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REVIEW ARTICLE

Exploring The Mechanism Of Vetiver System For Slope Reinforcement On Diverse Soil Types – A Review

Anissa Maria Hidayati[1], Kadek Hindhu Kedaton[1], Silvia Gabrina Tonyes[1,2], Elizar[4], Yenni Ciawi[1,2,3] *

[1] *Civil Engineering Department, Udayana University, Bali 80361, Indonesia*
[2] *Doctoral Program in Engineering Sciences, Udayana University, Bali 80234, Indonesia*
[3] *Environmental Engineering Department, Udayana University, Bali 80361, Indonesia*
[4] *Civil Engineering Department, Riau Islamic University, Pekan Baru 28284, Indonesia*

* Corresponding author: yenniciawi@unud.ac.id
Tel.:+62-8133-796-576;
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Abstract

Landslide, one of the important geomorphological processes, is essentially a natural phenomenon that is often exacerbated by human-induced activities. A stable sloping terrain will tend to collapse when it is subjected to forces that tend to destabilise it. Slope instability is one of the main factors leading to disasters that might be catastrophic to the environment and human life. Since the beginning of the year 2000 only, thousands of fatalities annually occurred globally due to landslides. With its predominantly sloping topography, the landslide is also a frequent natural disaster in Indonesia. BNPB data stated that between 2013 and 2022, there were 7,297 recorded cases of landslides in the country with more than 100 casualties on one occasion. To mitigate the impact of this disaster, measures such as reinforcing slopes or implementing retaining walls in vulnerable areas are urgently required. In recent decades, bio-engineering techniques gain more attention in slope reinforcement by combining the mechanical and hydrological abilities of vegetation in erosion control and slope stabilisation. Vetiver grass is one of the vegetation species used in bioengineering techniques due to its low cost and more sustainable solutions in many infrastructure projects. In this paper, a qualitative literature review is conducted and processed using descriptive-analytical methods to address the mitigation of landslides and their potential domino effects on the economy and people's welfare.

Keywords: *Disaster mitigation, Landslide, Bio-Engineering, Vetiver*

1. Background

Landslides are significant geomorphological processes that can be exacerbated by human activities. These events, characterized by a decline in slope shear strength, contribute to sediment fluxes in mountainous regions and often manifest as shallow slope failures and hillside debris flows triggered by rainfall-induced soil erosion (Ma et al., 2020; Yuskar et al., 2017). The ecological and man-made consequences of landslides include land degradation, infrastructure hazards, and fatalities (Shu et al., 2019). Due to its high rain intensities and steep topographical conditions, Indonesia is particularly susceptible to landslides (Isnaini, 2019; Zamroni et al., 2020).

According to (Ritchie et al., 2022), landslides have claimed thousands of lives worldwide since the year 2000. Indonesia, with its predominantly hilly terrain, has experienced 7,297 landslide incidents resulting in over 100 deaths in a single instance from 2013 to 2022, as reported by (BNBP, 2023). Urgent measures are necessary to mitigate the impact of this disaster, such as slope reinforcement and the construction of retaining walls in vulnerable areas.

Slope reinforcement involves increasing the soil's shear strength to withstand destabilizing forces. Conventional slope reinforcement methods typically employ hard engineering techniques, such as constructing retaining walls using materials like concrete, stone, or timber (Ciptaning et al., 2018). Alternatively, other approaches aim to prevent water accumulation and soil saturation through geometric adjustments, adequate drainage, and soil reinforcement methods, such as incorporating geotextiles, geogrids, and soil nails, and employing bio-engineering techniques. The latter approach involves utilizing plants (Islam, 2013) or utilizing plant roots (Khosiah and Ariani, 2017) to address slope landslides.

