OVERVIEW OF SOIL EROSION

Abstract

Soil, a complex and dynamic natural resource, plays a pivotal role in supporting terrestrial ecosystems and providing essential services to humanity. This abstract delves into the multifaceted nature of soil by exploring its composition, properties, and functions, highlighting its critical importance in sustainable land management. The composition of soil involves a heterogeneous mixture of mineral particles, organic matter, water, air, and various microorganisms. The interactions between these components give rise to distinct soil horizons, each with its unique characteristics that influence soil's physical, chemical, and biological properties.

Keywords: Soil, Soil Bio-Engineering, Soil Erosion, Root Morphology.

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I. SOILS

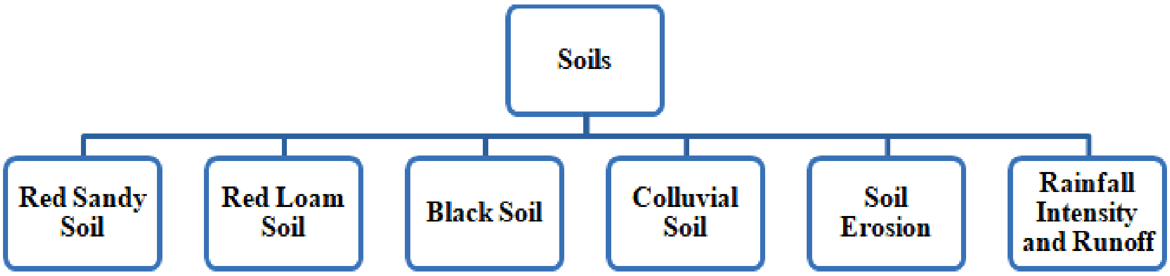

Figure 1: Classification of Soils

In some locations, the rocks forming the original slope have been altered, disturbedand mixed so much that they have lost most of their original characteristics. In figure 1 represent the classification of soils. The result is a material, which in engineering terms can cover anything not defined as a pure rock. Some materials have been altered sufficiently to be classed as a soil [1]. Whatever their state, all soils and altered materials have their own characteristics when subjected to geomorphological process. For this reason, they must be examined separately in any consideration of slope stability [2].

This research focus on reducing soil erosion and degradation combined withshallow landslips prevention, to have better understanding it is necessary to analyse the soil types in the area of study. The study area's soils are broadly categorized into five types suchas Black dirt, alluvial soil, and red loam, colluvial soil and in certain areas lateritic soils were also found. In the district, there are minor spots of red sandy soil and red loams.,it is noticed that black soil is also developed among the valleys susceptible to logging of water during rainy seasons. Valleys and major river beds and surrounding areas contains alluvial and colluvial soils [3].

1. **Red Sandy Soil:** Red soils form a group of soil which is developed in moist and warm, temperate climate near the deciduous forests. They possess smaller organic or inorganic mineral layers over an alluvial red layer. A set of soils known as "red soil" are those that have thin organic and organic-mineral layers atop a yellowish-brown leached layer resting on an organic layer and that have developed in a warm, humid climate beneath deciduous or mixed woods alluvial red layer. They are taken from crystalline rocks, termed as poor growing and contain low nutrients, humus, possess low capacity in terms of water holding. They are part of the omnibus group and have been developed on Gneiss, Archaean granite, and a few crystalline rocks. Because ferric oxides are present and form thin coats around soil particles, the color of the soil is due to their presence. This coating of ferric oxide on the soil particles is what gives the soil its color.[4].

2. **Red Loam Soil:** Loam is a type of soil that is not mostly sand, silt or clay as per Textural classification, they contain more moisture and nutrients coupled with humus when compared with any sandy type of soils, and also they possess more drainage capabilities. Every different type of loam soils have varying characteristics concerned with drainage characters, they naturally contain about sand: silt: clay as 40:40:20 by weight.

3. **Black Soil:** Black soil is a major type of soil which is created due to disintegration of lava rocks and hence they are found mostly in mountaneous regions, also its abuntandly found in coastal regions and its found to be more suitable for growing cotton which created a name “Black Cotton Soil”. They are called as black cotton soil or tropical black earth which has been developed due to the weathering of lava, their color is due to the presence of titaniferous magnetite, iron and Al2SiO3, soil humus and hydrated double iron and Al2SiO3. This type of soils have more clayey texture with clay content of more than 50% generally, but the clay content will be more uniform than other varieties of soil [6].

