THE ROLE OF VETIVER GRASS IN PROTECTING UNSTABLE SLOPES

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Abstract — Vetiver grass (*Chrysopogon spp.*) is characterised by creating a dense hedge that acts as a barrier against rainwater runoff. The barrier significantly reduces the runoff velocity that enables the sediment contents of the runoff to be deposited behind the hedge depending on the slope of the land that creates terraces over time. This case study aims to review the characteristics of the vetiver roots and evaluate its effectiveness in protecting unstable slopes. Field trials were conducted in selected mining areas in Papua New Guinea using quality planting materials and fertilizers for rapid growth and a very immense network of roots formed in the soil. Its root average tensile strength of 75 MPa or approximately 1/6th of mild steel, higher than several trees traditionally used for steep slope stabilization. Vetiver grass is tolerant to drought, saline soil, high and low temperature, thus it lives longer. The effectiveness of Vetiver System Technology is presented in this case study on very unstable sites in Papua New Guinea.

Keywords — **Vetiver grass, vetiver roots, slope stabilization**

INTRODUCTION

There are three well-known vetiver species: Indian vetiver (*Chrysopogon zizanioides*), African vetiver (*Chrysopogon nigritana*), and South East Asian vetiver (*Chrysopogon nemoralis*). In addition, there are five less known species: *Chrysopogon lawsonii* and *Chrysopogon gryllus* in northern India and three Australian native vetiver species: *Chrysopogon filipes*, *Chrysopogon elongata* and *Chrysopogon rigidus*.

The Indian vetiver species (*C. zizanioides*) is further distinguished in to South Indian and North Indian cultivars. Among these, South Indian vetiver *C. zizanioides* is the best known and globally most widespread species due to its essential oil production and use in thatching. Presently, the South Indian cultivar is cultivated for various applications in tropical and subtropical Africa, Asia, Americas, Oceania, and Mediterranean Europe. The North Indian cultivars is not commonly cultivated, and it only exist in swamps in the northern states of India.

Lavania (2008) of the Central Institute of Medicinal and Aromatic Plants in Lucknow, India stated that vetiver is native to India, where it is known to be used both for its fragrant oil and as traditional medicine since antiquity, and its hedges have been used for soil conservation of agricultural lands in India since centuries.

Throughout the tropical and sub-tropical wild states in India, vetiver occurs particularly in marshy land and along riverbanks. It has wide range of ecological distribution ranging from sandy coastal swamps to plains and foothills, and also on the hilltops up to elevations of 800m in the Kumaun hills of Uttar Pradesh. Two distinct morphological cultivars of vetiver are found to inhabit spatially separated geographic regions in India.

The two cultivars are distinctly different. The north Indian wild types flower profusely with high seed-setting and narrow leaves, roots produces superior quality laevorotatory oil (*ruh-khus* or *khus* oil). On the other hand, the south Indian cultivated types has low/ non seed-setting and wider leaves, non/ late flowering pattern, and produces lower quality of dextrorotatory root oil.

The South Indian *C. zizanioides* vetiver grass has deep penetrating tufted root system and a prolific clump of tillers above ground reaching the height of up to 2.5 meters, and the roots growing indeterminately reaching up to 3 meters in one year. Propagation can be done vegetatively through planting of tillers. Vetiver root complex has tuft of fibrous roots which grows vertically penetrating deep into the soil. However, this penetrating root system may have a diverse architectural pattern, ranging from limited spread to vertically penetrating. The main source of essential oil are the primary fibrous roots in contrast with the lateral hairy roots with little oil. However, these lateral hairy roots does help in the formation of root-web facilitating strong soil binding.

The objectives of this case study is to review the role of vertiver roots and evaluate the effectiveness of vetiver grass under different climatic conditions in Papua New Guinea in protecting unstable slopes.

Plant roots and their Interaction with Soil Medium

In the book Plant Roots: Growth, Activity, and Interaction with Soils, Gregory (2006) pointed out the importance of the following attributes of the root system and its interactions with the surrounding environment.