Historically, upland farmers have developed specific measures for landslide prevention, including maintenance strategies and early-stage erosion stabilization, such as closing stress cracks in the grass (Löbmann et al., 2020). However, in the mid-1980s, The World Bank introduced the Vetiver System (VS) as a biotechnological approach to agricultural land management in India. Currently, it is being developed as a technique to stabilize steep slopes and cliffs (Badriyah and Wulandari, 2020), as well as for wastewater disposal, and phytoremediation of contaminated soil and water (Abaga et al., 2021; Ambarwati and Bahri, 2018; Chen et al., 2021; Dorafshan et al., 2023; Komarawidjaja and Garno, 2016; Mahmoudpour et al., 2021), coastal erosion (Indriasari and Akhwady, 2017; Sufyan et al., 2020a), and rehabilitation of former mining lands (Kiiskila et al., 2020; Napitupulu and Purwanti, 2022; Putri, 2019). Additionally, the vetiver system is employed in the development of sustainable land use strategies from ecological, socio-economic, and environmental protection perspectives (Löbmann et al., 2020; Truong and Loch, 2004). The objective of this study is to investigate the application of the vetiver system in sloping terrains as a cost-effective, sustainable, and easily reproducible method for mitigating landslides and controlling soil erosion.

2. Slope stability

A thorough literature search was conducted using the keywords "vetiver," "slope stability," and "soil type". A total of 66 relevant sources were analyzed, including journals, and websites dating from 2010-2023. The search was conducted through a variety of search engines, such as Google, Google Scholar, NCBI Pubmed, Science Direct, MDPI, IOP Science, and Research Gate.

3. Soil Shear Strength

In geotechnical engineering, a slope is defined as the surface of the earth that forms a certain angle with the horizontal plane. On a sloping ground surface, the gravitational force component, i.e. the vertical force due to gravitational action, tends to move the soil downward. Slope failures occurred when there is a force acting upon the slope surface exceeds the internal soil shear strength (Das, 2019)

Soil shear strength, one of the soil geotechnical characteristics, is inversely determined by its water content: an increase in water content will result in a decrease in soil shear strength. Most slope failures occur after/during heavy or prolonged rains. In addition to reducing the shear strength of the soil, water that infiltrates into the soil pores also increases the weight of the soil adding vertical forces on the slope. The combination of the two can result in slope failures.

The annual rainfall characteristics influence the frequency of landslides. The softening of slope-forming materials due to the increase of the soil water content due to rain, as well as rising groundwater levels during the rainy season also affects the speed of soil mass movement. Rising groundwater level causes a reduction in the average shear strength of the soil. The increase in pore water pressure in the vicinity of the potential landslide area reduces the effective stress, thereby reducing the shear strength (Sinarta and Basoka, 2019). When it rains and water infiltrates into the ground, the soil around the soil surface gradually becomes saturated. Simultaneously with the increase in the water content in the soil, the shear strength of the soil gradually decreases, especially for fine-grained soils. This is because the pore water pressure, which was originally negative, moves to be positive (Blanco-Canqui et al., 2010).

The shear strength of the soil is affected by the surface tension in the pore water at the point of contact between the grains, which when the soil becomes saturated the surface tension disappears. As a result of the influence of surface tension, the sand seems to have cohesion (i.e. an apparent cohesion). In practice, under the influence of apparent cohesion, moist fine sand slopes can be excavated in upright conditions, even at relatively deep excavation depths. This visible cohesion sometimes does not disappear during heavy rains, however, as soon as the slope is submerged in water, the slope immediately collapses. A rise in the water level that causes an increase in pore water pressure can also cause slope failure on river banks, ponds or reservoirs. The speed of ground movement tends to increase with increasing water level. The shear strength of the soil can also be reduced by the presence of open cracks when fine-grained soils become dry or shrink. These shrinkage cracks can develop in shale or clay if the surface is not protected by sand or grass (Das, 2019).

There are two main factors controlling slope stability, i.e. the forces that tend to destabilise the slope and the inherent component of soil to resist those forces. These two factors are commonly known as Factors of Safety (FOS) or Safety Factors (SF). The factor of safety is defined as the ratio between the resisting force and the driving force, as given in Eqn 1.

$$SF = \frac{\tau}{\tau_d} \quad (1)$$

where τ is the maximum shear resistance that can be exerted by the soil (or available shear strength), τd is the shear stress that occurs due to the weight of the soil that will slide (or the shear strength mobilized by the soil to maintain balance), and SF is the factor of safety.