4. **Colluvial Soil:** Colluvial soil or in general colluvium is the name given for loosely packed, sediments that are unconsolidated and deposited in the hill base owing to various agents such as rain, sheet wash, downslope creep or combination of multiple factors mentioned. It is made up of heterogeneous rocks and sediments covering from silt to rock fragments of various sizes, this term colluvium may also refers to the sediment deposits that may occur due to the surface runoff or sheet erosion.

5. **Soil Erosion:** Hilly regions face many problems such as soil degradation combined with soil compaction, deterioration of organic content, soil structure loss, reduced internal drainage, soil saline issues and acidity related problems, the study area is affected by all of those issues coupled with soil erosion. Soil loss from slopes and farmlands results in reduced crops production potential, surface water quality reduction and discontinuous drainage networks. Major factors causing soil erosion along a slope can be classified into energy factors (erosion due to rain, runoff volume, angle and length of slope), protection factors (coverage of soil with plants, land management and population density) and resistance factors (erodibility of soil, infiltration capacity of soil and management of soil). Soil erosion in an area may be resulting due to any of this parameter or mostly due to the combination of the above parameters, identifying a single factor causing the soil erosion is tedious. During rainfall, when the exposed soil surface is touched by the rain water droplets, it ends up in any of the following: Production of smaller aggregates, particle dispersion and keeping them in suspension, deposition and translocation of particles. Break down of aggregates depends on soil strength, a certain amount of kinetic energy is required for the water to induce soil detachment, and this can be prevented by the prevailing plants. It is found that soils with high particle content suffers with more detachment such as silty loam, find sand, sandy loam etc. (particle size between 0.063 mm to 0.250 mm). In the study area most of the area is covered with this variety of soil and it’s susceptible to soil erosion with higher intensity of rainfall [8].

6. **Rainfall Intensity and Runoff:** Soil erosion is a major cause of concern that should be addressed in hilly regions, both precipitation and overflow components must be considered in analysing water Erosion issue. Raindrops falling on the soil surface can separate soil mass and may scatter the total material, if the material is lighter (fine sand, sediments etc.), they can be moved away effectively when it falls over them. For moving larger particles such as rock particles and bigger sand more velocity is required. Spillover may occur at the points where there is more water particles in a slope which cannot be drained or stopped naturally. Water runoff may occur when there is excess water prevailing in a slope that cannot be absorbed or trapped on the surface [9].

II. SOIL BIO-ENGINEERING

Numerous methods exist for enhancing slope stability, including soil nailing, retaining structures, geosynthetic reinforcement, geotextile reinforcement, shotcrete, and Vibro compaction. Here we adopt a moderate method to reduce the small-scale landslides by using soil bioengineering. Bioengineering involves employing living plants for engineering applications. The selection of vegetation is a meticulous process, considering its capacity to effectively stabilize roadside slopes and its compatibility with the site. Typically, it is employed in conjunction with civil engineering structures. While bioengineering introduces a novel toolkit for engineers, it generally complements rather than substitutes the use of civil engineering structures. Integrating bioengineering techniques typically provides a more efficient problem-solving approach. The necessary materials and expertise are accessible even in remote rural areas. Soil bioengineering is an emerging method that emphasizes enhancing slope stability through the characteristics of plant roots. This science focuses on mitigating small-scale landslides by harnessing the capabilities of plant and tree roots while understanding their contributions to slope stability. Roots exhibit two distinct behaviors: they act as mechanical reinforcements and enhance hydrological properties. Soil tends to have high compressive strength but lower resistance to tension. Similarly, root has a high resistance at tension and low strength at compression. In practically it is applicable for slope stability, so we conduct experiments for quantifying the root behavior on slope stability i.e a rise in the soil's shear strength characteristics.

The existence of vegetation elevates both soil shear strength and slope stability, making the choice of plant type and its root system critical factors in determining stability. When implementing soil bioengineering techniques at a local level, the careful selection of suitable plants is paramount. In various riverbank construction projects, bioengineering practices such as cutting, live fascines, and brush mattresses, combined with vegetated geogrids and geo-gabions, have been successfully employed. The anchoring capacity of roots can be assessed either in the field or through laboratory testing, revealing that the interaction between soil and roots significantly enhances shear strength [10].