Mass and Length

Most of the vetiver roots are fine roots (≤2 mm diameter), but coarse roots make up by far the majority of the root biomas in croplands and temperate grasslands. The fine roots constitute the primary pathway for water and nutrient uptake in many biomes.

Depth of Rooting

Factors which influences the depth of rooting are the genetic and environmental factors. The depth to which roots can grow has many implications for the hydrological balance and biogeochemical cycling of ecosystems. A maximum rooting depth of 253 woody and herbaceous species from the major terrestrial biomes were found to have a maximum rooting depth varying from 0.3m for some tundra species to 68m. Twenty-two species had roots that extended to 10m or more but 194 species had roots that were at least 2m deep.

Root Longevity and Turnover

High variability in the median lifespan of roots, ranging from a few weeks in some plants (annual crops like sweet potato and groundnut) to many months (sugar maple). In the grass family, thicker roots and high tissue density have also been associated with increased longevity. In nutrient-poor environments thicker roots with a longer lifespan may increase the residence time of nutrients in the plant, and provide an important means of nutrient conservation.

Lavania (2003) pointed out that the Vetiver Root System has diverse applications such as land/slope stabilization, bio-engineering, and environment specific cultivation.

Each application envisages specific a type of root system, hence search for an ideal Root Type for specific applications. For land/slope stabilization and other Bioengineering applications, its roots needs to be profusely branching, spreading type with the amount least essential oil.

VETIVER GRASS ROOTS

Botanical Organization of Vetiver Root System

The veritver roots are characterized to have a tufted vertically growing root system, primary roots are supported with secondary fibrous roots, juvenile primary/secondary roots are solid with persistent cortex and little oil, mature thick roots are spongy with schizogenous cortex and have well developed phloem, phloem is the site of essential oil synthesis and storage, solid vascular cylinder provides tensile strength to roots, and schizogenous cortex facilitates root aeration suitable for submerged conditions. Presented in Figure 1 is the vetiver root system showing its diversity.

Fig. 1. The diversity of the vetiver root system.

Lavania (2019) also pointed out that most grasses have fibrous roots, which spread out from the underground part of the crown and hold the soil in a horizontal pattern. However, the vetiver root whether it is the main and secondary roots ot their fibrous ramification, penetrate vertically into the soil. In vetiver, the roots are biologically the most important and economically the most useful part of the plant. In addition to absorbing water and stabilizing soil moisture, vetiver roots reinforce the integrity of the soil structure.

Structural Dynamics of Vetiver Root

Vetiver roots are comprised of the tufted mass originating from the crown from which shoots arise. In general, growth and behavior of roots is coupled closely to the growth and behavior of shoots. Twelve to eighteen months old vetiver plants has well-developed vascular cylinder and persistent cortex.

Yoon (1989), in an expert on bioengineering using vetiver for slope stabilization (cut and fill batters), described the vetiver root system as very deep and vigorous. With the use of quality planting materials and appropriate fertilizers, rapid growth was obtained and a very immense network of roots formed in the soil. These were clearly demonstrated by plant excavations in China, Malaysia, Thailand, Vietnam. Shown in Figure 2 is a one-year old vetiver roots in Thailand. In the Mediterranean climate of Spain, the roots reached down to 2.1m, after nine (9) months of growth. After I4 months in the field, the roots reached 2.6m depth, and this was despite going through a winter period when sub-zero temperatures killed the tops.

Fig. 2. One year old vetiver with 3.7m root in Thailand

Lifespan of Vetiver

As life span and size of its root system play a very important role in bioengineering, measures that encourage root growth and persistence, even at the expense of its shoot growth should be encouraged. Through a personal communication with Don Miller, as his review on the existence of vetiver in the South West Pacific Islands, he discovered some long lived vetiver plants in the region, which had been introduced earlier, that could be over 100 year old in New Caledonia.