According to the Mohr-Coulomb theory, the maximum shear resistance (τ) that can be mobilized by the soil, along its sliding plane, is expressed by Eqn. 2:

$$\tau = c + \sigma \tan\varphi \quad (2)$$

with c = cohesion, σ = normal stress, and ϕ = friction angle in the soil. The values of c and ϕ are the parameters of the shear strength of the soil along the failure plane.

In the same way, the equation for the shear stress that occurs (τd) due to soil loads and other loads on the sliding plane can be written in Eqn. 3:

$$\tau_d = c_d + \sigma \tan\varphi_d \quad (3)$$

where cd and ϕd are the cohesion and internal friction angles that occur or are required for balance in the sliding plane.

From the substitution of Eqn. 2 and Eqn. 3 into Eqn. 1, the equation for the safety factor is obtained, as in Eqn. 4.

$$SF = \frac{c + \sigma \tan\varphi}{c_d + \sigma \tan\varphi_d} \quad (4)$$

Eqn. 4 can also be written in the form of Eqn. 5:

$$c_d + \sigma \tan\varphi_d = \frac{c}{SF} + \sigma \frac{\tan\varphi}{SF} \quad (5)$$

Then the factor of safety for each component of the shear strength is written as Eqn.6 and 7:

$$SF_c = \frac{c}{c_d} \quad (6)$$

$$SF_\varphi = \frac{\tan\varphi}{\tan\varphi_d} \quad (7)$$

where SFc = safety factor for cohesion components and SFϕ = safety factor for friction components. In general, the boundary balance method assumes SFc = SFϕ, this indicates that the cohesion components c and friction (ϕ) are mobilized in equal proportions simultaneously along the failure plane. The safety factor has to be above 1 and typically has values ranging from 1-1.5.

4. Factors Instigate Slope Failure

Landslides on slopes can arise from various factors, including geological and hydrological conditions, topography, climate, and weather variations that influence slope stability, ultimately leading to landslides The stability of slopes can be compromised by natural elements such as weathering, intense or prolonged rainfall, seismic activity, and the presence of a vulnerable superficial soil. Additionally, human activities like excavation at the base of the slope and construction on its surface can also contribute to slope failure. In the case of clay soil slopes, landslides often occur due to erosion caused by river water flow or excavation activities at the slope's base. The erosion of the riverbed, particularly near the foot of the slope, can result in a steeper and deeper slope, rendering it unstable (Das, 2019; Fadilah et al., 2019). The occurrence of heavy rainfall frequently triggers significant erosion, especially in areas with easily erodible soil on steep hillsides, aggravated by human-induced vegetation damage. To effectively manage the erosion process, it is crucial to implement sustainable and cost-effective solutions such as employing bioengineering techniques that utilize vetiver grass (Azis, 2022; Hamdhan et al., 2020).

5. Bioengineering for slope reinforcement

Bio-engineering is interdisciplinary bioscience and engineering that is applied in bio-system-based engineering to increase the efficiency of the functions and benefits of bio-systems. Slope erosion is a natural disaster that often occurs on natural and artificial slopes (Sriwati et al., 2018). Slope erosion mostly occurs during the rainy season. Soil-bioengineering can be an alternative method of slope stabilization (Balangcod et al., 2015; Sittadewi, 2018). The analysis was carried out by comparing the soil shear strength values (cohesion and internal shear angle) from the results of triaxial soil tests without and with vetiver reinforcement. The use of vetiver as a stabilization method is proven to increase slope stability (Sittadewi and Tejakusuma, 2019).

6. Vetiver and Bio-Engineering

6.1 Characteristics of Vetiver Root Plants

Vetiver root or vetiver grass in the plant classification belongs to the Graimineae Family. The Latin name for vetiver is *Vetivera zizanioides* STAPF (Chou et al., 2016) or also called *Andropogon zizanioides* URBAN or *A. Muicatus* RETZ (Gautam and Agrawal, 2021) or *Asquarrosus* LINN (Sunandar, 2011). Vetiver with the application of the vetiver system (VS) is reclassified as *Chrysopogon zizanioides* L Roberty (Garzón et al., 2020a; Sari, 2021).

