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The Role Of Vetiver Grass In Soil Erosion And Slope Stabilization In Vietnam: A Review

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ABSTRACT

This study explores the use of vetiver grass (Vetiveria zizanioides) as a sustainable solution for addressing soil erosion and slope instability in Vietnam. Due to the country's diverse topography and high susceptibility to environmental issues, Vetiver grass, known for its deep root system, is being evaluated for its effectiveness in soil conservation and slope stabilization. The research compiles data from various studies, field trials, and community-based projects across regions like the Mekong Delta and Central Vietnam. Results show that vetiver grass significantly reduces runoff, minimizes soil erosion, and strengthens slopes, thereby reducing the risk of landslides and soil degradation, while offering ecological and socioeconomic benefits.

INTRODUCTION

The use of vetiver grass for soil improvement, erosion control and slope stabilization has been practiced for centuries and its popularity has increased significantly in recent years. This is partly due to the fact that there is now more knowledge and information about vegetation to apply in engineering designs, but also due to the cost-effectiveness and environmental friendliness of this "soft" bioengineering approach. Although vetiver grass had been used by Indian farmers for more than 200 years, its true potential in soil stabilization, soil improvement, and erosion control was not widely recognized until the mid-1980s, when the World Bank introduced it into soil and water conservation programs. Since the late 1980s, vetiver has been widely applied in environmental protection and sustainable agriculture programs. These applications still play a very important role in agricultural production today. A series of research results developed over the past 20 years have further demonstrated that, due to the unique characteristics of vetiver grass, the vetiver grass system is now also used as a bio-engineering measure (Soil Bio-Engineering) to stabilize soil on slopes, treat wastewater, treat polluted areas and improve the environment (Truong et al. (2008); Le and Le (2016)).

. Figure 1 illustrates some of the primary uses of vetiver grass in the transportation, environmental, and other fields.

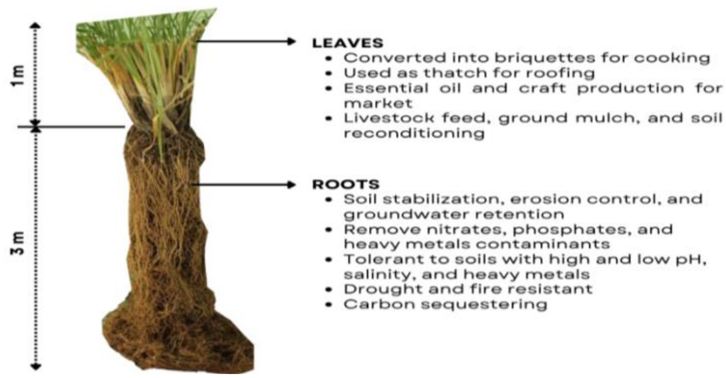


Figure 1. Some main applications of vetiver grass in the fields of transportation, environment, and other fields

. Figure 2 illustrates the number of studies on vetiver published annually from 1990 to 2024, based on a statistical analysis of 277 articles from the Scopus website. It should be noted that Figure 2 only shows the number of publications in Scopus indexed journals, so the actual number of publications may be higher. Statistics show that in the 1990s to 2010, the number of annual publications was less than 10. However, since then, the topic of vetiver has received significant attention from the global research community, leading to a steady increase in the number of publications. From 2017 onwards, the number of publications has fluctuated around 20 articles per year, indicating that the need for further research on vetiver remains urgent.

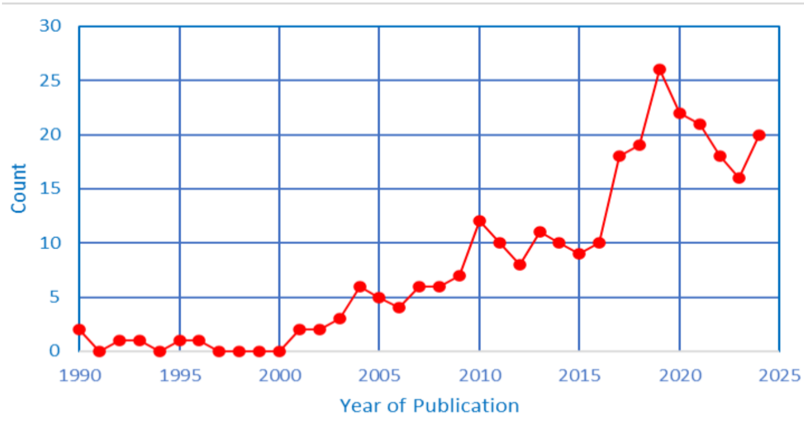


Figure 2. Number of papers on vetiver grass from 1990 to 2024 according to the Scopus portal

