Chapter 19
Landslides and Erosion Control Measures by Vetiver System

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Abstract Hill roads and allied developmental issues have been in the perennial mode of reconditioning especially after rainy season, which are more aggravated due to climate change-induced flash floods and ill-planned human settlements. Even though technology of stabilized hill slopes has been brought into fruitful practices, bioengineering solutions provide ample scope. Investigation of landslides takes into account of portending scenarios of road widening works, multistory buildings juxtaposed on steep slopes with little or no breathing space, and dwindling lifeline infrastructures in hilly terrain amid unplanned construction activities. As preparedness measures, simple guidelines for crack repairs and treatment, restoration and strengthening methodology, applicability of some sustainable technology in landslide mitigation such as anchored earth and geosynthetics-reinforced walls, and bioengineering methods for slope stabilization are emphasized. This paper explains the application of vetiver grass, which is primarily of Indian origin but increasingly used by more than 100 countries. The intention of trying vetiver as one of the bioengineering measures is to see how it can help replace or complement the conventional engineering measures for slope and erosion problems. Present study illustrated some of the potential applications in the North-Eastern India through methodologies along with some successful and failed examples.

Keywords Vetiver system • Erosion • Landslides • Slope stability • Retaining wall • Geosynthetics • Soil nailing

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19.1 Introduction

The use of vegetation as a bioengineering tool for erosion and drainage control has been implemented for centuries, but its popularity has increased in the last few decades. Many studies all over the world have shown that vetiver as a hedge is the ideal plant to conserve soil and rehabilitate eroded land. Nature has "designed" vegetation as a means to blanket and stabilize the good earth from erosion and conserve solar energy (Islam 2000). In the tropics or subtropical region, this has evolved into forests comprising big trees, shrubs, and leaf litters covering the organic humus-rich topsoil that offer excellent overall protection. In the light of current awareness and conscientiousness of environmental issues, the preferred option to address the above problems would be to go back and seek the solutions that nature has provided in varied forms. It's very much required to reinstate those areas ravaged by human beings by way of regrowing vegetation, i.e., the "green" or "soft" environment-friendly approach. This is in contrast to the conventional "hard" or "inert" engineering solutions using stones or concrete for protecting slopes (Truong 1999).

The reason why landslides occur in such a high frequency especially along the hill cut roads is to be realized in terms of efficacy of the slope maintenance measures, including drainages. The knowledge and understanding of landslides mechanism as one of the subjects in geology, geomorphology, hydrology, and geotechnical engineering have been phenomenal since the 1960s. However, the technology of landslides controls and mitigation roles played by construction agencies has to be looked into. In Fig. 19.1 rubble masonry wall is constructed along a national high-

Fig. 19.1 Rubble masonry gravity retaining wall along national highway, Himachal Pradesh, India

way in the state of Himachal Pradesh, India, to retain the cut slope. As has been experienced, efficacies of such walls are questionable, and they are not only costly but also unsuitable to the type of soil being tried to retain. Therefore, construction process is to be guided by proper landslide mitigation measures, including bioengineering measures, which will be mainly explained in the chapter.

Some indigenous techniques in controlling soil erosion and landslide problems are exemplified in Fig. 19.2, where bamboo poles are used as check dams. Drainage galleries are provided with concrete steps that facilitate the maintenance of the entire structure. As there is hardly any authentic documentation available for this kind of job, the proliferation of the same for mass-scale usage is limited. Hence, due to extensive skilled manual labor requirement, such practices remained limited application elsewhere. Such practices are quite uncommon these days as there is a wide-scale exploitation of mountain areas for the increased settlement densities, for which modern slope engineering techniques, such as soil nailing, reinforced earth retaining walls, gabion walls, etc., are applied. The efficacy of indigenous method as shown in Fig. 19.2 remains doubtful as they require regular monitoring.

Climate change/extreme weather phenomena vs. impact of deforestation and changes in the flora-fauna of mountains, possibly due to multipurpose hydropower projects and other tourism-driven vulnerable establishments along the towns and riverbanks in Uttarakhand state of India, have exposed badly during the June 2013 flash flood.

Fig. 19.2 Application of bamboo check dams for retaining water and concrete drain as one of the indigenous slope stabilization measures at Kalimpong, West Bengal (Photo: http://savethehills.blogspot.in/)

19.2 India: The Source of Vetiver Grass

Vetiver grass, although known in India centuries earlier and applied in specific locations with indigenous knowledge, only became known worldwide through the initiative of the World Bank in the 1980s, mainly in the agricultural sector. Later as the unique characteristics of vetiver became better known through scientific researches, it has emerged as an ideal plant for bioengineering and phytoremediation. In 1987, that soil erosion is the most serious agricultural problem in the world; Richard Grimshaw and John Greenfield, two agricultural scientists of the World Bank, decided to tackle it on war footing. During their visits to India, they tried the solution in a village near Gundlupet in Karnataka state:

> We learnt from these farmers that they have been successfully growing against soil erosion for centuries. It reduced rainfall runoff by as much as 70%, recharged groundwater (villages that use Vetiver have much higher water levels in their wells), and improved ephemeral stream flow.