Vetiver Root Responses to Varying Temperature

Although vetiver is a tropical plant, it is extremely tolerant to low temperature. In Australia, vetiver growth was not affected by severe frost at -14°C ground temperature, it survived for a short period at -22°C (-8°F) in northern China. In Georgia (USA), Vetiver survived in soil temperature of -10°C but not at -15°C.

Under phytotron conditions, on average, at temperature above 25°C, daily root growth of 3cm was recorded and at the soil temperature range of 15°C (day) and at 13°C (night), root growth continued at the rate of 12.6cm/day, indicating that vetiver grass was not dormant at this temperature. (Truong, 2003).

Physiological Adaptations of Vetiver under Drought

Under drought conditions, vetiver extends its roots until they reach the moist subsoil and beyond the water table. Significant physiological adaptations of its root must occur during this water stress period. Under artificial inducement it can be in excess of 11m as in Guatemala. At that depth, oxygen level in the soil is extremely low, to sustain this underground growth, vetiver has to rely on the oxygen supply from the shoot through its phenomenal network of parenchyma (Wang, 2000)

Salt Tolerance of Vetiver Grass

As shown in the graphs below, the saline threshold of Monto vetiver is ECse = 8 dSm-1 (left) and soil ECse values of 10 and 20 dSm-1 would reduce yield by 10% and 50% respectively (right). These results indicate vetiver grass compares favorably with some of the most salt tolerant crop and pasture species grown in Australia as shown in the Figure 3 (Truong, 2003).

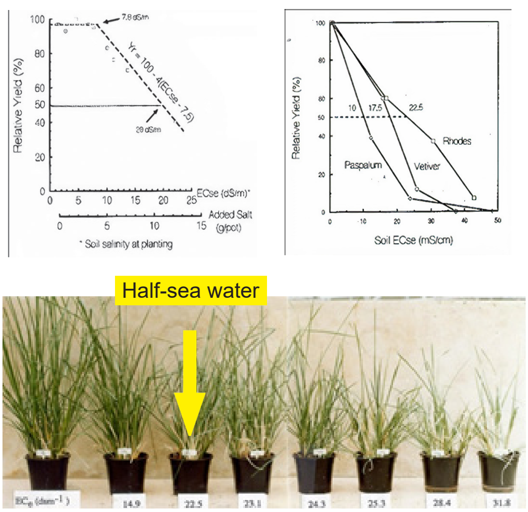

Fig. 3. Salt tolerance of vetiver grass.

Vetiver as a Bio-Engineering Tool

Hengchaovanich and Nilaweera (1998, 1999) reported that soil bioengineering is a recent technology using live materials, mainly vegetation, on its own or in integration with civil engineering works to solve problems relative to soil erosion and slope stabilization.

In the tropical and subtropical regions, the re-vegetation of slopes can be by means of hydroseeding of cover crops (for minor surface movement) or the use of fast-growing shrubs and trees for the mitigation of deep-seated erosion in the order of 20-150 cm depths. In the event of heavy and prolonged rainstorms, the tree or shrub roots are able to grip and bind the soils needed to prevent the deep-seated surface slips. This is because roots or "inclusions" impart apparent cohesion (cr) similar to "soil nailing" or "soil doweling" in the reinforced soil principle, thus increasing the safety factors of slopes permeated with roots vis-à-vis no-roots scenario.

Inherent drawbacks among trees and shrubs due to their too slow to establish to become effective. Even fast-growing species will take about 2-3 years to become established and are in danger of being uprooted during heavy storms, typhoons or cyclones. Although vetiver is a grass, it possess tree-like feature thus becomes a good alternative to trees or shrubs for bioengineering applications.

In 2000, the International Erosion Control Association published an article featuring vetiver grass as a bio-engineering tool due to its unique characteristics: a) vetiver grows upright, forming a dense hedge within 3-4 months, resulting in the reduction of rainfall runoff velocity and formation of an effective sediment filter; b) a vigorous, massive and dense subterranean root system that reaches vertically 2-5 m depth depending on soil types; c) the roots are very strong compared to other hardwood species as shown in Table below, having an average tensile strength of 75 MPa or approximately 1/6th of mild steel.