(https://www.scopus.com/home.uri Accessed August 23, 2024)

Figure 3 shows the main research directions of 277 articles recorded by VOS Viewer software with data from the Scopus portal from 2000 to 2024. The research results show two distinct trends. From 2015 onwards, the research direction on the application of vetiver grass only focuses on its function, soil erosion prevention, water treatment, and soil improvement, mainly serving agriculture. However, from 2015 to 2025, there has been, and will continue to be, significant development in stabilizing slopes and mitigating natural disasters.

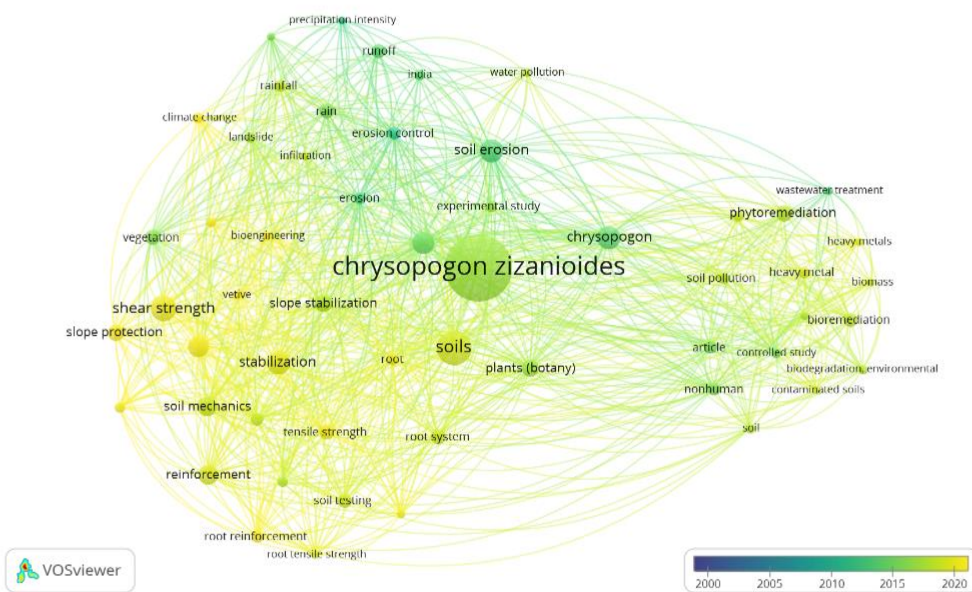


Figure 3. Research directions on vetiver grass from 2000 to 2024 by using VOS Viewer software combined with Scopus portal data (Van and Waltman (2010) and https://www.vosviewer.com)

Several main research directions for the application of vetiver grass in the 277 articles mentioned above related to the research topic are listed below.

Erosion Control and Soil Stabilization

Vetiver grass has been increasingly recognised for its role in reducing soil erosion and stabilizing slopes across various environments. For example, Hamidifar et al. (2018) found out the effectiveness of vetiver grass roots in enhancing the shear strength of riverbank soils. The study focused on clayey soils and investigated the morphological characteristics of the vetiver grass root system, such as root area ratio (RAR), root diameter ratio (RDR), root diameter and density ratio (RDDR), and root length density (RLD). It also examined how these traits affect soil shear strength parameters like soil cohesion (c) and internal friction angle (φ). The study provided empirical equations to calculate soil shear strength based on the morphological traits of vetiver grass roots. The findings suggested that vetiver is a highly effective, low-cost bioengineering tool for reinforcing riverbanks and stabilizing slopes, making it useful for natural waterway management. Likitlersuang et al. (2020) examined the effectiveness of different land covers, including geosynthetic cementitious composite mat (GCCM) and vetiver grass, in controlling soil erosion on mountainous slopes subjected to rainfall. The research involved a full-scale field experiment with an embankment measuring 8 m wide, 21 m long, and 3 m high, constructed using lateritic soil compacted to 70% to mimic natural conditions. The embankment's 45° side-slope was divided into six land cover zones: three bare soil areas, one with GCCM, one with vetiver grass, and one combining GCCM and vegetation. The study concluded that GCCM is ideal for immediate protection, while vetiver grass offers sustainable, long-term erosion control in mountainous terrains. Lastly, Aziz et al. (2023) investigated the effectiveness of vetiver grass (Chrysopogon zizanioides) in reducing erosion and runoff on steep hill slopes. The study focused on tropical regions where intense rainfall and human activities exacerbate soil erosion. Six small-scale glass models were constructed, one with bare soil and five with vetiver grass, all with a 37° slope. The models were subjected to high-intensity artificial rainfall one year after planting. Five models used sandy silt soil, while one used silty sand to examine the impact of soil texture. The study concluded that vetiver grass is highly effective in erosion control, especially for soils with higher sand content.