It started to gain impressive grounds in other fields during the mid-1990s arising from some breakthrough researches that reveal the unique properties of this grass, *Vetiveria zizanioides*, that lends itself ideally for bioengineering and phytoremediation purposes, hence touted as a miracle grass, wonder grass, or super grass (Greenfield 1990). There are 12 known species and may be hundred different cultivars that exhibit distinctive phenotypic which can be exploited by users depending on need. Widely used varieties are *Vetiveria zizanioides* (Asia subcontinent), *Vetiveria nigratana* (Southern Africa), and *Vetiveria nemoralis* (South East Asia). Among many other functions, Vetiver System prevents soil erosion, preserves rain water, stabilizes earth, beautifies landscapes, purifies wastewater, keeps away pests, and stabilizes slope. Vetiver and its component parts have been widely developed for other miscellaneous uses, i.e., as construction materials, forages for livestock, landscaping and ornamentals, mulch, compost, veneer, fiber board, ash for concrete work, and insecticide. The grass also was brought to get rid of heavy metals from industry sewage, leachate from garbage, and take part in various industrial commercial products. It grows best on deep sandy soils; however, it grows on most soil types ranging from black cracking vertisols through to red alfisols. It also grows on rubble, both acid and alkali, and on both shallow and deep soils. Glasshouse and field studies showed that vetiver grass can produce high biomass (>100 t/ha/year) and highly tolerate extreme climatic variation such as prolonged drought, flood, submergence and temperatures (−15 to 50 °C), soils high in acidity and alkalinity (pH 3–11), high levels of Al (85% saturation percentage), Mn (578 mg/kg), soil salinity (ECse 47.5 dS/m), sodicity (ESP 48%), and a wide range of heavy metals (As, Cd, Cr, Cu, Hg, Ni, Pb, Se, and Zn) (Danh et al. 2009). The longest recorded life period is about 60 years in Zambia and 100 years in Fiji.

19.2.1 Genesis of Vetiver

The plant vetiver belongs to the same group of grass family of rice, maize, sorghum, sugarcane, and lemongrass. It got its generic name *Vetiveria*, from its Tamil name "vetiver" which means root that is dug up. *Zizanioides* means by "the riverside." The fact is that the plant is commonly found along the waterways. Its name was later reclassified as *Chrysopogon zizanioides* (Madhu and Haridas 2011). Vetiver has been known to India since ancient times. It has been considered as a high-class perfume, and copper plate inscriptions list the perfume as one of the articles used by royalty. Two species of *Vetiveria* are found in India, of which *V. zizanioides* is the common source of the well-known oil of vetiver, which is used in medicine and in perfumery. The species of Vetiver System (*Chrysopogon zizanioides*) originates in the state of Tamil Nadu, South India, which is now being promoted in nearly 100 countries. It is sterile and noninvasive and has to be propagated by clump subdivision.

In general, nursery multiplication of bare-rooted plants is the preferred method. The average multiplication rate varies but is normally, in a nursery, about 1:30 after about 3 months, depending on climate and growing conditions. The Vetiver Network International (http://vetiver.org/) is the most thorough and current resource for this plant. Nursery clumps are divided into planting slips of about three tillers each and typically planted 15 cm apart on the contour to create, when mature, a barrier of stiff grass that acts as a buffer and spreader of downslope water flow and a filter to sediment. A good hedge will reduce rainfall runoff by as much as 70% and sediment by as much as 90%. A hedgerow will stay where it is planted, and the sediment that is spread out behind the hedgerow gradually accumulates to form a long-lasting terrace with vetiver protection. It is a very low-cost, labor-intensive technology with very high benefit/cost ratios. When used for civil works protection, its cost is about 1/20 of traditional engineered systems and designs. Engineers attribute the vetiver root to a "living soil nail" with an average tensile strength of one sixth of mild steel.

The Council of Scientific and Industrial Research (CSIR), India, recently launched the "Aroma and Phyto-Pharmaceutical Mission" to boost cultivation of aromatic crops like vetiver, lavender, rosemary, and lemongrass and medicinal plants like ashwagandha and shatavari. The Central Institute of Medicinal and Aromatic Plants (CIMAP) has to lead the movement to promote cultivation of these crops especially in unproductive, marginal waste lands including those affected by water scarcity, drought, salinity, or flood.

