POORTER, L., WRIGHT, I. J., RAY, P., ENRICO, L., PAUSAS, J. G., DE VOS, A. C., BUCHMANN, N., FUNES, G., QUETIER, F., HODGSON, J. G., THOMPSON, K., MORGAN, H. D., TER STEEGE, H., VAN DER HEIJDEN, M. G. A., SACK, L., BLONDER, B., POSCHLOD, P., VAIERETTI, M. V., CONTI, G., STAVER, A. C., AQUINO, S. & CORNELISSEN, J. H. C. 2013. New handbook for standardized measurement of plant functional traits worldwide. Australian Journal of Botany, 61, 167-234.

[29] PETLEY, D. 2012. Global patterns of loss of life from landslides. Geology, 40, 927-930.

[30] POHL, M., STROUDE, R., BUTTLER, A. & RIXEN, C. 2011. Functional traits and root morphology of alpine plants. Annals of Botany, 108, 537-545

[31] PUNETHA, P., SAMANTA, M. & SARKAR, S. 2019. Bioengineering as an Effective and Ecofriendly Soil Slope Stabilization Method: A Review. In: PRADHAN, S. P., VISHAL, V. & SINGH, T. N. (eds.) Landslides: Theory, Practice and Modelling. Cham: Springer International Publishing. 27

[32] SAHPUTRA, I.H., ALEXIADIS, A., ADAMS, M.J., 2019. Effects of Moisture on the Mechanical Properties of Microcrystalline Cellulose and the Mobility of the Water Molecules as Studied by the Hybrid Molecular Mechanics–Molecular Dynamics Simulation Method. Journal of Polymer Science Part B: Polymer Physics, 57(8), pp.454-464.

[33] SCHMIDT K.M., ROERING J.J., STOCK J.D., DIETRICH W.E., MONTGOMERY D.R., SCHAUB T. 2001. The variability of root cohesion as an influence on shallow landslide susceptibility in Oregon Coast Range. Canadian Geotechnical Journal 38: 995-1024.

[34] SCHWARZ, M., GIADROSSICH, F. & COHEN, D. 2013. Modeling root reinforcement using a root-failure Weibull survival function. Hydrology and Earth System Sciences, 17, 4367-4377.

[35] SCHWARZ, M., LEHMANN, P. & OR, D. 2010. Quantifying lateral root reinforcement in steep slopes - from a bundle of roots to tree stands. Earth Surface Processes and Landforms, 35, 354-367.

[36] SIMON A. & COLLISON A.J.C. 2002. Quantifying the mechanical and hydrological effects of riparian vegetation on streambank stability. Earth Surface Processes and Landforms 27: 527-546.

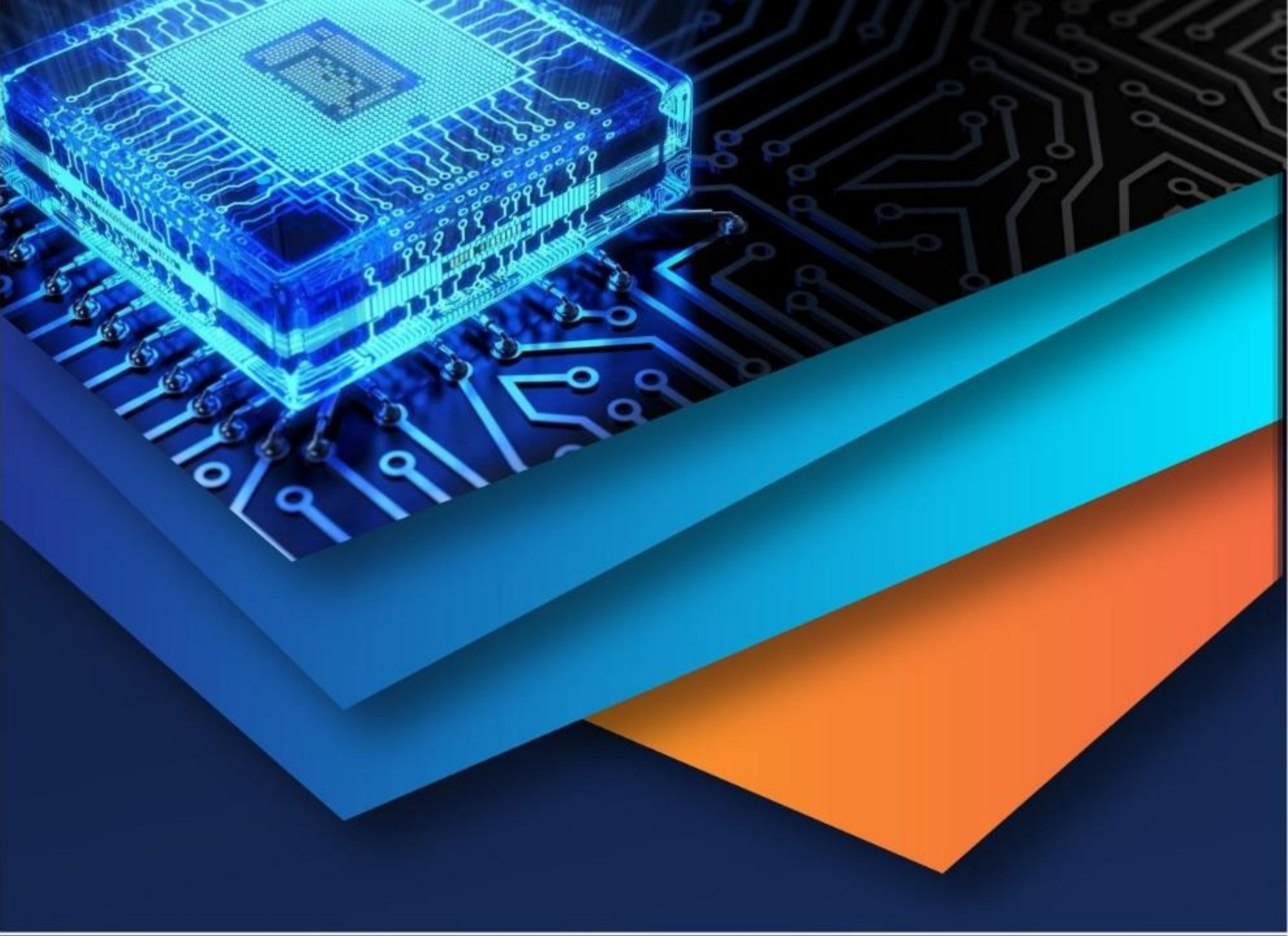
[37] SINGH, T. N. (eds.) Landslides: Theory, Practice and Modelling. Cham: Springer International Publishing. 27

[38] STOKES, A., ATGER, C., BENGOUGH, A. G., FOURCAUD, T. & SIDLE, R. C. 2009. Desirable plant root traits for protecting natural and engineered slopes against landslides. Plant and Soil, 324, 1-30.

[39] TOSI M. 2007. Root tensile strength relationships and slope stability implications to three shrub species in the Northern Apennines (Italy). Geomorphology 87: 268-283.

[40] VEYLON G., GHESTEM M., STOKES A., & BERNARD A. 2015. Quantification of mechanical and hydric components of soil reinforcement by plant roots. Canadian Geotechnical Journal 52(11).

[41] WALDRON, L. J. 1977. The Shear Resistance of Root-Permeated Homogeneous and Stratified Soil1. Soil Science Society of America Journal, 41, 843-849.



10.22214/IJRASET

INDEX COPERNICUS 45.98

IMPACT FACTOR: 7.129

TOGETHER WE REACH THE GOAL

IMPACT FACTOR: 7.429

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY