http://journal.uir.ac.id/index.php/JGEET

E-ISSN : 2541-5794
P-ISSN : 2503-216X

Journal of Geoscience,
Engineering, Environment, and Technology
Vol 11 No 2 2026

RESEARCH ARTICLE

Effectiveness of Vetiver (*Vetiveria zizanioides*) Application with Modular System in Soil Bioengineering for Soil Reinforcement

Muhammad Reza Nurmansyah [1], Heriansyah Putra [2,*], Chusnul Arif [2]

[1] *Graduate School of Civil and Environmental Engineering, IPB University, Bogor 16680, Indonesia.*
[2] *Division of Sustainable Infrastructure Engineering, Faculty of Engineering and Technology, IPB University, Bogor 16680, Indonesia.*

* Corresponding author: heriansyahptr@apps.ipb.ac.id
Tel.:+62-822-4664-3151

Received: Aug 23, 2025; Accepted: Apr 15, 2026.
DOI: 10.25299/jgeet.2026.11.02.24684

Abstract

Indonesia has a diverse topography characterized by many hilly and mountainous regions, rendering it vulnerable to landslides. BNPB data indicate that, in 2024, there were 207 landslide incidents in Indonesia. Soil bioengineering methods using vetiver plants can improve soil stability. This study aimed to evaluate the effectiveness of vetiver application via a modular soil stabilization system using soil bioengineering. The research was conducted by testing soil properties, followed by planting vetiver in 10-cm-diameter pipes 50 cm high, with a geotextile measuring 10 × 10 × 10 cm on top containing a mixture of soil and planting media. Subsequently, maintenance, soil shear strength testing, and root dimension observations were performed on samples aged 1, 2, and 3 months after planting (MAP). The test results showed that the root growth rate increased by 30–40 cm in vetiver samples in the modular system. The most significant increase in soil shear strength was observed in the cohesion parameter, reaching 19.55 kPa. Therefore, vetiver roots contributed to the greatest increase in cohesion (c), reaching 8.57 kPa. The application of vetiver significantly increases soil shear strength, making it suitable for use as a slope reinforcement method.

Keywords: Vetiver, modular, soil bioengineering, landside, shear strength

1. Introduction

Indonesia has diverse topographical conditions, generally consisting of hilly and mountainous areas with undulating plains and relatively steep to precipitous slope gradients, which can cause disturbances in slope stability, such as soil movement. Additionally, heavy rainfall can increase pore water pressure, leading to soil saturation and slope erosion or landslides (Yuskar et al., 2017; Zamroni et al., 2020; Simatupang and Kausarian, 2024). According to the National Disaster Management Agency (BNPB), over the past 10 years (2015–2024), an average of 824 landslide incidents occurred, and in 2024, 207 were recorded across various regions of Indonesia. This indicates that mitigation efforts and slope stabilization must be implemented to reduce the likelihood of such disasters. Slope stabilization generally uses conventional methods involving physical structures with concrete materials, such as retaining walls, shotcrete, and various other mechanical techniques (Ikrimah et al., 2020; Putro and Agustina 2023). The production of cement, a concrete material, results in CO2 emissions of 0.7–0.99 metric tons per 1 metric ton of cement produced (Nejad et al., 2025). Therefore, the emergence of negative environmental impacts has driven the search for sustainable and environmentally friendly alternatives. One solution is soil bioengineering.

Soil bioengineering methods for slope stabilization use plants as surface cover for vulnerable slopes prone to erosion. This slope cover increases soil bearing capacity and reduces water infiltration into the soil, thereby enhancing the bond between roots and soil and increasing the slope's strength to retain it (Nugraha et al., 2016; Hidayati et al., 2023). Additionally, soil bioengineering methods can reduce environmental impacts and gradually improve slope stability while providing long-term protection (Wandira and Rahayu 2021). Currently, more environmentally friendly alternative methods, such as hydroseeding, have been developed for slope stabilization. Hydroseeding techniques can reduce surface erosion by nearly 100% (Sunandar and Prananda 2020). Furthermore, the application of hydroseeding techniques can increase slope safety factors by 5.87% (Sari and Dharmawansyah 2023). However, in field applications, hydroseeding techniques face challenges such as water control factors, relatively steep slope contours, and extreme weather conditions; therefore, the hydroseeding method has not been able to effectively increase slope strength (Sunandar dan Prananda 2020). Direct planting of vegetation may be considered.

Selecting plant types for soil bioengineering methods is important. Plant type selection is based on several criteria, such as plants that can strengthen slopes, resist erosion, and slow runoff (Dorairaj and Osman 2021). The type of vegetation that can be used is plant species that grow quickly and have deep, extensive root systems. Vetiver, also known as fragrant root, is one type of plant suitable for slope stabilization using soil bioengineering. Vetiver (Vetiveria Zizanioides) is a plant type that meets the ecological and phytoremediation needs for land and water, prevents erosion on slopes, and improves the environment using plants (Sari et al., 2024). Moreover, vetiver cultivation can contribute to CO^2 absorption at rates of up to 0.543 tons/ha/day (Resqiyanto et al., 2025). This indicates that vetiver planting represents a more environmentally friendly and sustainable alternative approach to soil reinforcement. Additionally, valves have fibrous root characteristics that can penetrate hard soil layers up to 15 cm thick and reach depths of 5.2 meters. Furthermore, vetiver can penetrate slopes with hard and rocky soil (Hamdhan et al., 2020). Plant root growth can be influenced by the amount of water absorbed by plants. Therefore, it is necessary to ensure the availability of soil water for plant absorption so that plant roots can grow well, as soil water content directly influences root morphology development and the water-holding capacity of the root–soil system (Wang et al., 2023). However, direct field planting of vegetation faces several challenges, including slope conditions that can lead to soil erosion and the potential for plants to be carried away. Additionally, nutrient problems on slopes caused by erosion also become a challenge in field applications because nutrients in the soil are generally abundant in the topsoil layer (Pratama et al., 2022).