19.2.2 Vetiver: Global Scenario

This indigenous knowledge was taken along when Indians migrated overseas and usage resumed in new localities around the globe. Thus, one reads of vetiver usage for slope protection and reinforcement of embankments and cuttings outside of

Table 19.1 Various vernacular names used for vetiver grass across the country

Dialect/ language	Vernacular name
Hindi, Bengali	Khas, Khas-Khas, Khus-Khus, Khus
Gujarati	Valo
Marathi	Vala
Telugu	Kuruveeru, Vettiveellu, Vettiveerum
Tamil	Vattiver
Kannad	Vattiveeru, Laamancha, Kaddu, KaridappasajjeHullu
Malayalam	Ramaccham, Vettiveru
Ayurvedic name	Ushira

farmlands since the early 1900s in the West Indies, South Africa (NRC 1993), Brazil (Grimshaw 1993), Fiji (Truong and Gawander 1996), etc. In 1931, it was on record that vetiver was grown at Serdang, near Kuala Lumpur, Malaysia, where it is used for holding up steep banks. It is well-known to be good for this purpose (World Bank 1995). Vetiver has been used extensively all over the world for erosion and sediment control, such as Brazil, China, the Congo, Australia, Indonesia, Venezuela, Vietnam, Thailand, India, the Philippines, Senegal, Zimbabwe, Nigeria, Colombia, El Salvador, Nicaragua, Guatemala, Costa Rica, and the southern United States. This paper presents some applications of Vetiver System in the erosion and landslide control for the hill states in India. In Western and Northern India, it is popularly known as khus (Table 19.1).

It has been extensively used as a cost-effective stabilization of karst stony slopes in high-altitude region, and the revegetation of barren quarried face by an innovative patented method by vetiver combined with other ancillary works was conceived and implemented in China. Riverbank stabilization has been successfully carried out on a major scale in fresh and brackish water environment in the Mekong Delta in Vietnam subjected to waves caused by motorized boat traffic as well as on the Hanjiang River (a Yangzi River tributary) in China (Islam 2011). Trials on the use of vetiver for beach protection were successfully achieved in Senegal, and slope stabilization of 100 km length of 18 coastal polders by vetiver was attempted in Bangladesh with varying success (Islam 2003). Flume tests were conducted in Australia to throw light on hydraulic characteristics of vetiver in deep flow that will aid in the design of channel stabilization and flood erosion control (Hengchaovanich 1998).

19.2.3 Application Domain

In addition to its very important application in agricultural lands, scientific research conducted in the last three decades has clearly demonstrated that VS is also one of the most effective and low-cost natural methods of environmental and infrastructure protection. Besides, it has great socioeconomic impact on local population and climate change. Historically, the order of development of the five main applications of VS is (Truong 2015):

1. Soil and Water Conservation in Agricultural Land
   (a) In agricultural land, vetiver hedges provided a very effective and low-cost method of soil and water conservation on sloping land and resulted in significant crop yield improvement.
2. Stabilization of Infrastructures
   (a) Its extensive and deep root system provides an ideal tool for erosion control of unconsolidated soil and the stabilization of steep slopes such as road and railway batters, dam wall, river and canal banks, and landslips.
3. Environmental Protection
   (a) Phytoremediation of wastewater: The Vetiver System can dispose and/or treat wastewater by reducing the volume or improving the quality of polluted water.
   (b) Phytoremediation of contaminated lands: Vetiver grass has been used successfully for rehabilitation of mine overburden and phytoremediation of mine tailings.
4. Socioeconomic Impact on Rural Community
   (a) Poverty alleviation: Providing income through supply planting materials and handicraft production
   (b) Rural employment to rural community particularly women and children
5. Positive Impacts on Climate Change
   (a) Disaster mitigation
   (b) Carbon sequestration
   (c) Biofuel
6. Agricultural Applications
   (a) Soil and water conservation
   (b) Erosion control
   (c) Slope stabilization
   (d) Embankment stabilization
   (e) Trapping of agrochemicals and nutrients
7. Nonagricultural Applications
   (a) Bioengineering
      (i) Erosion control
      (ii) Slope stabilization
      (iii) Embankment stabilization

8. Phytoremediation
   (a) Reclamation of Problem Soils
      (i) Reclamation of saline soils
      (ii) Reclamation of sodic soils
      (iii) Reclamation of acid sulfate soils
      (iv) Reclamation of other deteriorated soils
9. Rehabilitation of Contaminated Soils and Water
   (i) Rehabilitation of contaminated soils
   (ii) Treatment of mining spoils
   (iii) Treatment of landfills and garbage dumps
   (iv) Removal of agrochemicals and pesticides
   (v) Absorption of heavy metals
10. Rehabilitation of Contaminated Water
   (i) Water treatment and purification
   (ii) Treatment of eutrophicated water
   (iii) Wetland applications
   (iv) Removal of effluents

19.2.4 Medicinal Use

Vetiver widely cultivated in the tropical regions of the world is a miraculous grass native to India, first developed for soil and water conservation by the World Bank during the mid-1980s. Popularly known as "khus," it is the major source of the well-known oil of vetiver, which is used in medicine, in cosmetics, and in perfumery making agarbattis, soaps, soft drinks, and pan masala. Being a major constituent of "rasayana" in Ayurveda, different parts of the vetiver plant have traditionally been used by the Indian tribes for treating various ailments, diseases, and disorders including boils, burns, epilepsy, fever, scorpion sting, snakebite, sores in the mouth, headache, toothache, weakness, lumbago, sprain, rheumatism, urinary tract infection, malarial fever, and acidity relief and as an antihelminthic. It has also been used in traditional medicine of Asia and Africa; particularly ancient Tamil literature mentions the use of vetiver for medical purposes. The essential oil of vetiver has extensive applications in toiletries and cosmetics, possesses sedative property, and has traditionally been used in aromatherapy for relieving stress, anxiety, nervous tension, and insomnia. Root is also important in traditional medicine as a carminative, stimulant, and diaphoretic. Besides these medicinal properties of the plant, the dried culms of the plant are used as brooms and to thatch roofs. Pulp of the plant is used to prepare straw boards and paper. In India, the roots have been used for making screens, mats, hand fans, and baskets (Luqman 2011).