The soil-root system is expected to serve as a reinforcing agent, capable of absorbing tensile stresses on the soil by enhancing its shear strength. The effectiveness of this reinforcement relies on several factors, including root length, penetration depth, lateral spread, thickness, and the development of root hairs. According to some researchers, slopes' resistance to failure will increase as root penetration increases. [11]. Furthermore, root growth is influenced by soil type, with roots tending to be constrained to cracks in clay or clayey loam textures, while they can penetrate large pores in soils with a granular structure. The mechanical properties of roots are contingent on factors such as plant species, soil characteristics, and the method used for planting [12].

In the oldest stand, tree roots exhibited greater tensile strength in comparison to roots in both the middle-aged and young stands, even within the same diameter range. The variance in root tensile strength among the plantations may be attributed to variations in root structure, with older trees potentially having higher cellulose content. [13]. Hence, examining the cellulose content in roots from the three plantations becomes a compelling area of investigation. Soil bioengineering is a technique that harnesses the capabilities of plants to fulfill essential engineering roles such as catchment, armor, reinforcement, drainage, and support. It has proven to be a highly effective method for transforming potential failure surfaces into stable and erosion-resistant terrains. This approach is widely embraced worldwide as a viable solution for combatting soil erosion and averting the collapse of unstable slopes [14].

1. **The Role of Bioengineering:** Bioengineering mitigates the occurrence of shallow planar sliding.

   - Bioengineering can safeguard nearly all slopes from erosion.
   - Bioengineering enhances surface drainage and minimizes slumping.
   - Bioengineering systems function similarly to civil engineering systems, serving the same purposes, and are effective up to a depth of approximately 500 mm beneath the surface. However, they are not suitable for addressing deep-seated slope failures. Bioengineering entails utilizing grasses, shrubs, and certain tree varieties to protect slopes by harnessing the hydrological and mechanical effects of these plants. The presence of vegetation increases the slope's factor of safety, a well-acknowledged parameter among researchers. However, vegetation alone is insufficient and should be combined with engineering structures. Many regions find bioengineering advantageous due to factors such as an abundant labor force, a predominantly agricultural workforce, and a wide variety of indigenous plants suitable for local growth. Bioengineering's limitations are evident in its inability to impact stability beyond the depth of root penetration, typically limited to around 1 meter. Claims of exceptionally deep rooting should be approached with caution, as they are exceptions rather than the norm. The effects of vegetation on a slope are site-specific, and making broad generalizations can lead to unwarranted optimism about achievable results. While bioengineering techniques may involve higher upfront costs compared to a "do nothing" approach, they are expected to yield long-term benefits through reduced maintenance expenses [14].

2. **Bioengineering Systems and their Effects:** The practical application of using vegetation for engineering purposes often diverges from theoretical ideals. In cases of gentle slopes, a straightforward planting pattern often suffices. However, when dealing with steep and inherently unstable roadside slopes, practical experience has revealed that a relatively small set of robust techniques can effectively address the various engineering needs. The slopes addressed in this manual exhibit extreme characteristics in terms of length, steepness, the vulnerability of their materials, and the intensity of recurring monsoon rainfall. At this juncture, our focus is solely on identifying the engineering functions required to stabilize them. Thus far, we've explored the fundamental principles of vegetation in engineering and the contributions of individual plants. Yet, the combined use of multiple plants can yield much more significant effects than what individual plants can achieve alone. For instance, a single grass plant can capture a modest amount of debris and reinforce a small volume of soil with its root system. However, by planting grasses across a slope, they form a continuous line for debris capture, effectively providing reinforcement along an extended line rather than just a single point. In fulfilling these functions, the contour line of grass also enhances the soil's infiltration capacity. Despite the versatility of bioengineering techniques, the intricate nature of most sites necessitates the use of a variety of techniques, similar to how civil engineering projects typically involve a range of distinct structures that serve separate yet complementary functions [15].

III. ROOT MORPHOLOGY

It is the architecture, structure and shape of root system that is being used in soil bioengineering purpose, it plays key role in soil strength enhancement and nutrient acquisition (Bibalani et al., 2007, Noorasyikin and Zainab Mohamed, 2015). Plant roots contribute to the apparent cohesion of soil by providing root reinforcement, consequently bolstering slope stability (Schmidt et al., 2001; van Beek et al., 2005). The root soil reinforcement model, initially formulated by Wu (1976) and later refined by Waldron (1977), is a commonly adopted framework for quantifying the supplementary cohesion attributed to the presence of roots within the soil matrix (Bischetti et al., 2005). Some of the main features of root morphology that are viewed while considering the plant for bioengineering includes root biomass, spread of root, depth of root, distribution of root [16].