Several studies have addressed slope erosion using modular materials (geotextiles). These modular materials can be used to retain slope contours and prevent erosion. Additionally, modular materials were used to prevent nutrients in the planting media from being washed away by erosion. Geotextile materials include synthetic, composite, and natural fiber materials. The use of geosynthetic materials above the soil surface can increase soil strength by up to 18.2% (Ogundare et al., 2018). However, geotextiles made from synthetic materials are not environmentally friendly because they are manufactured from chemicals and do not decompose naturally. Geotextile materials from jute fibers have a lower environmental impact. Additionally, during the early growth phase of vegetation, modular materials from jute fibers are used to prevent soil movement on slope surfaces and for subsequent slope degradation processes (Kalibová et al., 2016). This study was conducted to evaluate the effectiveness of using vetiver in modular systems as a soil stabilization measure through soil bioengineering at the laboratory scale.

2. Materials and Methods

2.1. Material

The tools used for vetiver planting included PVC pipes with a 10 cm diameter and a 50 cm length. These pipes are used to facilitate the observation of root length and standard direct shear testing. In addition, the pipes were used to determine the duration of vertical vetiver root growth. The modular units made of jute fiber had dimensions of 10 cm × 10 cm × 10 cm. In addition, the jute fiber modular units used measure 10 × 10 × 10 cm. The dimensions of the modular units, with a length and width of 10 × 10 cm, are matched to the pipe diameter, while the height of the modular unit is adjusted to the planned growing medium thickness of 10 cm to be placed inside. The vetiver seedlings used were three months old and were obtained from the Agricultural Equipment Standardization Agency (BSIP) in Bogor. Soil samples were collected from landslide areas at Cainekol Agrotourism, Petir Village, Dramaga District, Bogor Regency, West Java (Fig. 1).

The results of soil gradation testing indicate that the soil sample is fine-grained, with more than 50% passing through a No. 200 sieve (0.075 mm). Then, the specific gravity (GS) of 2.64, water content (ω) of 38.66%, bulk density (γ_w) of 1.51 g/cm³, dry density (γ_d) of 1.12 g/cm³, water holding capacity (WHC) of 47.9%, liquid limit of 59.64%, plastic limit of 45.12%, and plasticity index of 14.52%. Based on the Unified Soil Classification System (USCS), the plasticity index curve indicates that the tested soil sample is MH, an elastic silt soil with low organic content. The particle size distribution curve is shown in Fig. 2.

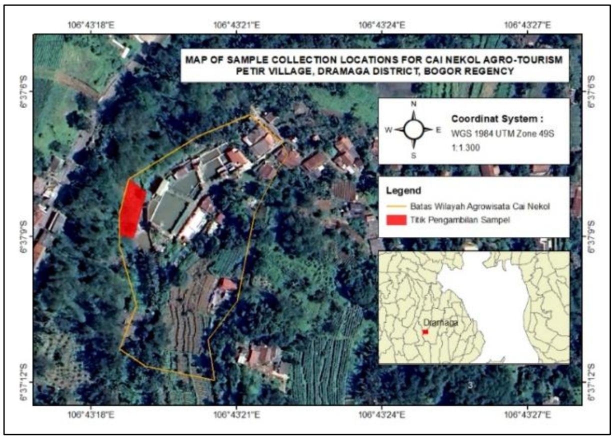

Fig. 1 Map of soil sampling location

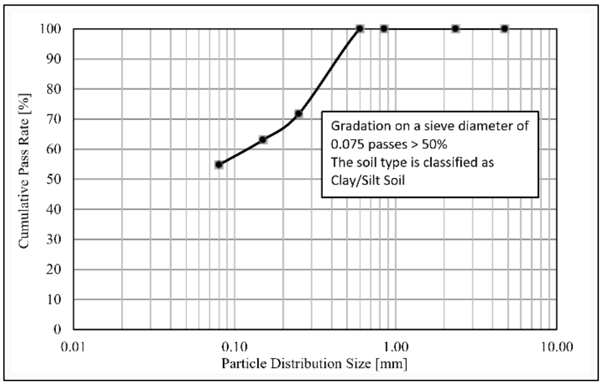

Fig. 2 Particle size distribution

2.2. Planting and Care of Vetiver Plants

The vetiver planting process begins by filling the pipes with soil samples. Vetiver is planted in an open area to allow the plants to receive direct sunlight. The soil conditions used are adjusted to match the soil density (γ_w) at the sampling site, ensuring they accurately represent field conditions. The calculation of soil requirements per pipe is performed using Eq. (1). The calculation of the soil requirement per pipe yielded a result of 6.97 kg/pipe. Next, a modular unit containing the growing medium is placed on top of the pipe and provided with a 5 cm-diameter hole for the planting area. The growing medium is a 3:1 mixture of soil and compost. Additionally, 3 grams of NPK fertilizer is added to each planting hole before planting begins. Then, 3-month-old vetiver seedlings were planted in the prepared planting holes. A schematic for planting vetiver using a modular system on pipes is shown in Fig. 3.

Subsequently, maintenance was performed through regular watering and fertilization in accordance with the Ministry of Public Works and People's Housing (PUPR) guidelines for vetiver grass planting. Watering was performed twice a day (morning and evening) until the plants were 1 month old, and then once every 2 weeks until 3 months after planting. The watering volume was adjusted based on the water-holding capacity (WHC) test results, with a volume of 0.42 L per plant per watering. Meanwhile, 1-month-old plants were fertilized with 3 g of NPK fertilizer per plant. Subsequently, analysis and observation of the vetiver plants were conducted at 1, 2, and 3 months after planting (MAP) by measuring vetiver root dimensions and conducting direct shear strength tests on a laboratory scale. The experimental design for vetiver planting for soil stabilization is presented in Table 1.

Table 1 Experimental design for vetiver planting

Sample code	Planting age (month)	Total Sample
A1	1	6
A2	2	6
A3	3	6

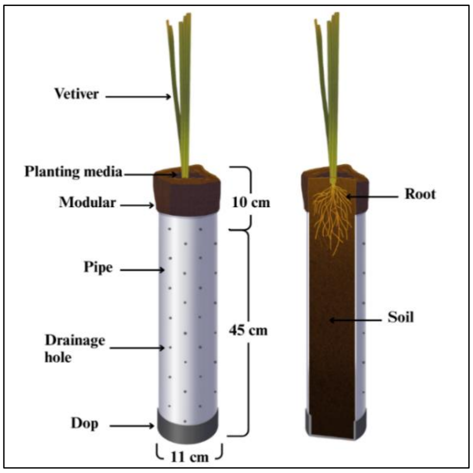

Fig. 3 Schematic of vetiver planting with modular on pipes

2.3. Direct Shear Test

Direct shear strength testing was conducted to determine the effectiveness of vetiver planting on cohesion, attractive forces between particles, and the internal friction angle (friction between soil grains). This test referred to SNI3420:2016 the Direct Shear Strength Method for Unconsolidated and Undrained Soils. Direct shear strength testing was performed on control samples (non-vegetation) and on samples with vegetation planted at 1, 2, and 3 months after planting (MAP). Direct shear strength testing was conducted on control samples (non-vegetation) to represent field soil conditions prior to soil reinforcement using vegetation. Subsequently, sampling was conducted at depths of 0-15 cm, 15-30 cm, and 30-45 cm to observe soil shear strength at each depth interval. The experimental design for the direct shear strength test is presented in Table 2. The direct shear test scheme for a single specimen is illustrated in Fig. 4.

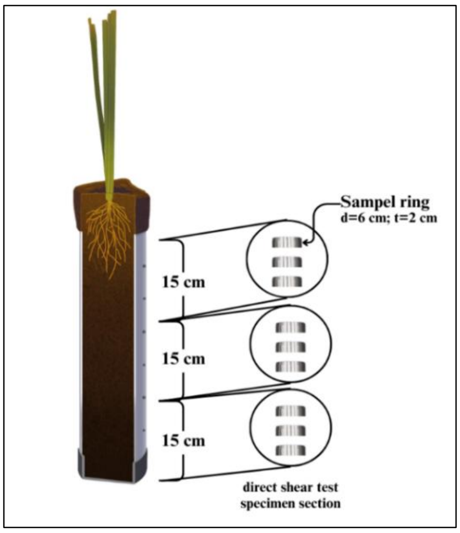

Fig. 4 Schematic of shear strength test

Soil shear strength analysis was performed using the Mohr-Coulomb equation. Eq. (2) shows the relationship between normal and shear stresses on the soil plane, where the shear stress (τ) (kPa), cohesion (c) (kPa), normal stress (σ) (kPa), and friction angle (φ) (°). Furthermore, soil shear strength analysis with additional vegetation influence was conducted using Eq. (3), with soil cohesion influenced by roots is the (c_R) (kPa), and the internal friction angle influenced by roots is the (φ_R) (°). This root influence is represented by the increment c, which is the additional cohesion from plant roots. The calculation of the value (Δc_R) is performed using Eq. (4).

Table 2. Experimental design for the direct shear strength test

Sample code	Planting age (month)	Sample depth (cm)	Total Sample
Control	-	0-15	3
		15-30	3
		30-45	3
A11	1	0-15	3
A12		15-30	3
A13		30-45	3
A21	2	0-15	3
A22		15-30	3
A23		30-45	3
A31	3	0-15	3
A32		15-30	3
A33		30-45	3

$$\tau = c + \sigma \tan \varphi \quad \text{......(2)}$$

$$\tau = (c + c_R) + (\sigma).\tan\,(\varphi + \varphi_R) \quad \text{......(3)}$$

$$\Delta c_R = (c + c_R) - (c_{control}) \quad \text{......(4)}$$

3. Result and Discussion

3.1. Analysis of Vetiver Root Growth Rate

Root growth analysis was conducted to determine the vetiver root growth rate at each measurement interval. Root length was measured continuously for each sample at 1, 2, and 3 months after planting (MAP). The relationship between root length and time demonstrated a strong linear pattern ($y = 38.583x - 24.889$, $R^2 = 0.9904$), confirming that the vetiver root elongation progressed consistently and predictably throughout the observation period. Root length increased progressively at each MAP, indicating that the modular system effectively supported the sustained root development. The results of the root length measurements based on planting age are shown in Fig. 5.