19.2.5 Disaster Prevention

Growing of vetiver hedges on contours and adopting conservation tillage practices between them have been proven to be an effective method to reduce runoff and soil loss and increase in situ moisture, thereby obtaining higher crop yields. Besides conventional slope stability measures such as Gabion, retaining wall, etc., solving erosion and landslide problems has been synonymous with disaster managers dealing in various other natural and man-made disasters. This paper presents some of the potential application of vetiver grass in India, with some case studies, where it has been applied successfully with potential applications. Soil erosion is a quiet crisis, largely man-made disaster that is unfolding gradually.

More than half of India's cropland is losing productivity because topsoil is being washed or blown away faster than natural forces can replace it. Reducing the topsoil layer means reducing plants' access to essential soil nutrients and water. For at least the next decade environmental issues will dominate the agricultural and natural resource sectors. Already the focus of much attention are the problems of deforestation, increased flooding by major rivers, and reduced dry-season water flows for irrigation and urban and industrial supplies. Not enough attention, however, has been given to the massive problem of soil erosion and, more specifically, to the need to reduce soil and water losses caused by excessive rainfall runoff. Changes in farming practices have made the problem worse in recent years. In response to the growing need for grain for exploding human and livestock populations, farmers switched from traditional rotations and multiple cropping to continuous-row cropping, a practice that encourages rainwater to run off the land at a faster and more destructive pace. As a result, crops are denied the moisture they need for optimum growth (Truong and Baker 1998).

Results of numerous trial and mass applications of vetiver grass in the last 30 years in many countries show that the grass is particularly effective in natural disaster reduction (flood, landslide, road batter failure, riverbank, irrigation canal and coastal erosion, water retaining structure instability, etc.), environmental protection (reduction of land and water contamination, treatment of solid and liquid waste, soil improvement, etc.), and many other uses.

19.3 Vetiver System

Vetiveria zizanioides (Linn.) Nash, a member of the family Poaceae commonly known as the *khas-khas*, *khas*, or *khus* grass in India, is a perennial grass with thick fibrous adventitious roots which are aromatic and highly valued. This tufted grass grows throughout the plains of India ascending up to an elevation of 1200 m. Having wide ecological amplitude, this grass grows in a wide variety of ecological habitats covering all biogeographic provinces of India. Vetiver is most closely related to sorghum but shares many morphological characteristics with other fragrant grasses, such as lemongrass (*Cymbopogon citratus*), citronella (*Cymbopogon nardus*, *C. winterianus*), and palmarosa (*Cymbopogon martinii*). It is a tall, tufted, perennial, scented grass, with a straight stem, long narrow leaves, and a lacework root system (Fig. 19.3) that is abundant, complex, and extensive. It offers an inexpensive yet effective and eco-friendly tool to combat soil erosion. The roots have been used in Asia for centuries for their fragrance and are woven into aromatic matting and screens. The roots of some cultivars and ecotypes possess essential oil that has been utilized as fragrant material since ancient times. The plant used as active ingredients in traditional medicine and also as botanical pesticide.

The plant vetiver belongs to the same group of grass family of rice, maize, sorghum, sugarcane, and lemongrass. It got its generic name *Vetiveria*, from its Tamil name "vetiver" which means root that is dug up. Its specific epithet, *Zizanioides*, means "the riverside." The fact is that the plant is commonly found along the waterways. Its name was later reclassified as *Chrysopogon zizanioides*. There are two types of vetiver; one is seedling and the other is non-seedling. Seedling type is commonly found in North India, whereas non-seedling variety is common in South India. Only the non-seedling variety can be recommended for any purpose connected with vetiver, because the other variety is able to spread unwantedly through seeds. The South Indian variety of vetiver has existed for centuries under cultivation and is widely distributed throughout the continents. This variety can be propagated only through vegetative method.

The plant can be grown over a very wide range of climatic and soil conditions and if planted correctly can be used virtually anywhere under tropical, semitropical, and Mediterranean climates. It has characteristics that in totality are unique to a single species. When vetiver grass is grown in the form of a narrow self-sustaining hedgerow, it exhibits special characteristics that are essential to many of the different applications that comprise the Vetiver System. Vetiver grass can be used for applications that will protect river basins and watersheds against environmental damage, particularly from point source factors relating to sediment flows (often associated with agriculture and infrastructure) and toxic chemical flows resulting from excess nutrients, heavy metals, and pesticides in leachate from agriculture and other industries. It can be established on very acid, sodic, alkaline, or saline soils.