Mechanical and Biomechanical Properties

The mechanical reinforcement properties of vetiver roots play a crucial role in slope stabilization and soil reinforcement. For examples, Patil et al. (2024) explored the role of vetiver grass (Chrysopogon zizanioides) in enhancing slope stability through mechanical root reinforcement in tropical and mountainous regions. The research highlighted soil bioengineering as an eco-friendly and viable alternative to traditional slope stabilization techniques. Vetiver roots, due to their interaction with the soil along the failure surface, provide additional shear strength and improve slope stability. Furthermore, Jandyal and Shah (2024) investigated the effects of vetiver grass roots on the engineering properties of soil, focusing on their potential for slope reinforcement and erosion mitigation. The study emphasized vetiver roots' ability to protect soil from raindrop impact and securely anchor it, thereby enhancing both slope stability and soil cohesion. The research involved a laboratory experiment where vetiver root fibers were added to soil at varying concentrations (0-2% in 0.5% increments) and fiber lengths (20-25 mm). The study concluded that vetiver root reinforcement significantly enhances soil properties, making it an effective natural solution for slope stabilization. These findings provided technical justification for using vetiver grass in soil bioengineering projects aimed at controlling erosion and stabilizing slopes. Lastly, Phan and Likitlersuang (2024) focused on modeling and measuring the root system architecture of two vetiver species, Chrysopogon nemoralis and Chrysopogon zizanioides, to enhance understanding of their root reinforcement potential for slope stabilization. Root system architecture—encompassing root area ratio, root diameter, and root orientation—is critical for bioengineering applications, but has been underexplored for vetiver species. The study provided valuable data on root architecture for both species, contributing to improved root reinforcement models for soil bioengineering. These insights are crucial for applications in earth slope stabilization and erosion control using vetiver grass.

In Vietnam, successful research results from scientific research and practical pilot projects when deployed in localities have shown that the application of vetiver grass in Vietnam is effective for environmental protection and natural disaster mitigation, especially along traffic routes. In this article, the authors will summarize the applications, slope stabilization mechanisms and practical projects that have applied vetiver grass in preventing soil erosion and landslides along traffic works in Vietnam. Through this discussion, the authors aim to strongly promote the application of vetiver grass systems in natural disaster mitigation and protection of traffic infrastructure in Vietnam.

VETIVER GRASS SLOPE REINFORCEMENT AND EROSION CONTROL MECHANISM

Vetiver Grass Slope Reinforcement Mechanism With The Function Of "Living Soil Nail".

Vetiver grass roots develop a dense root system, grow quickly and firmly, and penetrate deep into the ground from 2 m to 3 m. Therefore, this root system helps prevent soil erosion and keeps the grass alive through the dry season. (Figure 4).

Figure 4 illustrates how vetiver grass aids in soil stabilization on slopes. Here's a breakdown:

- Vetiver Hedgerows: Rows of vetiver grass planted along the slope.
- Deep Roots: The roots penetrate deep into the soil
- Slipping Zone: An orange area labeled "Slipping zone on slopes usually from 2 m to 3 m depths" indicates where soil erosion or slipping is likely to occur.
- Stabilization: The deep roots of vetiver grass stabilize this zone, preventing soil erosion.