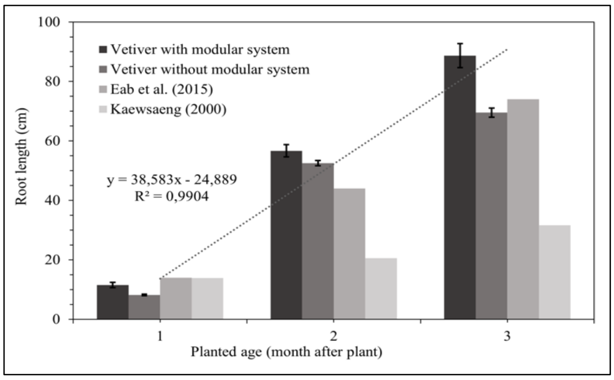

Fig. 5 Average values for vetiver root growth rate measurement

The test results from the 1 MAP sample showed that root development remained limited across all treatments. Vetiver with the modular system recorded an average root length of approximately 11.5 ± 0.87 cm. Meanwhile, the vetiver sample without the modular system yielded an average of 8.2±0.29 cm, comparable to those reported by Eab et al., (2015) at ~13 cm and Kaewsaeng (2000) at ~13 cm. The small standard deviation indicates that root growth among the samples remained relatively uniform at this stage. The limited root development at 1 MAP was attributed to suboptimal nutrient and water uptake during the plant establishment period. In accordance with PUPR guidelines on vetiver planting, fertilization is applied one month after planting; therefore, samples at this stage had not yet received external nutrient supplementation. Adequate availability of macronutrients, particularly nitrogen (N), phosphorus (P), and potassium (K), is essential for optimal vetiver root growth (Dwicaksono 2023). During this phase, the modular units pre-filled with compost fertilizer played an important role in maintaining nutrient availability and soil moisture within the root zone, thereby supporting early root establishment before external fertilization was applied (Septyani et al., 2014; Komarawidjaja dan Garno 2016).

The test results from the two MAP samples showed that root growth was significantly improved. In these samples, the vetiver root system grew vertically, and in samples with modular units, the roots penetrated the modular layer, as shown in Fig. 6. Vetiver with the modular system recorded an average root length of approximately 57 ± 2.08 cm, whereas the vetiver sample without the modular system yielded an average of 52.5 ±0.87 cm, increasing substantially compared with Eab et al. (2015) at ~45 cm and Kaewsaeng (2000) at ~20 cm. The increased standard deviation relative to that of the 1 MAP indicates the emergence of growth variation among samples, likely influenced by differences in the ability of individual plants to penetrate the modular layer. This growth acceleration was supported by improved nutrient availability following fertilization and by the capacity of the modular layer to retain compost nutrients within the root zone while preventing their loss through surface runoff (Septyani et al., 2014). Furthermore, biodegradation of the coconut fiber geotextile components within the modular unit released additional organic nutrients into the growth medium while simultaneously softening the substrate structure, thereby facilitating root penetration into deeper soil layers (Kalibová et al., 2016).

Fig. 6 Vetiver specimens grown in pipe conditions after two months

The test results from the three MAP samples showed that vetiver root growth reached its optimal stage. Vetiver with the modular system recorded an average root length of approximately 88 ± 4.04 cm. Meanwhile, the vetiver sample without the modular system yielded an average of 69.5±1.5 cm, considerably exceeding the values reported by Eab et al. (2015) (~74 cm) and Kaewsaeng (2000) (~31 cm). The consistent upward trend in standard deviation throughout the observation period (0.87, 2.08, and 4.04 cm) reflects increasing individual growth variation with advancing plant age, suggesting that local factors, such as nutrient distribution and moisture retention within each modular unit, exert an increasing influence on individual root development over time. These results collectively confirm the effectiveness of the modular system in supporting vetiver root growth by maintaining consistent nutrient availability and moisture levels in the upper root zone. However, observations at the three MAPs also revealed root accumulation at the base of the modular unit, as roots were unable to freely penetrate the rigid boundary at the pipe cap. This condition is consistent with findings that vetiver root clumping occurs when further penetration is restricted at the interface between a hard layer and the overlying soil (Andiyarto and Purnomo 2012).

3.2. Analysis of Soil Shear Strength

Soil shear strength testing was conducted to determine the effect of vetiver planting using modular materials on soil shear strength. Soil shear strength testing was performed at the laboratory scale. This was performed to facilitate the preparation of the vetiver samples. Direct shear strength testing was performed on samples without vegetation and samples with vegetation planted at 1, 2, and 3 months after planting (MAP). Subsequently, sampling was conducted at depths of 0-15 cm, 15-30 cm, and 30-45 cm to observe the soil shear strength parameters at each depth variation. Shear strength analysis was performed by interpreting displacement-versus-shear-stress graphs. The dial proving ring for shear force was read until the sample failed or until the sample reached a maximum displacement of 20% of the clay soil sample diameter during testing. The results of the direct shear test are shown in Fig. 7.

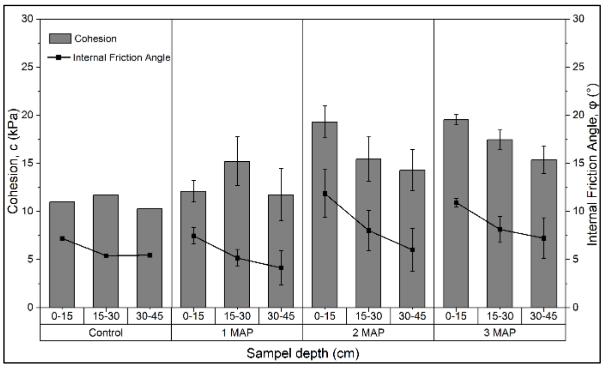

Fig. 7 Average shear strength values of soil samples without vegetation (control) and soil samples with vegetation (vetiver)

In tests with no vegetation cover (controls), no significant differences in soil shear strength parameters were observed across layers. The cohesion values obtained for each layer were 10.98 kPa, 11.70 kPa, and 10.29 kPa, respectively. The soil shear strength parameters for these control samples reflected the field soil strength conditions. The resulting soil shear strength parameters can be influenced by several factors, such as moisture content and soil density. Based on the density test results for the vegetation-free (control) sample, a dry density of 1.12 g/cm³ was obtained at a moisture content of 39.88%, decreasing to 1.08 g/cm³ at a moisture content of 41.12%. A graph of the density and water content relationship for samples without vegetation cover (Control) is shown in Fig. 8.