(a) (b)

Fig. 19.3 (**a**) North Indian variety vetiver grass tillers with roots, (**b**) grown vetiver with long roots suitable in any soil with air temperature ranging from −15 to 50 °C at pH 3.0–11.0

Table 19.2 Comparison of metal absorption capacity of vetiver grass (Hengchaovanich and Nilaweera 1996)

	Threshold levels in soil (mg/kg) (available)		Threshold levels in plant (mg/kg)	
Heavy metals	Vetiver	Other plants	Vetiver	Other plants
Arsenic	100–250	20.	21–72	1–10
Cadmium	20–60	1.5	45–48	5–20
Copper	50–100	Not available	13–15	15
Chromium	200–600	Not available	5–18	0.02–0.20
Lead	>1500	Not available	>78	Not available
Mercury	>6	Not available	>0.12	Not available
Nickel	100	7–10	347	10–30
Selenium	>74	2–14	>11	Not available
Zinc	>750	Not available	880	Not available

Vetiver tolerates very high levels of aluminum and manganese and a range of heavy metals in the soil (Table 19.2). Due to its extensive and deep root system, vetiver is very tolerant of drought. It can stand extreme heat (50 °C) and frost (−15 °C) and can be established in areas with an annual rainfall from 450 mm and higher. Vetiver is sensitive to shade, and this will slow growth, especially in young plants.

19.4 Conventional Slope Treatment

Compared to traditional and modern system of slope stabilization (Fig. 19.4) available, VS is a very simple, practical, inexpensive, low-maintenance, and very effective means of soil and water conservation, sediment control, land stabilizations and rehabilitation, and phytoremediation (Islam et al. 2013a, b). Being vegetative, it is also environment-friendly. When planted in single rows, vetiver plants will form a hedge which is very effective in slowing and spreading runoff water, reducing soil erosion, conserving soil moisture, and trapping sediment and farm chemicals on-site. Although many hedges can do this, vetiver grass, due to its extraordinary and unique morphological and physiological characteristics described below, can do it better than all other systems tested. In addition, the extremely deep and massively thick root system of vetiver binds the soil and at the same time makes it very difficult for it to be dislodged under high-velocity water flows. This very deep and fast-growing root system also makes vetiver very drought tolerant and highly suitable for steep slope stabilization.

Typical sediment landslide control measures are hard engineering solutions such as gabions, rock fall netting, and geotextiles. Underappreciated and rarely used are biotechnical methods such as the use of vegetation for both erosion and sediment control, alone or in combination with other structures. The revegetation of slopes can be by means of grassing or leguminous cover crops (for minor surface move-

Fig. 19.4 Vetiver grass and its root system at varied stages of growth signifying root matrix suitable to hold soil from washing out

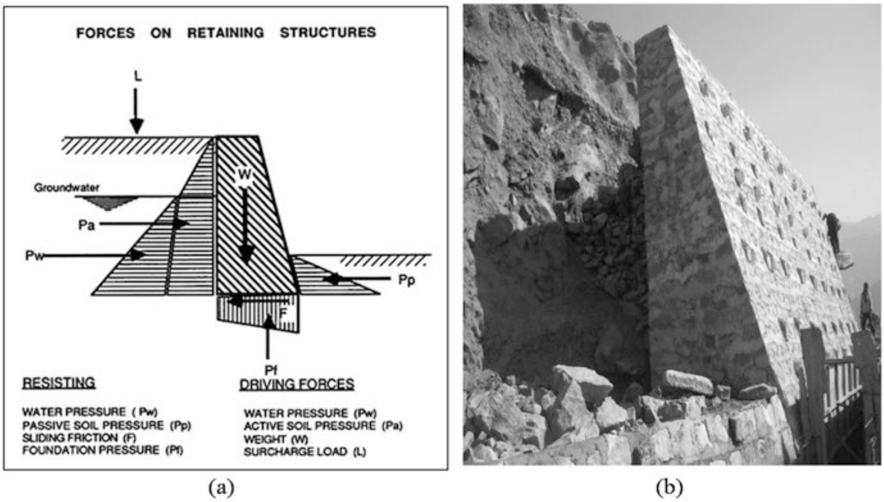


Fig. 19.5 (**a**) Mechanics of traditional gravity retaining wall, (**b**) constructions of stone masonry walls based on the concept of earth retaining structures

ment) or the use of fast-growing shrubs and trees for the mitigation of deep-seated erosion in the order of 20–150 cm depths. Tree or scenario (Gray 1994) and shrub roots are able to grip and bind the soils needed to prevent the deep-seated surface slips in the event of heavy and prolonged rainstorms, while normal grasses are unable to do so. This is because roots or "inclusions" impart apparent cohesion (c) in similar to "soil nailing" or "soil doweling" in the reinforced soil principle (Fig. 19.5), thus increasing the safety factors of slopes permeated with roots vis-à-vis no-root.