Vetiver in Indonesia known as root vetiver (*Vetiveria zizanioides*), is a type of large grass that has many features. This magic grass in Indonesia has been used as a producer of essential oils (Sufyan et al., 2020). It grows upright and reproduces quickly to form large clumps that can survive and thrive in cold weather. In very cold weather the shoots die or become dormant but the underground growth parts persist. Vetiver is very effective in dealing with erosion because of its long roots that penetrate the earth with a height of 1.5 m and can grow up to 2-4 meters (Wijayakusuma, 2007). The roots of several species that produce essential oils can grow to a depth of 3-5 m (Ambarwati and Bahri, 2018; Teshale and Legesse, 2022).

6.1.1 Morphological Characteristics

Vetiver root has a strong and massive structure, has no teeth or rhizomes, and reaches 3-4 meters in length. Its stems are stiff and upright and can remain standing even in strong currents (Sari, 2021; Sufyan et al., 2020). Vetiver is resistant to pests, disease and fire (Brandt, 2006), withstands snow, traffic and heavy grazing pressure resulting from new shoots developing from its crown in the soil and filters sediment effectively when densely planted (Löbmann et al., 2020) (Fig.1b and 1c). The physical form of vetiver is given in Fig.1a.

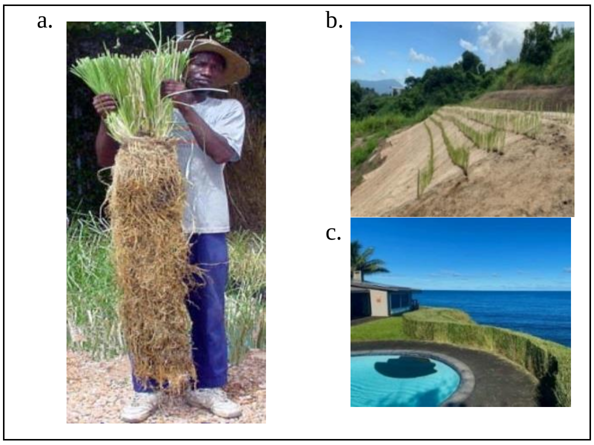

Fig. 1.a. Vetiver (Pineiro, 2021a), b.Vetiver Planted on Hillside (Pineiro, 2021b), c.Vetiver Planted on Coast (New, 2021)

6.1.2 Physiological Characteristics

Vetiver root can withstand extreme climate changes such as floods, prolonged drought, submersion and extreme weather from -14˚C to +55˚C (Winata, 2018), has a soil pH that varies from 3.3 to 12.5 which made it able to survive without soil amendment. Vetiver is also efficient in absorbing soluble soil nutrients such as N and P and heavy metals in polluted water (Hailu et al., 2020; Susilawati and Veronika, 2016), as well can tolerate medium to a high level of alkalinity, solidity, acidity, salinity (Novita et al., 2022; Sari, 2021). In addition, vetiver is tolerant to high herbicides and pesticides (Susilawati and Veronika, 2016). It can withstand pollution of hazardous toxic substances such as atrazine (Zhang et al., 2023), various dyes (Aarthy et al., 2022), EDTA and metals and heavy metals such as Mg, Al, Mn, As, Cd, Cr, Ni, Pb, Hg, Se and Zn in the soil (Kereeditse et al., 2023; Sari, 2021).

6.1 Ecological Characteristics

Vetiver is an ecologically versatile plant that can survive for many years under normal conditions without being overly aggressive (Sari, 2021). It has been observed to withstand extreme environmental conditions such as droughts lasting several months or floods lasting up to 45 days. Vetiver can grow in a variety of environments, including sea-level swamps and mountains up to 2600 meters. Unlike other plants, vetiver does not become a weed and does not spread uncontrollably, making it a suitable option for reducing rain flow speed and increasing the absorption of rainwater and plantation productivity. Additionally, vetiver can form dense, upright hedges that are easy and inexpensive to create and permanent on the soil surface. While there are reports of vetiver being unable to survive in areas with very strong waves on the coast, leading to all being uprooted (Sufyan et al., 2020), the application of vetiver for beach and sand dune stabilisation proved to be very effective in reducing erosion in the coastal area.