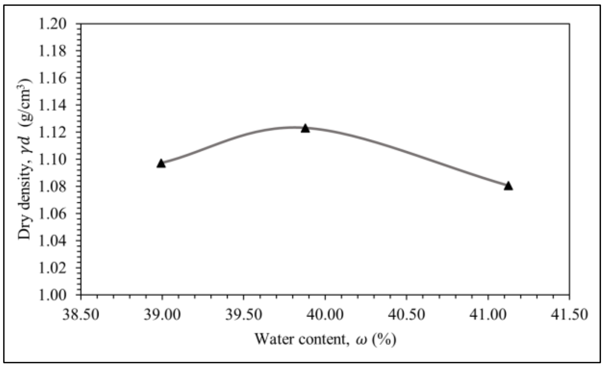

Fig. 8 Graph of density and water content relationship for samples without vegetation (Control)

Soil shear strength parameters, such as cohesion (c) and internal friction angle (φ), decrease when the moisture content exceeds its optimum value (Agustina and Elfrida 2019; Hakim et al., 2020). Soil saturation can result from increased pore water, which can trigger landslides (Agung et al., 2025). Hakim et al., (2020) indicated that soil shear strength peaks at a moisture content of 20–32% and then decreases when the moisture content exceeds 32%. High moisture content causes the soil to become saturated, thereby increasing pore water pressure and reducing soil shear stress (Muchtaranda et al., 2022; Kang et al., 2022). Low soil shear strength parameters are closely associated with a high landslide risk, necessitating slope stabilization. In this study, slope stabilization was achieved by planting vetiver, which has been proven to increase soil shear strength (Eab et al., 2015).

The test results for sample 1 MAP indicated that the shear strength had not increased significantly. Based on the test results, at a depth of 0–15 cm, an average cohesion of 12.11 ± 0.92 kPa and an angle of internal friction of 7.48° ± 0.72 ° were obtained. However, the soil cohesion value actually increased at a depth of 15–30 cm, with a cohesion value of 15.21 ± 0.92 kPa and a friction angle of 5.57° ± 0.73°, then decreased again at a depth of 30–45 cm, with a cohesion value of 11.47 ± 2.21 kPa and a friction angle of 5.40° ± 1.46°. The higher cohesion observed at depths of 15–30 cm compared to 0–15 cm at 1 MAP may be due to the relatively low root content in the upper layer during the early growth stage; this occurs because the root system is still confined to the upper layer with relatively short lengths, and root biomass has not yet reached the threshold density required for effective mechanical reinforcement (Wang et al., 2023; Kurniawati and Wulandari 2020). Additionally, natural consolidation due to water infiltration loads may have contributed to increased particle contact in the mid-depth layers. Therefore, during the early growth phase of vetiver, the topsoil layer requires reinforcement. The application of modular systems in the field serves to replace the role of roots in reinforcing the soil, while vetiver grass still requires intensive care until it grows strong enough to resist soil movement (Susilawati and Veronika 2016; Kurniawati and Wulandari 2020).

Based on the test results of samples MAP 2 and 3, the soil shear strength parameters increased with depth. The highest cohesion value was observed at 0–15 cm and subsequently decreased with increasing depth. In the 2 MAP sample, the highest cohesion (c) value was obtained at a depth of 0–15 cm, amounting to 19.31±1.36 kPa, and the internal friction angle (φ) was 11.87°±2.03°. Meanwhile, in the 3-month-old sample, the highest cohesion (c) value obtained was 19.55 ± 0.46 kPa, and the internal friction angle (φ) was 10.94° ± 0.37°. The test results indicate that the soil cohesion in the 3-month-old sample increased by 78.06% compared to that in the 1-month-old sample, with a maximum cohesion of 19.55 kPa. The percentage increase in cohesion values aligns with the study conducted by Eab et al. (2015), where the 4-month-old sample showed a 100% increase, with a cohesion value of 13.6 kPa. These observations indicate that the duration of vetiver planting affects the resulting shear strength. This may occur because the longer the vetiver is planted, the more roots it produces (Kurniawati and Wulandari 2020).

At 2 and 3 MAP, the vetiver root growth formed a denser structure with vertical growth, in which most of the roots penetrated the modular layer, allowing the roots to bind the soil particles beneath them. Root growth is more evenly distributed across depths and develops more densely, enveloping soil particles, thereby increasing the bonding strength between soil particles at each depth and strengthening and stabilizing soil conditions stronger and more stable (Andiyarto and Purnomo 2012; Zayadi et al., 2020a). Denser root growth can create mechanical interactions between roots and soil particles, thereby increasing resistance to shear forces and stabilizing soil conditions (Zayadi et al., 2020b).

3.3. Analysis of the Effect of Root Mass on Soil Cohesion

The relationship between vetiver (Chrysopogon zizanioides) root weight and soil cohesion (c) showed a consistent positive trend across all planting age and soil depth treatments. This indicates that mechanical reinforcement occurs in the root-soil matrix as root biomass accumulates. Root weight was measured by separating the roots from the shear test sample rings and recording their weights. Based on the test results, at 1 MAP, root weight was relatively low, ranging from 0.1 to 0.5 g, with average cohesion values ranging from 8.6 to 14.5 kPa. This indicates that root growth has not yet developed optimally and is confined to the upper soil layer. Subsequently, in the 2 MAP samples, root weight increased to 0.7–2.25 g, with average cohesion values of 11.8–19.7 kPa. Meanwhile, in the 3 MAP samples, root weight increased significantly to 2.5–3.9 g, accompanied by an increase in cohesion to 15.0–21.5 kPa. These test results show that soil cohesion increases with increasing root weight.