19.5 Special Characteristics of Vetiver Grass

19.5.1 Morphological Characteristics

- Vetiver grass is listed in the Global Compendium of Weeds. Vetiver grass genotypes that produce viable seed exist in certain areas and countries, such as the Caribbean and Australia, and are considered invasive weeds.
- Vetiver grass does not have stolons or rhizomes. Its massive finely structured root system that can grow very fast, in some applications rooting depth can reach 3–4 m in the first year, thus checking erosion of soil. This deep root system makes vetiver plant extremely drought tolerant and difficult to dislodge by strong current.
- It has stiff and erect stems, which can stand up to relatively deep water flow.
- Highly resistant to pests, diseases, and fire.
- A dense hedge is formed when planted close together acting as a very effective sediment filter and water spreader.
- New shoots develop from the underground crown making vetiver resistant to fire, frosts, traffic, and heavy grazing pressure.
- New roots grow from nodes when buried by trapped sediment. Vetiver continues to grow up with the deposited silt eventually forming terraces, if trapped sediment is not removed.
- Trees and shrubs inherently have several drawbacks in that they are too slow to establish to become effective (even with fast-growing species, this process will take about 2–3 years) and the danger of being uprooted, in cases of heavy storms, typhoons, or cyclones. Vetiver does possess several treelike features.

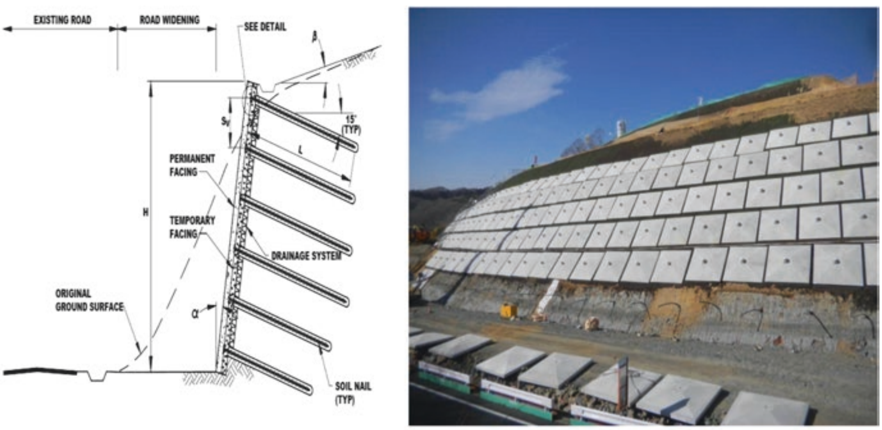
19.5.2 Physiological Characteristics

- Tolerance to extreme climatic variation such as prolonged drought, flood, submergence, and extreme temperature from −15 to +50 °C. The optimal soil temperature for root growth is 25 °C. Root dormancy occurs under a temperature of 5 °C. Under frosty conditions, shoots become dormant and purple, or even die, but the underground growing points survive and can regrow quickly if the conditions improve.
- Ability to regrow very quickly after being affected by drought, frosts, salinity, and adverse conditions after the weather improves or soil ameliorants added.
- Tolerance to wide range of soil pH from 3 to 11 without soil amendment.
- High level of tolerance to herbicides and pesticides.
- Highly efficient in absorbing dissolved nutrients such as N and P and heavy metals in polluted water (Table 19.2).
- Highly tolerant to growing medium high in acidity, alkalinity, salinity, sodicity, and magnesium.
- Highly tolerant to Al, Mn, and heavy metals such as, Cd, Cr, Ni, Pb, Hg, Se, and Zn in the soils.

19.6 Vetiver for Slope Stabilization

In order to stabilize slopes live crib walls, vegetated rock gabions, vegetated rock walls, and joint plantings are some of the soil bioengineering techniques that use porous structures with openings through which vegetative cuttings are inserted and established. The inert structural elements provide immediate resistance to sliding, erosion, and washout. As vegetation becomes established, roots invade and permeate the slope, binding it together into a unified, coherent mass. Over time, the structural elements diminish in importance as the vegetation increases in strength and functionality. Vetiver's unique attributes have been researched, tested, and developed throughout the tropical world, thus ensuring that vetiver is one of the very effective bioengineering tools (Fig. 19.6):

- Although technically a grass, vetiver plants used in land stabilization applications behave more like fast-growing trees or shrubs. Vetiver roots per unit area are found stronger and deeper than tree roots.
- As strong or stronger than those of many hardwood species, vetiver roots have very high tensile strength that has been proven positive for root reinforcement in steep slopes.
- These roots have a mean tested tensile strength of about 75 megapascal (MPa), which is equivalent to one sixth of mild steel reinforcement and a shear strength increment of 39% at a depth of 0.5 m (Table 19.3 and 19.4).
- Slope engineering combines biological elements with engineering design principles practiced in civil-geotechnical discipline. The requirements for both must be considered when planning and designing the measures.