1. **Root Area Ratio (RAR):** It is the ratio of the cross-sectional area of root covered on the soil to the cross- sectional area of root covered on soil at rooting depth. It is calculated by counting the total roots of various diameter classes in a particular cross sectional area of the soil, exposed on a vertical face (De Baets and Poesen, 2008). It is an important parameter that defines and controls the shear strength increase due to the presence of roots. The Root Area Ratio can be calculated by dividing root biomass by the root fiber's unit weight (Leuschner et al., 2004). To establish a model for determining the unit weight of roots per stand, measurements of root length, diameter, and weight were taken from a chosen sample of roots.

2. **Root Biomass:** It is calculated by weighing the total amount of roots per unit volume of soil, rootswere taken from core samples and separated as per their diameter classes before weighing (Drexhage and Gruber, 1998). Each diameter class of root is weighed with a precision balance of accuracy greater than 0.001 mg and the root biomass was obtained according tothe volume of auger, it's usually expressed in g /m^3.

3. **Root Distribution:** Distribution of root inside the soil depends on type of plant and the type of roots it develop, also the resource uptake and efficiency is influenced by the distribution, this canchange the stress distribution , plastic type of strains that develop in the soil and also it modifies the pull-out resistance. Studies convey that most preferred systems are dichotomous than herringbone when it comes to anchorage of roots. In any plant, if the root forks grow vertically downwards, they may cross the potential shear zone and they can anchor the soil properly [19].

IV. ROOT TRAITS

Root reinforcement is the main parameter that should be looked upon while deciding the stability of slopes. On the figure 2 represent the classification of root traits. One of the researcher studied and obtained the root characteristics that may have possible impact of reducing soil erosion. After the intersection point they found the parameters namely root length density, The parameters under consideration encompass Root Area Ratio, root taper, basal diameter, root density, root inclination, the proportion of exposed soil covered by fine roots, maximum root depth, branching pattern, angle between lateral roots, and total length. It is clear that, particularly in the context of soil mechanics, the structural characteristics of roots, referred to as root architecture, assume a pivotal role. In addition to these parameters, we delve further into the examination of root traits, including root length density, root density, specific root length, total root length, root diameter, root angle, and leaf area index [20].

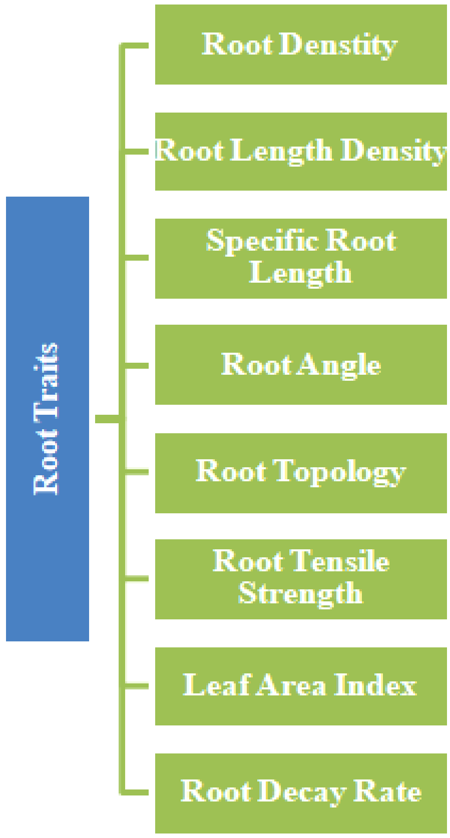

Figure 2: Classification of Root Traits

1. **Root Density:** Root density is the main affecting the permeability of the soil caused by creates the voids. It is the weight of root per unit volume of the root. Normally it is expressed in g/cm3. The proliferation of shear strength due to vegetation is directly proportional to the root density [20].