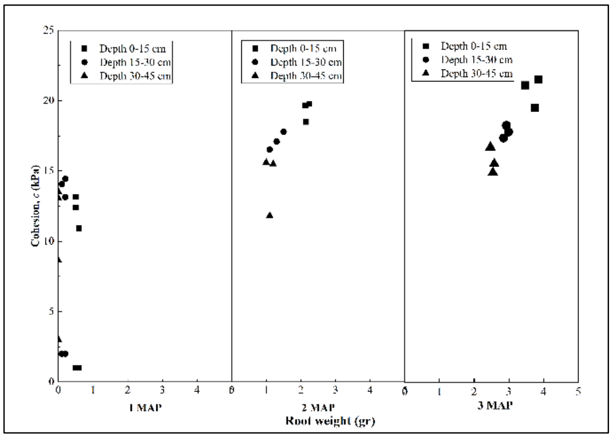

Fig. 9 The relationship between root weight and cohesion

A graph of the relationship between root weight and soil cohesion is shown in Fig. 9. A simple linear regression analysis was conducted to determine the relationship between soil cohesion (c, kPa) and vetiver root weight (g). The analysis results showed an R^2 of 0.623, indicating that 62.3% of the variation in root weight was explained by changes in soil cohesion. The F-test yielded an F value of 11.5 with a p-value of 0.011 (< 0.05); thus, the regression model was statistically significant. The regression equation obtained was $c = 12.950 + 1.704 \times$ root weight; an increase of 1 g in root biomass contributed to an average increase in soil cohesion of 1.704 kPa, with a 95% confidence interval of 0.518–2.889 kPa/g ($p = 0.003$; 95% CI: 0.070–0.183).

These results confirm that vetiver root biomass growth is strongly and significantly positively correlated with increased soil cohesion, consistent with the root reinforcement mechanism proposed by Wu et al. (1979). Hamidifar et al., (2018) reported that soil cohesion increased by up to 119.6% in vetiver-reinforced clay soils compared to the vegetation-free control. Meanwhile, Badhon et al. (2021) showed an 88.2% increase in shear strength in vetiver-reinforced soil, with cohesion as the dominant parameter responding to root reinforcement. Wang et al., (2023) further demonstrated, in a study on expansive soils, that the relationship between vetiver root density and cohesion increment follows a strong linear trend, with correlation coefficients of $r = 0.91–0.99$ across depth layers, reinforcing the use of a linear model in this study.

3.4. Analysis of Root Contribution to Soil Shear Strength Parameters

The effect of vetiver roots on soil shear strength parameters can be observed through changes in cohesion (c) and the effective internal friction angle (φ). Based on the test results, the presence of vetiver roots increased soil cohesion compared with the samples without vegetation. The increase in cohesion and internal friction angle influenced by the roots occurred as the plants aged. The results of the observation of the contribution of roots to soil cohesion are shown in Fig. 10.

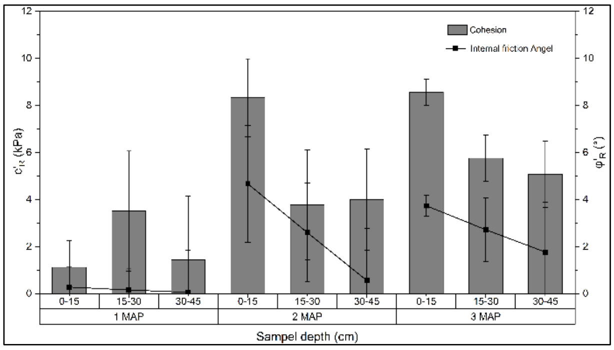

Fig. 10 Vetiver root contribution to the soil shear strength parameter

The test results for Sample 1 MAP indicated that the contribution of vetiver roots to the increase in soil cohesion was still relatively low, increasing by 1–3 kPa, while the effective internal friction angle increased by only 0.3°. This suggests that vetiver roots have not yet developed sufficiently to have an optimal impact on soil shear strength parameters. However, the test results for Sample 2 MAP showed that the soil shear strength parameters increased at every soil depth layer compared to those for sample 1 MAP. The largest increase occurred at a soil depth of 0–15 cm, with an increase in cohesion of 8.33 ± 1.66 kPa and an increase in the internal friction angle of 4.67° ± 2.49°. This increase may have occurred because of the growth of more roots that penetrated deeper, thereby strengthening the soil structure and enhancing interparticle adhesion (Zayadi et al., 2020b). Additionally, sample 3 MAP also showed an increase at every soil depth layer. The largest increase was observed at 0–15 cm soil depth, with an increase in cohesion of 8.57 ± 0.56 kPa and an increase in the internal friction angle of 3.74° ± 0.45°. The greater increase in cohesion in the 3 MAP sample indicates that as vetiver roots grow longer, they contribute more to increasing soil shear strength (Kurniawati and Wulandari 2020). Therefore, based on the research results, the combined application of vetiver and modular systems can accelerate vetiver root growth, thereby optimally enhancing soil shear strength.

The application of vetiver grass requires intensive initial care until it is sufficiently stable to prevent soil movement on slopes (Susilawati and Veronika 2016). Additionally, weather factors, such as extreme rainfall, can be challenging during the early growth period of vetiver, namely, the vulnerability to surface erosion, which can carry vetiver plants and soil nutrients away (Pratama et al., 2022). In this study, the module played a role in maintaining moisture and nutrients in the root growth area, thereby enabling vetiver root growth to develop optimally and increasing soil shear strength (Septyani et al., 2014). Furthermore, the application of modular materials functions in soil retention until vetiver roots develop stronger, so they can replace the modular role, which begins to experience degradation (Susilawati and Veronika 2016). The application of modular materials made from jute fiber can make the soil denser by interlocking the soil grains and the jute layer above it, thereby increasing the resulting soil shear strength (Martini et al., 2023).