Vu et al. (2013) reported that vetiver grass can reduce up to 60% wave overtopping. In Brazil, Pereira et al. (2015) reported vetiver plantation in front of a hotel complex keeps the beach safe from erosion, even in extreme weather. The fact that vetiver is unable to survive a daily high tide, but can withstand fortnightly tidal surges (Bertel and Truong, 2013). The important factors determining the effectivity of vetiver grass in saline and/or coastal environment is the regular maintenance and keeping the grass root not to be directly immersed continuously in saline/brackish water. Bertel and Truong (2013) suggested growing vetiver grass above the high tide, and in case the area to be protected is submerged in the water regularly, planting a more salt-tolerant species, e.g. sea ferns, on the foot of vetiver plants to keep the environment save for the vetiver roots

6.1.1. How Vetiver Works To Slow Down or Prevent Landslide

Vetiver root has a unique way of working, which is to stop the rate of water run-off and erosion material that is carried along with the body (Hamdhan et al., 2020; Sari, 2021). In Fig.2 it can be seen that vetiver leaves and stems can slow down the flow of sediment carried by run-off at point A so that it accumulates at point B, while water will continue to flow down the lower slope at point C (Susilawati and Veronika, 2016) (Fig.2). The soil is bound by plant roots to a depth of 3 meters so that it looks like a pole and will be effective if planted in rows that form a fence (Holanda et al., 2022; Susilawati and Veronika, 2016).

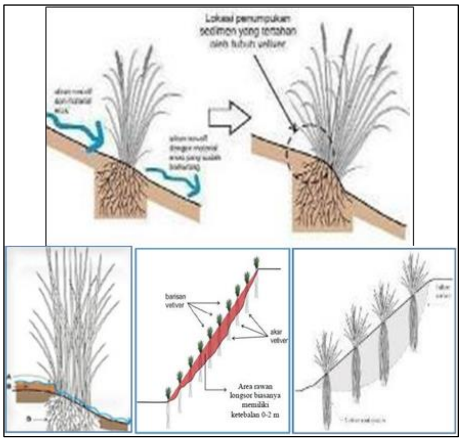

Fig. 2. Mode of Action of Vetiver in Preventing Soil Erosion (Wijayakusuma, 2007)

6.2.1. Application of vetiver system on Red Soil

The application of the vetiver system on compacted embankment soil was also examined for the response of root growth. Dense soil structure will inhibit the rate of root penetration, and this condition has implications for root fibres not contributing to the increase in soil shear strength because the root fibres have not crossed the slip surface in surface landslides. In the planting medium in the form of coarse-grained clay silt soil reddish brown or often called red soil, at the planting age of 90 days, the roots of vetiver grass plants can penetrate the compacted red soil layer with a dry unit weight (γd) ranging from 1.28 – 1 .34 gr/cm^3 and 16.8 cm thick. At the bottom of the pot, there is a collection of roots due to the roots not being able to penetrate the gutter closure. Root length can reach an average of 29.69 cm and root diameter of 0.40 mm. This shows that vetiver can develop well on slopes with a reddish-brown coarse-grained silt loamy soil type or often called red soil. The closeness of the relationship between variables such as dry unit weight of soil, number of roots, root length and root diameter in response to root growth is that the more the average number of roots is possible the greater the average root diameter. The higher the dry unit weight of the soil, the larger the average root diameter will be. In addition, the relationship between root length and diameter shows a similar distribution pattern for relatively the same level of density (Andiyarto and Purnomo, 2012).