2. **Root Length Density:** It is a critical feature which determines the crops potential to uptake soil water and nutrients, mostly it's a parameter that is very difficult to measure which has no standard methods to measure. It is measured that the resistance to pull-out will increase with the increase in root length density since it causes the roots to break in tension rather than slipping out of soil. Soil water content also affects the slopes stability and a plant having higher RLD is desirable since they absorb more water [20].

3. **Specific Root Length:** It is defined as the length of the roots per unit dry soil mass, higher the value indicates more thinner roots and if it's low the plant will have less but thick roots, for soil bioengineering practice it is advisable to have herbs and grasses with high SRL values as much as possible [21].

4. **Root Angle:** Root angle is the angle between the daughter and mother roots measured in both vertical and horizontal planes, a plant that contains roots with multiple orientation

ranges, will develop wide shearing zones, it can fully mobilize the root reinforcement by the tensile strength of the roots [22].

5. **Root Topology:** Topology of roots in the organization of the roots branching, it influences various parameters such as uptake of resources (soil nutrients) and can also effect the stress distribution within soil and also modifies the pull-out resistance of the roots. Concerned with root topology preferred for soil bioengineering Dichotomous systems are preferred than herringbone systems owing to their better anchorage capability [23].

6. **Root Tensile Strength:** Tensile strength of root is defined as the maximum resistance it can offer without disintegrating in tension, to mobilize fullest strength a high resistance is required and also to increase the shear strength of the soil. Thus it's preferred to have more finer and smaller roots in soil, rather than having few long and thick roots [24].

7. **Leaf Area Index:** It is defined the ratio of the area of one leaf to the whole leaf covered to the soil. It will give a state of plant growth proliferation. It can be helpful to the study on how the plant grew and their area of leaf spreading [24].

8. **Root Decay Rate:** Roots decay when the plants die, the rate of decay depends on diameter of the root, roots chemical composition and the plant species. Concerned with soil bioengineering plant roots that possess slow decaying characteristics is preferred since they will be able to fix soil for quite longer period, also the decayed roots create a flow path for the water to drain [23].

V. ROOT REINFORCEMENT

In hilly terrain slope stability is directly proportional to the vegetation's contribution in terms of root reinforcement (Sidle et al., 1992). A plant root plays a huge role in soil reinforcement function through anchoring the soil and formation of a binding network within the layers of soil which ties the soil masses. Quantification of roots reinforcement capability is bit more complex owing to the heterogeneity or root distribution and the turnover dynamics which ends up creating complexity in calculation of slope stability (Schwarz et al., 2013). The factors that influences the FOS includes density of soil, porosity, saturation level of soil, natural water content, permeability characteristics etc. In terms of hydrological concepts, the plant canopy present above the ground acts as a soil erosion protection agent owing to its intercepting capability of raindrops. Also, it enhances the soil filtration rather and removes the water present is soil through evapo-transpiration. The quantum of reinforcement a plant can offer is related to the capacity of its individual roots tensile strength and the architecture of the roots, it varies from plant to plant and depends on the diameter of root, its age, the properties of soil nutrients, moisture content of soil and the chemical composition[25].

VI. CONCLUSIONS

In summary, the exploration of soil types serves as a reminder of the intricate relationships between Earth's geological processes, ecological systems, and human activities. As stewards of the land, it is incumbent upon us to recognize the value of soil diversity, implement responsible practices, and safeguard this precious resource for present and future generations. Through continued research, education, and conscientious actions, we can ensure that soil types remain a foundation for thriving ecosystems and sustainable development.