4. Conclusion

This study demonstrated that the combination of vetiver (*Chrysopogon zizanioides*) and a jute fiber modular system effectively enhanced soil shear strength through progressive root mechanical reinforcement. Vetiver root length increased consistently at a rate of approximately 30–40 cm per month, with the modular system promoting sustained root development by maintaining moisture and nutrient availability in the root zone throughout the observation period. The most significant improvement in soil shear strength was recorded at 3 MAP, with a maximum cohesion value of 19.55 kPa, representing a 78.06% increase relative to 1 MAP, and a root cohesion contribution (ΔcR) of up to 8.57 kPa in the 0–15 cm depth layer.

Linear regression analysis confirmed a statistically significant positive relationship between root biomass and cohesion ($R^2 = 0.623$; $p = 0.011$), with each additional gram of root weight contributing an average increase in cohesion of 1.704 kPa. These findings demonstrate that vetiver combined with biodegradable modular materials represents a viable, low-cost, and environmentally sustainable alternative to conventional slope reinforcement methods, particularly during the critical early establishment phase when root systems are not fully developed. The primary limitation of this study is its laboratory scale; future research should validate these findings through field-scale trials incorporating in situ shear testing and longer observation periods to fully characterize the long-term reinforcement capacity of the vetiver–modular system.

Acknowledgements

This research was partially supported by Directorate of Agromaritime Community Development, IPB University trhough Program *Dosen Pulang Kampung* (grant no. : 1S948/IT3.L1/PM.ol.01/Pr/2025). The authors sincerely appreciate this support.

References

Agustina, D.H., Elfrida., 2019. Influence of moisture content on the shear strength of clay soil. Sigma Tek. 2(1), pp115–122. doi:10.33373/sigma.v2i1.1935.

Agung, P.A.M., Gautama, G.A., Amir, M., Adinegara, A.W., Wiyono, E. and Wacono, S., 2025. Investigation of Aquifer Model to Potential of Ground Movement at Brau Village, Kota Wisata Batu, Jawa Timur, indonesia. Journal of Geoscience, Engineering, Environment, and Technology, 10(3), pp.300-311.

Andiyarto, H.T.C., Purnomo, M., 2012. Efektifitas pemanfaatan tanaman rumput akar wangi untuk pengendalian longsoran permukaan pada lereng jalan ditinjau dari aspek respon pertumbuhan akar. J Tek Sipil Perenc. 14(2), pp151–164.

Badhon, F.F., Islam, M.S. and Islam, M.A., 2021. Contribution of Vetiver root on the improvement of slope stability. Indian Geotechnical Journal, 51(4), pp.829-840.

Dwicaksono, G., 2023. Tinggi Bibit Terhadap Pertumbuhan Akar Wangi (Vetiveria Zizanioides L.) Dengan Uji Dosis Pupuk NPK 16: 16: 16. J Ilm Mhs Pertan [JIMTANI]. 3(1), pp1–12. http://jurnalmahasiswa.umsu.ac.id/index.php/jimtani/article/view/967.

Dorairaj, D. and Osman, N., 2021. Present practices and emerging opportunities in bioengineering for slope stabilization in Malaysia: An overview. PeerJ, 9, p.e10477.

Eab, K.H., Likitlersuang. S., Takahashi, A., 2015. Laboratory and modelling investigation of root-reinforced system for slope stabilisation. Soils Found. 55(5), pp1270–1281. doi:10.1016/j.sandf.2015.09.025.

Hakim, R.N., Santoso. E., Teguh. G., Prihatino, J., 2020. Studi pengaruh kadar air terhadap kuat geser tanah pada area bekas tambang di Kota Banjarbaru. J Geosapta. 6(1), pp19–21.

Hamdhan, I.N., Pratiwi, D.S., Rahmah. R.A.K., 2020. Analisis stabilitas pada lereng dengan perkuatan tanaman vetiver menggunakan metode elemen hingga 3D. J Ilmu dan Terap Bid Tek SIpil. 26(2), pp174–182.

Hamidifar, H., Keshavarzi, A. and Truong, P., 2018. Enhancement of river bank shear strength parameters using Vetiver grass root system. Arabian Journal of Geosciences, 11(20), p.611.

Hidayati, A.M., Kedaton, K.H. Tonyes, S.G., and Ciawi, Y., 2023. Exploring The Mechanism Of Vetiver System For Slope Reinforcement On Diverse Soil Types–A Review. Journal of Geoscience, Engineering, Environment, and Technology, 8(2), pp.123-130.

Ikrimah, M.A., Sutanto, H., Budiman, E., 2020. Studi Penanganan Longsor Dengan Beberapa Alternatif Dinding Penahan Tanah (Studi Kasus : Area Gedung Politeknik Balikpapan). J Ilmu Pengetah dan Teknol Sipil. 4(2), pp30–43. https://e-journals.unmul.ac.id/index.php/TS/article/view/5236.

Kalibová, J., Jačka, L., Petru, J., 2016. The effectiveness of jute and coir blankets for erosion control in different field and laboratory conditions. Solid Earth. 7(2), pp469–479. doi:10.5194/se-7-469-2016.

Kang, Q., Xia, Y., Li, X., Zhang, W., Feng, C., 2022. Study on the Effect of Moisture Content and Dry Density on Shear Strength of Silty Clay Based on Direct Shear Test. Adv Civ Eng. (1), pp1–10. doi:10.1155/2022/2213363.

Komarawidjaja, W., Garno, Y.S., 2016. Role of vetiver grass (Chrysopogon zizanioides) in phytoremediation of contaminated river waters. J Teknol Lingkung. 17(1), pp7–14. doi:10.29122/jtl.v17i1.1459.

Kurniawati, P., Wulandari, S., 2020. Analisis Pengaruh Tanaman Vetiver Terhadap Stabilitas Lereng. J Poli-Teknologi. 19(2), pp185–196. doi:10.32722/pt.v19i2.2744.