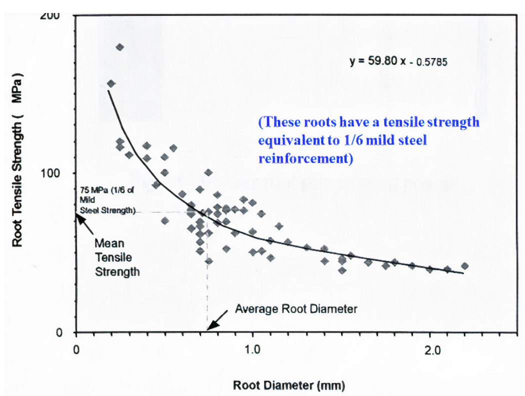

Fig. 4. Tensile strength of vetiver roots.

Effectiveness of Vetiver Grass in Steep Slopes Stabilisation, a Case Study in Tabubil, Papua New Guinea

The Fubilan Mine Pit and Kiunga Port facility are linked up by the Mill-Tabubil-Kiunga road corridor that stretches out for approximately 158km. This road corridor is critical to the business as it facilitates the movement of materials necessary for the operations of the Mining Limited Company at Papua New Guinea. Furthermore, it is essential for the service of Copper and Pyrite Concentration Pipes, Power Pylon and water supply pipes as they are located alongside the road corridor. The existence of geotechnical hazards along the road corridor and around the mine poses significant threats to the stability of the roads, service lines, infrastructures and ultimately the business. Geotechnical hazards are erodible slopes and road batters along road corridor of the mill-mine access roads that are prone to failure. Hence, regular geotechnical visual inspections and survey monitoring of these identified geotechnical hazards are carried out to ensure the stability of the road and other business infrastructures are maintained to allow for consistent traffic flow for normal business operations. Therefore, survey prisms are installed at selected active geotechnical hazard sites which are considered to be active having moderate to high risk with the potential to have an impact on the roads, service lines and other infrastructures.

The Problem

The geographical setting of Mining Limited at Papua New Guinea makes it vulnerable to natural disasters. It is mountainous and hilly with torrential monsoon rains. Landslides, is one of the frequent natural disasters commonly causing severe damage, thus constituting a severe threat to human life, infrastructure and mine production. Excessive water is the common cause that triggered major landslide in Tabubil. The current climate change effects will continue to result in more frequent and intensive storm events, and the landslide disasters will become increasingly more severe for the highway and this access roads which is the lifeline of Mining Limited at Papua New Guinea.

Eagle Vetiver Systems Ltd. as a consulting contractor with the Roads and Civil Engineering team carried out a joint visit of the geo-hazard sites and identified, accessed and evaluated the procedures, and thereafter implemented the Vetiver System Technology (VST) for the re-vegetation and stabilization of slopes as identified to be hazardous.

As per observation, the geology of the entire slopes comprises silty clay to silty loam clay soil structures that was weathering and/or has completely weathered due to accumulation of excess water by the high rainfall (averaging 8,000mm annually) activities, which was resulting in occasional landslips.

Site Inspection of the Slopes

Eagle Vetiver Systems Limited's qualitative assessment classified the road into five categories during the site inspection. The categorization were done basically to categorize each hazard site for ease of management in terms of prioritizing which slopes needed urgent remedial works to prevent slope failures. The purpose of the characterization was to distinguish between slopes that are highly likely to pose a risk to the road, the people, and the damage it will cause to the infrastructure.

Native vegetation on the slopes was minimal, consisting mostly of shrubs and creeping grasses. All have shallow rooting structures and, if disturbed by human activities, will poses risk. Therefore, it was highly recommended that vetiver grass be planted as a primary grass, which will encourage other grasses to grow between vetiver rows.