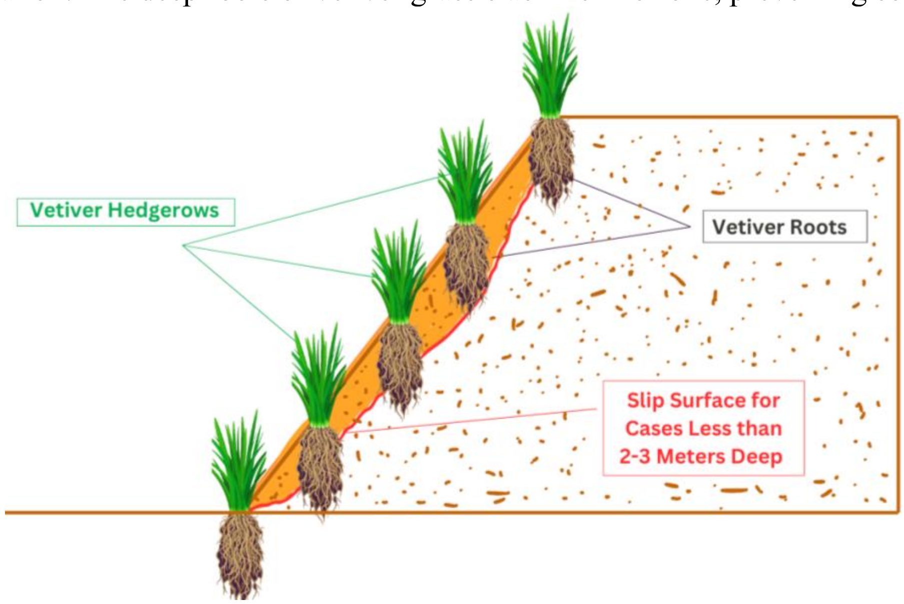


Figure 4. Soil stabilization mechanism by vetiver grass.

Shear Strength Of Vetiver Root System

Experiments by Nilaweera and Hengchaovanich (1996) and Hengchaovanich (1998) showed that the tensile strength of vetiver roots increased inversely with root diameter. The curve followed the equation $y = 59.80x - 0.5785$, where y represents the tensile strength (MPa) and x is the root diameter (mm). The data points show that smaller roots exhibit higher tensile strength, with the mean tensile strength noted at around 75 MPa for roots with a diameter of 1 mm. This relationship is critical in studies involving root systems, such as those of vetiver grass, where tensile strength plays a significant role in soil reinforcement and slope stabilization.

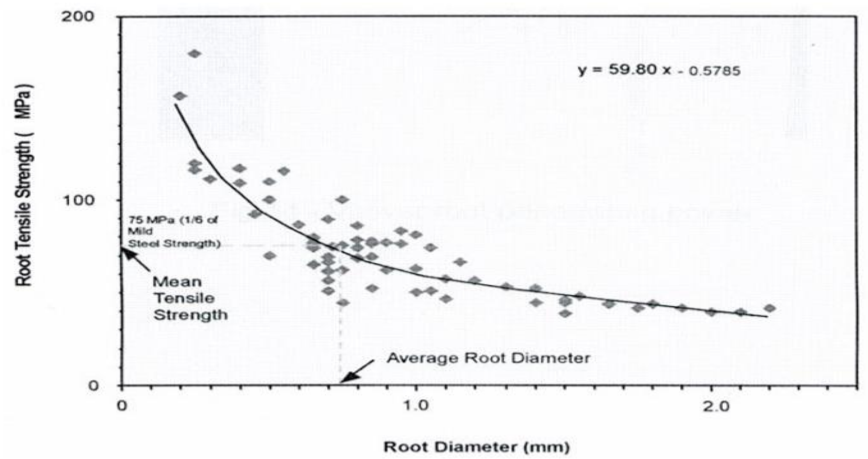
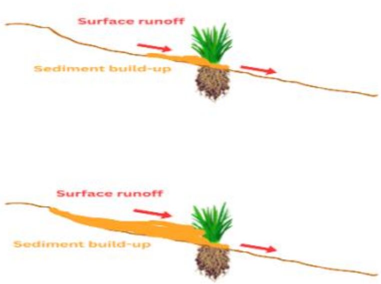


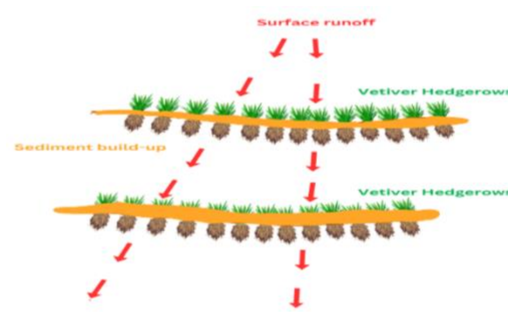
Figure 5. Correlation between shear strength and root diameter of vetiver grass (Nilaweera and Hengchaovanich (1996); Hengchaovanich (1998)).