Martini., Fadliah, I., Biru, B., 2023. Kajian perilaku kuat geser tanah terhadap penambahan serat karung goni. Rekonstruksi Tadulako Civ Eng J Res Dev. 4(1), pp9–16. doi:10.22487/renstra.v4i1.536.

Muchtaranda, I.H., Sulistyowati, T., Muhajirah., 2022. The effect of rain on slope stability with cracks in cohesive soil (case study: landslide in Guntur Macan Village, Gunung Sari District, West Lombok Regency). J Spektrum Sipil. 9(2), pp97–110. doi:10.29303/spektrum.v9i2.239.

Nejad, B.M., Enferadi, S. and Andrew, R., 2025. A comprehensive analysis of process-related CO2 emissions from Iran's cement industry. Cleaner Environmental Systems, 16, p.100251.

Nugraha., Yudhistira, F., Hamdhan., Noer, I., 2016. Analisis stabilitas lereng menggunakan perkuatan tanaman switchgrass. J Tek Sipil Itenas. 2(2), pp71–82. https://en.wikipedia.org/wiki/panicum_virgatum.

Ogundare, D., Familusi, A., Osunkunle A., Olusami J., 2018. Utilization of geotextile for soil stabilization. Am J Eng Res. 7(8), pp224–231.

Pratama, Z.W., Syarif, M., Junedi, H., 2022. Dampak erosi terhadap kehilangan hara makro pada lahan agroforestry kopi dan kayu manis di Kecamatan Siulak Kabupaten Kerinci. J Agroecotania. 5(2), pp14–22. doi:10.22437/agroecotania.v5i2.23036.

Putro, M.F.E.N., Agustina, D.H., 2023. Analisis Kestabilan Lereng Dengan Perkuatan Shotcrete Menggunakan Plaxis (Studi Kasus : Ruas Jalan Tarempa – Rintis Sta 07+800 Kab. Anambas). Sigma Tek. 6(1), pp223–230. doi:10.33373/sigmateknika.v6i1.5150.

Resqiyanto, M.A., Chadirin, Y., Putra, H., 2025. Vetiver grass-based bioengineering for slope reinforcement and carbon sequestration : a sustainable innovation in bioresource science. 03008.

Sari, D.P.D., Dharmawansyah, D., 2023. Evaluasi penggunaan vegetasi dengan media tanam cocomesh untuk stabilitas lereng pada area tebing saluran irigasi di Bintang Bano Sumbawa Barat. J Tambora. 7(1), pp276–281.

Sari, R.O., Zain, A., Pratiwi, D., 2024. Analisis penggunaan tanaman vetiver terhadap stabilitas lereng pada Bendungan Way Sekampung. J Ilm Univ Batanghari Jambi. 24(2), pp1376–1382. doi:10.33087/jiubj.v24i2.5040.

Septyani, R.P., Ardie, S.W., Susanto., 2014. Vetiver (Vetiveria zizanioides (L.) Nash) cultivation in container: effect of media composition and number of seedling planted. J Bul Agrohorti. 1(4), pp111–121.

Simatupang, I.D. and Kausarian, H., 2024. Geotechnical insights into andesite quarry slope stability: A case study from Desa Usul, Indragiri Hulu, Riau, Indonesia. Journal of Geoscience, Engineering, Environment, and Technology, 9(04), pp.591-599.

Sunandar, A., Prananda, I.A., 2020. Penerapan teknologi hydroseeding dikombinasi dengan matras organik di lereng jalan bebas hambatan Manado – Bitung. J HPJI (Himpunan Pengemb Jalan Indones. 6(2), pp105–118.

Susilawati., Veronika., 2016. Kajian rumput vetiver sebagai pengaman lereng secara berkelanjutan. J Ilmu dan Terap Bid Tek SIpil. 22(2), pp99–108. doi:10.14710/mkts.v22i2.12886.

Wandira, S.A., Rahayu, A., 2021. Peningkatan stabilitas lereng pada ruas jalan Tawaeli – Toboli dengan vegetasi/bioengineering. Rekonstruksi Tadulako Civ Eng J Res Dev. 2(1), pp23–32. doi:10.22487/renstra.v2i1.235.

Wang, X., Li, Z., Chen, Y. and Yao, Y., 2023. Influence of vetiver root morphology on soil–Water characteristics of Plant-Covered slope soil in South central China. Sustainability, 15(2), p.1365.

Yuskar, Y., Putra, D.B.E., Suryadi, A., Choanji, T. and Cahyaningsih, C., 2017. Structural Geology Analysis In A Disaster-Prone Of Slope Failure, Merangin Village, Kuok District, Kampar Regency, Riau Province. Journal of Geoscience, Engineering, Environment, and Technology, 2(4), pp.249-254.

Zamroni, A., Kurniati, A.C. and Prasetya, H.N.E., 2020. The assessment of landslides disaster mitigation in Java Island, Indonesia: a review. Journal of Geoscience, Engineering, Environment, and Technology, 5(3), pp.124-128.

Zayadi, R., Kusuma, Z., Leksono, A.S., Yanuwiadi, B., 2020a. Soil Reinforcement Modelling on a Hilly Slope with Vegetation of Five Species in the Area Prone to Landslide in Malang, Indonesia. Int J Sci Res Eng Dev. 2(6), pp1207–1214. doi:10.5755/j01.erem.78.3.30670.

Zayadi, R., Kusuma, Z., Leksono, A.S., Yanuwiadi, B., 2020b. The influence of vegetation roots on slope stability in landslide susceptible areas. Int J Civ Eng Technol. 11(4), pp124–133. doi:10.34218/ijciet.11.4.2020.011.