(a) (b)

Fig. 19.6 (**a**) Principles of soil nailing techniques, (**b**) application of the soil nails for slopes in Japan

Table 19.3 Tensile strength of some common grass plant roots (Hengchaovanich and Nilaweera 1996)

Botanical name	Common name	Tensile strength (MPa)
Salix spp.	Willow	9–36
Populus spp.	Poplars	5–38
Alnus spp.	Alders	4–74
Pseudotsuga spp.	Douglas fir	19–61
Acer saccharinum	Silver maple	15–30
Tsuga heterophylla	Western hemlock	27
Vaccinium spp.	Huckleberry	16
Hordeum vulgare	Barley grass	15–31
	Forbs moss	2–20
		2–7 kPa
Chrysopogon zizanioides	Vetiver grass	40–120 (average 75)

Table 19.4 Mean diameter and tensile root strength of various herbs (Hengchaovanich and Nilaweera 1996)

Grass	Mean diameter of roots (mm)	Mean tensile strength (MPa)
Late *Juncellus*	0.38 ± 0.43	24.50 ± 4.2
Dallis grass	0.92 ± 0.28	19.74 ± 3.00
White clover	0.91 ± 0.11	24.64 ± 3.36
Vetiver	0.66 ± 0.32	85.10 ± 31.2
Common centipede grass	0.66 ± 0.05	27.30 ± 1.74
Bahia grass	0.73 ± 0.07	19.23 ± 3.59
Manila grass	0.77 ± 0.67	17.55 ± 2.85
Bermuda grass	0.99 ± 0.17	13.45 ± 2.18

19.6.1 Slope Inspection

19.6.1.1 Topography and Exposure

- Note the degree of slope in stable and unstable areas. Also note the presence or lack of moisture. The likely success of slope treatment can best be determined by observing existing stable slopes in the vicinity of the project site.
- Note the type and density of existing vegetation in areas with and without moisture and on slopes facing different directions. Certain plants grow well on east-facing slopes, but will not survive on south-facing slopes.
- Look for areas of existing vegetation vis-à-vis proposed vetiver grass that may be growing more vigorously than other site vegetation (NRC 1993).

19.6.1.2 Geology and Soils

- Consult geologists about geologic history and types of deposits (colluvium, glacial, alluvium, etc.).
- Note evidence of past sliding. If site evidence exists, determine whether the slide occurred along a deep or shallow failure surface. Leaning or deformed trees may indicate previous slope movement or downhill creep. In addition to site evidence, check aerial photos, which can reveal features that may not be apparent from a site visit.
- Determine soil type and depth. Use the soil survey report, if available, or consult SCS soil scientists.

19.6.1.3 Hydrology

- Determine the drainage area associated with the problem area. Note whether water can be diverted away from the problem area.
- Determine the annual precipitation. Are there concentrated discharges?
- Calculate peak flows or mean discharge through the project area.
- If a seep area was noted, locate the source of the water. Determine whether the water can be intercepted and diverted away from the slope face (NRC 1993).

19.7 Erosion Control by Vetiver

Erosion control at the source is rarely addressed, and resultant sediment control is often underanalyzed, inappropriate, inadequate, or poorly implemented, resulting in frequent slope failures, water body contamination, and road closures. In mountainous terrain, erosion problems are mainly associated with land use changes from native forest to agriculture, grazing, timber harvesting, and road development. The change in land use, including road development, has mainly been done on the municipal and local level. Vetiver planting has been very effective in erosion control or stabilization (Fig. 19.6) in the following conditions:

- It is well adapted to the vegetative barrier practice used to control erosion on farmland because of its strong, compact root system, and numerous stiff stems.
- Slope stabilization along highways and railways especially effective along mountainous rural roads, where retaining structures are either costly or unsuitable (Fig. 19.6).
- Dike and dam batter stabilization, reduction of canal, riverbank and coastal erosion, and protection of hard structures themselves (e.g., rock riprap, concrete retaining walls, gabions, etc.).
- Slope above culvert inlets and outlets (culverts, abutments).
- Interface between cement and rock structures and erodible soil surfaces.

Fig. 19.7 Stabilization of cut slope as of July 2015 by vetiver grass along Guwahati–Shillong National Highway, Meghalaya State, India

- As a filter strip to trap sediment at culvert inlets.
- To reduce energy at culvert outlets.
- To stabilize gully head erosion, when vetiver hedges are planted on contour lines above gully heads.
- To eliminate erosion caused by wave action, by planting a few rows of vetiver on the edge of the high watermark on big farm dam batters or riverbanks (Fig. 19.7a, b).
- In forest plantations, to stabilize the shoulders of access roads on very steep slopes as well as the gullies (logging paths/ways) that develop following harvests.

19.8 Other Applications of Vetiver System

Bioengineering is a relatively new subbranch of civil engineering. It attempts to use live materials, mainly vegetation, on its own or in integration with civil engineering works to address the problems of erosion and slope stabilization. In the late 1980s and the following decade, due to heightened awareness of environmental issues and availability of knowledge and parameters of plants that can aid as well as lend credence to the designs, bioengineering became more well-known and accepted (Xia et al. 1999).