The Mechanism Of Erosion Control Of Vetiver Grass

Figure 6 shows the anti-erosion mechanism of vetiver grass, according to which vetiver grass is planted in rows along the contour lines on the slope, contributing to diverting the flow to another place. In addition, the vetiver fence after being formed functions like earth banks, making the surface water flow slowly and evenly on the slope, thereby reducing leaching, erosion and surface water seeping more deeply into the ground .



(a)



(b)

Figure 6. (a) The mechanism of erosion control of vetiver grass; (b) Actual slope planted with vetiver grass in contour form (Phan et al., 2024).

PRACTICAL PROJECTS APPLYING VETIVER GRASS IN VIETNAM

Applying Vetiver Grass To Prevent Erosion And Stabilize Slopes At The Ho Chi Minh Highway Project

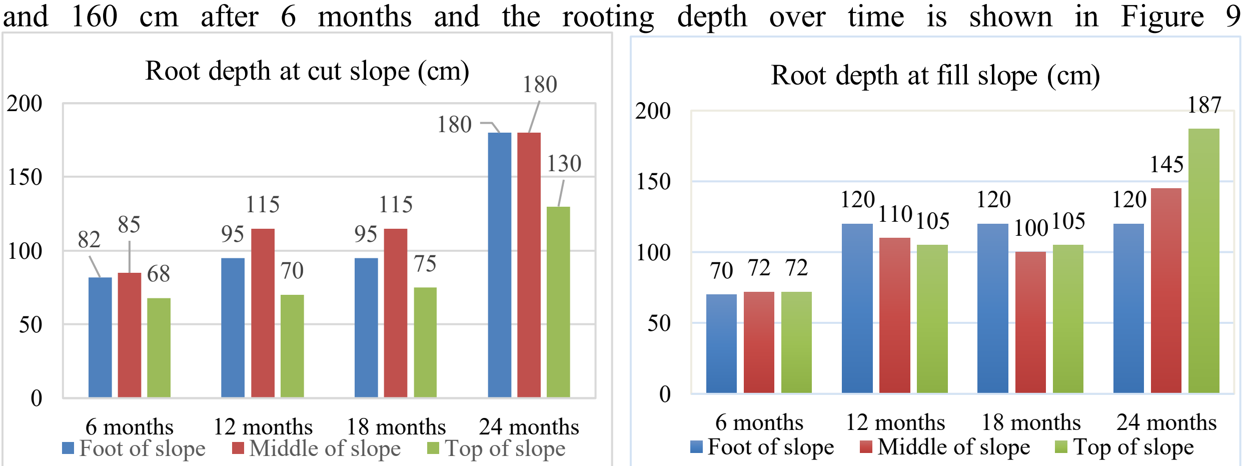
The Vietnamese Ministry of Transport has planted vetiver grass on a large scale to protect hundreds of kilometers of Ho Chi Minh Road slopes since 2002, from Quang Binh province to Quang Nam (Figure 7). In addition, vetiver grass is currently planted on many other national and provincial highways such as in Quang Ninh Province, Da Nang City, and Khanh Hoa Province.

Figure 7. The location of vetiver sites in Quang Binh - Quang Nam.

Figure 8. Ho Chi Minh Road slope (a) Before, (b) After being planted for protection with vetiver grass (Tran et al., 2014)).

Figure 8 compares the slope conditions along the Ho Chi Minh Road before and after the application of vetiver grass for erosion control (Tran et al., 2014). The left image depicts severe soil erosion and instability resulting from heavy rainfall, whereas the right image illustrates a stabilized slope following the introduction of vetiver grass. By developing an extensive root system, vetiver grass strengthens soil structure, mitigates runoff impact, and effectively prevents erosion. As a result, this cost-effective and environmentally sustainable solution not only enhances slope stability but also contributes to long-term land conservation and infrastructure resilience.

Truong et al. (2008) tested planting vetiver grass on a section of the provincial road to Hon Ba Area (Khanh Hoa Province) which also clearly demonstrated the effectiveness of planting vetiver grass to stabilize the slope. Observation results show that 65% to 100% of newly planted grass survives, with the branching rate of 18 to 30 branches/clump, the height reaches between 95 and 160 cm after 6 months and the rooting depth over time is shown in Figure 9.