6.2.2. Application of Vetiver on Silty Sand Soil and Sandy Silt Soil

In a research conducted by Azis (2022), six small-scale models were created, one without vetiver grass and five with vetiver grass, having a slope angle of 37°. Artificial high-intensity rainfall was applied to all six models one year after planting, to observe the role of the canopy and vetiver roots in erosion and runoff control. Out of the five small-scale models, one was made with silty sand soil while the other four models were planted in sandy silt soil media to see the effect of soil texture. The results of the study showed that for sandy silt, the inclusion of vetiver reduced soil loss (erosion) by 94%–97% and soil loss rates were reduced by 95%. Canopy cover showed a positive impact in reducing both of these quantities. Increasing the average root diameter from 1.6 to 2.5 mm increased soil loss due to its negative impact on cohesion addition. Cohesion addition showed a linear negative correlation with soil loss. The vetiver and jute geotextile composite system was the most effective in reducing erosion among the four vegetation models with sandy silt. Under the same vetiver planting layout, the grass-covered silty-sand model resulted in 84% lower erosion and 62.5% lower runoff than the grass-covered model on sandy silt soils. Vetiver is more effective in reducing erosion and runoff for soils with a greater percentage of sand, and the soil type dominates the erosion process (Azis, 2022; Islam et al., 2016).

6.2.3. Application of vetiver on high plasticity soil

Badriyah and Wulandari (2020) conducted a study on slope modelling with dimensions of 150 cm x 50 cm x 70 cm and slopes of 700 and 800. The researchers tested the soil properties both physically and mechanically before and after strengthening with vetiver. Direct shear strength testing was conducted on samples at depths of 0-30 cm and 30-60 cm before and after planting vetiver. The results showed that the vetiver roots were able to significantly increase the cohesion value at both depths on both slopes. On slope 700, the cohesion value increased by 358.037% at a depth of 0-30 cm and 218.182% at a depth of 30-60 cm. On slope 800, the cohesion value increased by 251.928% at a depth of 0-30 cm and 220.514% at a depth of 30-60 cm. This study suggests that planting vetiver can be an effective method for strengthening slopes and reducing the risk of landslides (Badriyah and Wulandari, 2020).

6.2.4. Application of Vetiver on Silty Clay Soil

Garzón et al. (2020a) analyzed to evaluate the effect of vetiver reinforcement on slope stability using two types of prototypes with a planting time of 16 weeks and an 80° slope, namely the 3-bud prototype and the 6-bud prototype. The soil medium used was silty clay. The study aimed to investigate the impact of *Chrysopogon zizanioides* (vetiver) on the hydrophysical properties of soil and infiltration rate to prevent soil erosion in slopes. The study was carried out in Guatemala using selected grounds, and the soil samples analyzed showed a predominant sand fraction and a plasticity index of 7.9%, which suggested non-swelling, slightly acidic soils with negligible salinity. Nitrogen adsorption-desorption analysis indicated a specific surface area ranging from 11.7-15.5 m^2/g, with pore sizes between 17-160 µm that changed to 20-100 µm, with a predominant pore size of approximately 40 µm after cultivation. The soil was found to possess cohesion (2.05 t/m^2) and an internal friction angle $\Phi = 31.69^o$. After vetiver planting, a decrease in cohesion and an increase in internal friction angle were observed. Additionally, the sowing of vetiver resulted in a decrease in soil infiltration rate due to compaction caused by the plant roots. These results were obtained using the Kostiakov-Lewis classical model, which was mathematically fitted to the data. The findings of Garzón et al. (2020a) and Kurniawati P. & Wulandari S. (2020) indicate that planting vetiver can effectively stabilize slopes and prevent soil erosion caused by heavy rainfall. Results from a 16-week test showed that the qu value increased by 121.74% and the cohesion value increased by 260% in prototype 3 buds, while prototype 6 shoots had a 137.7% increase in the qu value and a 1200% increase in cohesion value. Analysis results also showed that the slope safety factor (SF) in prototype 3 increased from 0.516 to 1.519, indicating a safety increase of 194.38%, while in prototype 6, the SF increased from 0.201 to 1.545, indicating a safety increase of 668.6%. Therefore, it can be concluded that planting vetiver can enhance slope stability.

Analysis of soil shear strength with vetiver grass reinforcement was also carried out by comparing the soil shear strength values (cohesion and soil shear angle) from the results of triaxial soil tests without and with vetiver reinforcement. The test results show an increase in the shear strength of the soil. The use of vetiver as a stabilization method is proven to increase slope stability. The cohesion value (c) contributes more to the increase in soil shear strength compared to the internal friction angle (ϕ). The percentage increase in soil shear strength varies depending on the diameter, number and slope of the roots. Likewise, plant spacing and root depth greatly affect the increase in slope safety scores (Agustina, 2012; Fata et al., 2022).