Field Trial

Field trials were conducted at two sites on road embankments for slope protection with vetiver on two different geohazard sites along the Kiunga/Tabubil highway to evaluate the effectiveness of vetiver grass under Papua New Guinea climatic conditions. Slope stability analysis from our planting showed that the growth of vetiver grass increased the factor of safety hence, reducing slope movement significantly. The slope stability analysis was done by way of monthly survey prism movement monitoring. Iron prisms were placed randomly across the slope face and movement data compilation were collected to analyze the elevation movement trend.

Site 1

This site at KM99 was identified to be potentially an unstable area with landslides on both sides of the road. This slope had conventional engineering structures constructed but with little success with ongoing slope movements hence affecting the road from time to time.

Fig. 5. View of the slope planted with Vetiver Grass (Site 2).

As shown in Figure 5, this site has a maximum length of 150m and maximum width of 39m. The slope gradient has a main scarp around 190%, the head about 40% and the minor scarp around 60% on the right and 50% on the left. From the foot to the toe was 15%. The soil was mainly fine-textured, with a mixer of grey sand stone siting on completely weathered hard clay. Due to recent site preparation for the vetiver grass planting, there was no vegetation. The main scarp was unstable and there was potential for a failure that would cause material to fall, however it will be moderate. vetiver grass was also planted to minimize and to stabilize the slip area.

Slope gradient as indicated in red circle is 214% and about 62m² in surface area, but it was identified to be stable, so planting of vetiver grass was not needed. On the other hand, the zone of accumulation was sitting on riverine gravel and sand stone remains from the landslip, 3 rows of vetiver were planted at 7.5 meters between rows to control soil erosion at the toe. When Vetiver was planted on compacted riverine, growth was slow initially. However, when top soil was applied at the base of the grass to provide plant nutrient, plant growth improved remarkedly.

Site 2

This site at KM98 was unstable due to landslides. The total slip face area was 2616.1m², with minimum width of 27.0m and maximum length was 74.8m. It has a 15% gradient on the left, with the middle being 14% and the right with 20% gradient.

The right flank was noted to be stable. Traverse cracks and radial cracks were evident on the foot and toe of the slope and poses risk of further slumping. Underground water was also seeping out from adjacent pool of water, drains were constructed to drain out the sitting water in the pool.

Fig. 6. View of slope from the toe (Site 2).

Bamboos that were planted on the slope a few months back were removed and replanted at the toe of the slope to increase shear strength. Some small trees growing in the middle were also cut back to avoid the trees from over shading the vetiver at initial growing stages. Figures 6, 7 and 8 show the site before, during and after planting.

Assessment of the trial plantings

Site 2 planting has shown very encouraging results, as reported by Nolin Munia (2018). They were reported to be a success with the site having fully grown vetiver hedges. Active movements of the slope (both downward movement and cumulative elevation trend) have significantly reduced over time with minimal movements picked up during monitoring as shown in the following pictures. The reduction in slope movements have indicated that with time and root growth of the vetiver grass, slope stability has significantly improved.

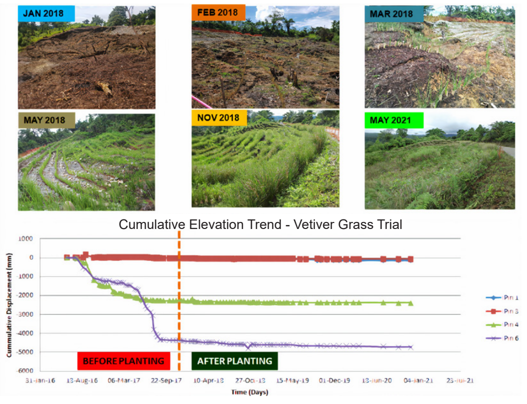

Fig. 7. The growing stages of the trial planting on KM98.

Figure 7 above is a pictorial representation of the growing stages from planting through to full hedge establishment, with the graph below the pictures showing the cumulative elevation trend of the slope before planting of the vetiver grass and the result two and half years after the planting of vetiver grass.