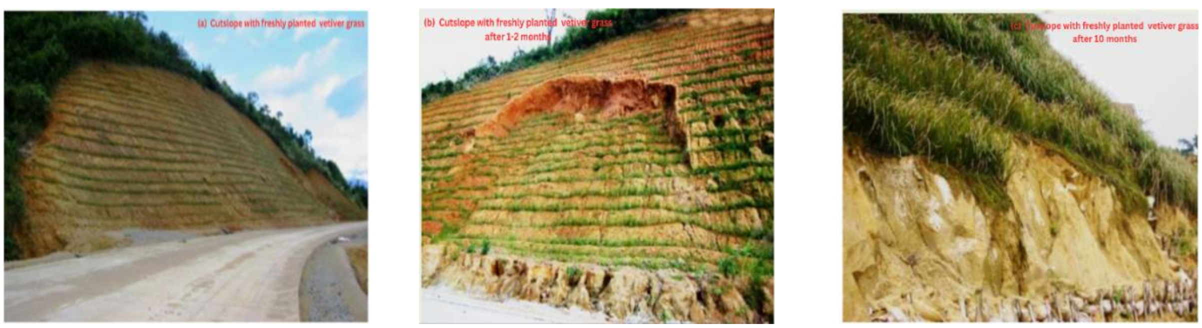
(a) (b)

Figure 9. Rooting depth of vetiver grass at different locations on the road slope in Hon Ba area (Khanh Hoa Province): (a) Cut slope; (b) Fill slope.

Research findings indicate that vetiver grass requires sufficient time to mature before it can effectively reinforce and stabilize slopes. This process is most effective when the slope's internal structure has already reached a stable state. The maturation period of vetiver grass plays a crucial role in mitigating landslide risks, particularly under heavy rainfall conditions. During its initial growth phase (0–6 months), the reinforcement effect remains limited, leaving the soil vulnerable to erosion, runoff, and shallow landslides. Therefore, additional stabilization measures may be required during this period to maintain slope integrity until vetiver grass can fully exert its stabilizing effects.

To maximize effectiveness, vetiver grass should be planted on slopes with an inclination not exceeding 45° to 50°. Slopes steeper than 50° are more susceptible to shear failure, reducing root anchorage and overall stability. Furthermore, steeper slopes intensify erosion and surface runoff, limiting water infiltration and increasing soil displacement. Research by Likitlersuang et al. (2020) suggests that slopes above 45° require supplementary stabilization measures, such as geosynthetic reinforcements, to prevent soil loss. Maintaining slopes ≤ 45° to 50° ensures optimal root reinforcement, effective erosion control, and long-term slope stability, reducing the need for additional engineering interventions.

Finally, periodic cutting of vetiver grass is essential to promote continuous growth and form a dense barrier, further enhancing its effectiveness in slope stabilization (Figure 10).



(a) (b) (c)

Figure 10. Ecological characteristics of vetiver grass growth: (a) Newly planted; (b) After 1-2 months; (c) After 10 months (Tran et al., 2014).

Application Of Vetiver Grass To Protect Riverbanks In Hoa Phong Commune, Da Nang City

In recent years, the problem of riverbank erosion in the downstream area of the Vu Gia - Thu Bon River basin, Da Nang City, has been quite serious, significantly impacting the socio-economic development of the city. The largest erosion point is located on the left bank of the Yen River, which is heavily affected by the basin flow regime from the Vu Gia River (Figure 11). The land stratigraphy mainly consists of sandy soil, sandy clay, while deeper below the river there is sandy soil mixed with gravel or sandy clay. In this project, Vo et al. (2021) implemented an experimental reinforcement section by planting vetiver grass along a 20-meter-long strip, combined with additional stabilization measures such as bamboo piles and steel anchors. The advantage of this method is that it utilizes the shear resistance and tensile resistance of the vetiver root system, as well as stabilizes the bank area during the first 1 to 2 years (Figure 12).