On the other hand, Garzón et al. (2020a) reported that the planting of vetiver resulted in a decrease in cohesion and an increase in the internal friction angle of sandy soil in Guatemala. The authors concluded that this plant protected the slope by reducing the infiltration rate due to soil compaction caused by the roots. Moreover, Wang et al. (2023) found that the presence of vegetation enhanced the soil's ability to increase matric suction, which was attributed to the increase in soil root surface area index. Specifically, the matric suction of vegetation soil was significantly greater than bare soil at the same water content. However, Li et al. (2021) found that a capillary barrier system was more effective in stabilizing slopes than vetiver, as it limited antecedent rainwater infiltration.

6.2.5. Application of Vetiver on Coarse Grain Soil

To accurately assess the mechanical characteristics of soil, samples with grass ages ranging from 2 to 8 months as well as bare soil were processed and prepared. Experimental outcomes demonstrated that the shear strength of the soil was boosted by the presence of grassroots and matrix suction. As the age of grass or matrix suction increased, the peak shear strength and cohesion of grassed soil tended to rise. In addition, matrix suction was found to have a more significant strengthening effect than grassroots in increasing the overall cohesion of the soil sample. Furthermore, grassed soils displayed higher water retention capacity, and soil specimens with older grass ages showed a greater volumetric water content under the same matrix suction conditions. The study outcomes illustrate an increase in the unsaturated mechanical properties of grassed soil (He et al., 2023a; Nguyen et al., 2020).

From some of the research results above, it can be concluded that vetiver with a bio-engineering system as soil reinforcement on slopes can be concluded, among others: (1) can increase soil cohesion; (2) can increase the friction angle in the soil; (3) can increase the value of qu; (4) can increase the shear strength of the soil; (5) can increase soil stability; (6) Peak shear strength and turf soil cohesion tended to increase with increasing grass age and root planting depth.

6.2.6. Effectiveness of Vetiver in Soil Stabilization under High Annual Rainfall

Several studies have been conducted to evaluate the effectiveness of vetiver in soil stabilization under high annual rainfall conditions (He et al., 2023b; Suyana and Nugraheni, 2022). A study conducted in Thailand found that vetiver hedgerows reduced soil erosion by 82% and sediment yield by 75% (Leknoi and Likitlersuang, 2020). The study also found that the plant's deep roots improved soil porosity and water infiltration rates, leading to improved soil quality (Hailu et al., 2020). Another study conducted in Nigeria found that vetiver hedgerows reduced soil erosion by 90% and sediment yield by 95%. (Ewetola et al., 2021). Several studies have shown that vetiver grass is effective for slope stabilization (He et al., 2023b; Suyana and Nugraheni, 2022). In one study conducted in the Philippines, vetiver grass was found to reduce soil erosion on slopes by 80-90% (Asio et al., 2015). Another study in Guatemala showed that the use of vetiver grass reduced soil erosion by 96% and increased soil stability by 98% (Garzón et al., 2020b). In addition, vetiver is effective in reducing landslides, and it has been used successfully in landslide-prone areas in India, China, and Indonesia (Abaga et al., 2021; Liu et al., 2022; Suyana and Nugraheni, 2022).

7. Conclusion

Reducing the risk of landslides, which are significant geological disaster that damages natural and social environments, is important. Various types of mass movement on slopes, such as rockfalls, falls, and debris flows, contribute to landslides. Therefore, natural methods must be used to reduce disaster risk. The morphological, physiological, and ecological characteristics of vetiver roots make them a suitable candidate for bio-engineering in landslide-prone areas, but this approach requires community involvement. Building resilience for disaster risk reduction is a complex process that necessitates a comprehensive, whole-of-society approach, which requires the commitment, good faith, knowledge, experience, and resources of all stakeholders involved in disaster risk reduction. Therefore, applying vetiver with bio-engineering as a soil reinforcement on slopes can improve the efficiency of biosystems' functions and benefits. This literature review emphasizes the importance of guidelines for planting vetiver grass as a soil-strengthening method on slopes, enabling the widespread and comprehensive application of this technique.

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