REFERENCES

[1] Kolapo P, Oniyide GO, Said KO, Lawal AI, Onifade M, Munemo P. An overview of slope failure in mining operations. Mining. 2022 Jun 2;2(2):350-84.
[2] Fookes PG. Geology for engineers: the geological model, prediction and performance. Quarterly Journal of Engineering Geology and Hydrogeology. 1997 Nov;30(4):293-424.
[3] Poesen J. Soil erosion in the Anthropocene: Research needs. Earth surface processes and landforms. 2018 Jan;43(1):64-84.
[4] Carroll D. Rock weathering. Springer Science & Business Media; 2012 Dec 6.
[5] Siderius W. *Soil transitions in central east Botswana (Africa)* (Doctoral dissertation, International Institute for Aerial Survey and Earth Sciences).
[6] Siderius W. *Soil transitions in central east Botswana (Africa)* (Doctoral dissertation, International Institute for Aerial Survey and Earth Sciences).
[7] Dethier DP, Birkeland PW, McCarthy JA. Using the accumulation of CBD-extractable iron and clay content to estimate soil age on stable surfaces and nearby slopes, Front Range, Colorado. Geomorphology. 2012 Nov 1;173:17-29.
[8] Borrelli P, Alewell C, Alvarez P, Anache JA, Baartman J, Ballabio C, Bezak N, Biddoccu M, Cerdà A, Chalise D, Chen S. Soil erosion modelling: A global review and statistical analysis. Science of the total environment. 2021 Aug 1;780:146494.
[9] Carey SK, Woo MK. Slope runoff processes and flow generation in a subarctic, subalpine catchment. Journal of hydrology. 2001 Nov 15;253(1-4):110-29.
[10] Hubble T, Clarke S, Stokes A, Phillips C. 4th International Conference on soil bio-and eco-engineering (SBEE2016)'The Use of Vegetation to Improve Slope Stability'. Ecological engineering. 2017 Dec 1;109:141-4.
[11] Giadrossich F, Cohen D, Schwarz M, Seddaiu G, Contran N, Lubino M, Valdés-Rodríguez OA, Niedda M. Modeling bio-engineering traits of Jatropha curcas L. Ecological Engineering. 2016 Apr 1;89:40-8.
[12] McCauley A, Jones C, Jacobsen J. Basic soil properties. Soil and water management module. 2005;1(1):1-2.
[13] Genet M, Stokes A, Fourcaud T, Hu X, Lu Y. Soil fixation by tree roots: changes in root reinforcement parameters with age in Cryptomeria japonica D. Don. plantations. InInterpraevent 2006 Sep 25 (pp. 25-27).
[14] Kotay SM, Mansell BL, Hogsett M, Pei H, Goel R. Anaerobic ammonia oxidation (ANAMMOX) for side- stream treatment of anaerobic digester filtrate process performance and microbiology. Biotechnology and Bioengineering. 2013 Apr;110(4):1180-92.
[15] Chang HN, editor. Introduction to Emerging Areas in Bioengineering. Emerging Areas in Bioengineering. 2018 Jan 9;1:3-20.
[16] Barber SA, Silberbush M. Plant root morphology and nutrient uptake. Roots, nutrient and water influx, and plant growth. 1984 Jan 1;49:65-87.
[17] Takatsuki-Hira A, Kaketani M, Shimizu K, Tamura T, Nakamura T, Toyama Y, Yoneyama T, Takeichi O. Efficacy of prototype endodontic obturators for novel root canal obturation techniques using a resin-based sealer in various powder-liquid ratios. Journal of Oral Science. 2021;63(2):157-62.
[18] MEVENKAMP G, LIEBEREI R, HARNISCHFEGER G. III Baptisia tinctoria (L.) R. Brown: Micropropagation, In Vitro Culture and Production in Direction of Pharmaceutically Used Root Biomass. Medicinal and Aromatic Plants VII. 2013 Nov 11;28:43.
[19] de Kroon H, Visser EJ, editors. Root ecology. Springer Science & Business Media; 2003 May 21.
[20] Kumar B, Dhar S, Vyas AK, Paramesh V. Impact of irrigation schedules and nutrient management on growth, yield and root traits of wheat (Triticum aestivum) varieties. Indian Journal of Agronomy. 2015;60(1):87-91.
[21] Atkinson D. Root characteristics: why and what to measure. InRoot methods: a handbook 2000 (pp. 1-32). Berlin, Heidelberg: Springer Berlin Heidelberg.
[22] Qian YM, Zhong Q, Chen S, Tie SJ. Effects of different post-core materials with different angles on fracture resistant ability of the maxillary central incisor. Chinese Journal of Tissue Engineering Research. 2017 Aug 8;21(22):3507.

[23] Robinson D, Hodge A, Fitter A. Constraints on the form and function of root systems. InRoot ecology 2003 (pp. 1-31). Berlin, Heidelberg: Springer Berlin Heidelberg.
[24] Velagala MK, Buddi G, Chari KB, Kishore IS. Tensile and flexural behavior of high strength concrete reinforced with natural (velvet mesquite) fibers. Technology. 2017;8(4):1384-93.
[25] Wu TH. Root reinforcement of soil: review of analytical models, test results, and applications to design. Canadian Geotechnical Journal. 2013;50(3):259-74.