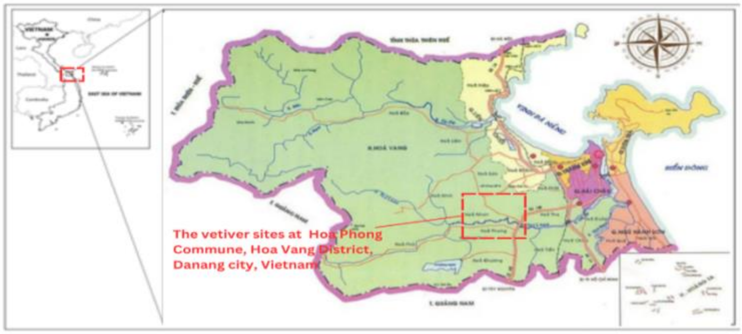
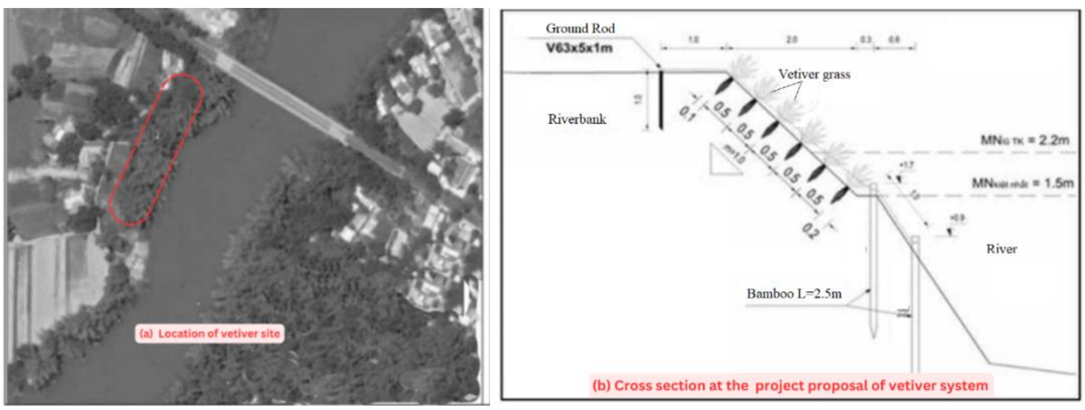


Figure 11. The location of vetiver site at Hoa Phong Commune, Hoa Vang District, Danang city, Vietnam.



(a) (b)

Figure 12. (a) Location of vetiver site; (b) Proposed solution using vetiver grass system in the project (Vo et al., 2021).

Application Of Vetiver Grass To Protect Dyke Banks In An Giang Province

An Giang province, located in the Mekong Delta region and frequently affected by flooding, has faced erosion and weakening of dykes due to strong water flows and natural factors. To protect the dyke system from erosion, vetiver grass has been tested and proven to be an effective biological solution, offering many benefits to areas prone to flood damage. The results of these trials demonstrated that vetiver grass not only effectively controls erosion but also helps stabilize the soil, providing significant advantages for vulnerable lands affected by flooding. This highlights the potential of using vetiver grass to protect and maintain the integrity of dyke systems in areas susceptible to natural disasters (Figure 13a) (Le at al., 2003).

Figure 13. The location of: (a) An Giang Province; (b) Vetiver sites at Tan Chau and Tri Ton District, An Giang Province, Vietnam (Le et al., 2003).

According to Le et al. (2003), two experimental sites were established to test the effectiveness of vetiver grass in protecting dykes in An Giang Province. At the Tan Chau District site, vetiver grass successfully adapted to local conditions, even after being submerged during the flood season. However, the experimental plots were destroyed by cattle, which ate the vetiver as it was the only available fodder during the floods. At Tri Ton District, the grass was initially planted during the dry season, but due to a lack of irrigation, it failed to establish and died after the flooding. A second planting in May 2002, with adequate watering, resulted in strong growth, proving the region's suitability for vetiver when properly managed. Authorities in An Giang plan to plant vetiver immediately after the flood season or during the rainy season to utilize natural moisture and reduce irrigation needs. A more recent experimental site at Bay Xa canal in Tan Chau district demonstrated the effectiveness of vetiver in protecting dykes, as the grass was successfully planted along a 10-kilometer stretch and withstood two flood seasons, preventing erosion that has affected unprotected dykes (Figure 13b).

CONCLUSION

Based on the findings of this study, the following key conclusions can be drawn:

- Vetiver grass has played an important role in preventing landslides and protecting transport infrastructure in Vietnam and has brought about significant results through projects across Vietnam.
- Vetiver grass is well-suited for preventing erosion and stabilizing slopes along the transport system in Vietnam.
- Using vetiver grass system is feasible and brings relatively good economic and technical efficiency compared with traditional hard structure solutions.
- Research results show that more attention should be given to the growth process of vetiver grass to maximize its working capacity, particularly in reinforcing slopes and preventing erosion.

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