Fertilizer was not applied to this site, however top soil from nearby was applied to the base of the plant to provide the much needed plant nutrient during the initial growth stages.

The following figures are the growth stages of the trial planting on Site 1, a very challenging site as vetiver grass was planted on compacted road base material. Application of fertilizer was not done as a control however, humus soil from nearby was collected and placed under the stems to provide plant nutrients and moisture to encourage plant growth.

Fig. 8. Vetiver growth in March 2018.

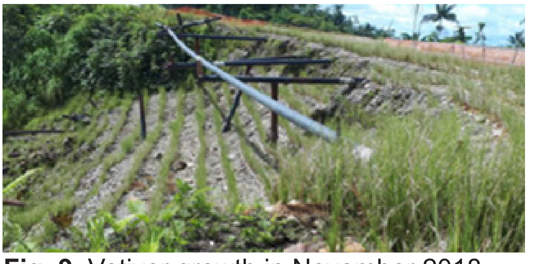

Fig. 9. Vetiver growth in November 2018.

Vetiver growth on this site was slow at the establishment stages as shown in this picture as vetiver was planted on compacted road base material with no topsoil for plant nutrient, however with deep penetrative root growth and uptake of plant nutrient plant growth improved a lot with excellent hedge establishment.

Fig. 10. Vetiver growth in May 2020.

The slope with fully established vetiver hedgerows in 2020 (Figure 10) and regrowth of native vegetation after slope being fully stabilized (Figure 11).

Fig. 11. Vetiver growth in May 2021.

CONCLUSION

Of the two trial sites, the trial planting at Site 2 appeared to be more effective in stabilizing the failed slope due to the excellent growth of vetiver. Contributing factors for the excellent growth of vetiver was due to good sub-surface soil conditions with adequate soil moisture as it was planted at the beginning of the rainy season complimented with readily available plant food nutrient.

During the visit in 2018, the planting on Site 1, plants appeared to be growing slowly and withering during the long dry periods. Contributing factors that affected the vetiver from growing well were due to poor ground conditions. There is a need to apply N and P fertilizers in planting holes before planting and after planting to encourage and stimulate plant growth during establishment phase.

The success of the trial plantings on both these sites has resulted in rolling out of vetiver planting program on all its vulnerable geohazard sites along the road corridor of the mine-mill access road and the highway. The long term goal of the slope stabilization trial using vetiver grass is also to allow regrowth of native vegetation after the failed slopes have been fully stabilized within four to five years of planting vetiver grass.

REFERENCES

Gregory, P.J. 2006. Plant Roots: Their growth, activity and interaction with soils. Blackwell Publishing Ltd.

Hengchaovanich, D. and Nilaweera, N.S. 1998. An assessment of strength properties of vetiver grass roots in relation to slope stabilization. Proc. First Int. Vetiver Conf. (ICV-1) Chiang Rai, Thailand.

Hengchaovanich, D. 1999. Fifteen years of bioengineering in the wet tropics from A (*Acacia auriculiformis*) to V (*Vetiveria zizanioides*). Proc. Ground and Water Bioengineering for Erosion Control and Slope Stabilization, Manila, Philippines.

Lavania, S. 2003. Vetiver Root System: Search for the Ideotype. Proc. Third Int. Vetiver Conf. (ICV-3) Guangzhou, China.

Lavania, S. 2019. Vetiver grass model and phenomics of root system architecture. J. Indian Bot. Soc. vol 98, pages 176-182.

Lavania, U.C. 2008. Vetiver in India. Proc. Vetiver system for environmental protection and Natural disaster management Cochin, India, 21-23 February 2008.

Truong, P. 2003. Vetiver System for Water Quality Improvement. Proc. Third Int. Vetiver Conf), October 2003, Guangzhou, China.

Wang, Y.W. 2000. The root extension rate of vetiver under different temperature treatments. Proc. Second Int. Vetiver Conf. (ICV-2) Thailand.

Yoon, P. K. 1989. A Look-see Vetiver grass in Malaysia. First progress Report. TVNI Archive.