Vetiver hedgerows can reduce sediment/soil loss by 90%; reduce rainfall runoff by as much as 70%; significantly help in the maintenance of soil fertility; provide a source of byproducts that can be used as mulch, forage, and thatch; clean up farm pollution; recharge groundwater; be used as biofuel; and in some cases protect crops from insect damage (Grimshaw 2008):

- Vetiver's extremely deep and massive finely structured root system can extend down to 2 to 3 m in the first year. On fill slope, many experiments show that this grass can reach 3.6 m in 12 months. Vetiver does not penetrate deeply into the groundwater table. Therefore, at sites with a high groundwater level, its root system may not extend as long as in drier soil. Vetiver's extensive and thick root system binds the soil which makes it very difficult to dislodge, and it is found extremely tolerant to drought.
- Vetiver roots can penetrate a compacted soil profile such as hardpan and blocky clay pan common in tropical soils, providing a good anchor for fill and topsoil.
- When planted closely together, vetiver plants form dense hedges that reduce flow velocity, spread and divert runoff water, and create a very effective filter that controls erosion. The hedges slow down the flow and spreads it out, allowing more time for water to soak into the ground.
- Acting as a very effective filter, vetiver hedges help reduce the turbidity of surface runoff. Since new roots develop from nodes when buried by trapped sediment, vetiver continues to rise with the new ground level. Terraces form at the face of the hedges; this sediment should never be removed. The fertile sediment typically contains seeds of local plants, which facilitate their reestablishment (Truong et al. 1996).
- Vetiver grass regrows very quickly following drought, frost, salt, and other adverse soil conditions when the adverse effects are removed.
- Vetiver displays a high level of tolerance to soil acidity, salinity, solidicity, and acid sulfate conditions (Van Du and Truong 2003

19.9 Vetiver Grass Technology

The Vetiver Grass Technology (VGT) is a low-cost and extremely effective system for soil and water conservation, pollution control, wastewater treatment, mitigation and prevention of storm damage, and many other applications. Vetiver can be used in the tropics and semi-tropics, where there are hot summers and winters that do not include permanently frozen soil conditions (Man et al. 2003, 2011). Some of the specific areas where vetiver is beneficial are:

- *A permanent*, *low-maintenance solution*: Vetiver grass is a perennial plant, which provides a permanent solution with little or no maintenance.
- *Strong anchorage to soil*: The vetiver root mass is very large, and the fibrous roots are very strong (Figs. 19.3 and 19.4).
- *Deep anchorage*: Vetiver roots penetrate several meters into native soil or fill material.
- *A durable surface*: Vetiver foliage is tough; it survives fire and extended flooding.
- *Stops soil erosion*: The dense foliage traps soil particles being washed downhill.

- *Improves water quality*: Sediments are trapped by foliage before entering nearby waterways.
- *Water harvesting, flood mitigation*: Vetiver greatly increases percolation rates.
- *Supports local economies*: Vetiver projects are labor intensive. They employ locals, especially in rural areas.
- *A "Green" solution*: Vetiver is more natural and more attractive than stone or concrete.
- *Side benefits*: Vetiver foliage may be harvested for thatching, fodder, composting, or other purposes where biomass is required.
- *Vetiver is noninvasive*: It sets sterile seed and does not have running stolons.
- *Vetiver is noncompetitive*: Roots grow vertically downward; vetiver does not compete with adjacent plants.
- *Safe from pests and disease*: Vetiver has been shown to have very few pest or disease problems. Vetiver can check weed invasion too. It can block the spread of other grasses including the world's worst creeping grasses.
- *Precedents*: Vetiver has been proven in many projects in many countries around the world.

19.10 Vetiver as Sustainable Living

- *Harvest rainwater* – Vetiver hedges intercept and retain overland flows (storm runoff) and significantly increase soil porosity in the root zone.
- *Protect infrastructure* – Road shoulders/cuttings/banks, causeways, bridges, pathways, canals, and drainage systems.
- *Protect structures* – Stabilizes unconsolidated banks and cuttings and mitigates flood damage.
- *Protect coastlines* – Barrier to windblown sand; grows well in the littoral zone.
- *Protect waterways* – Stabilizes riverbanks and improves water quality (reduces sediment loads) by filtering runoff.
- *Stabilize sloping land* – Permanent bioengineering solution against sheet erosion, gully erosion, and landslides.
- *Protect flood-prone land* – Slows down overland flows and traps sediments.
- *Protect farmland* – Stabilizes slopes, riverbanks, and flood zones and does not compete with adjacent crops; vetiver is noninvasive.
- *Sequester carbon* – Creates a permanent, massive root system comprised mainly of carbon. Estimates of carbon sequestration have been made.
- *Facilitate reforestation and plantation establishment* – Increases survival rates and promotes rapid growth of tree seedlings.
- *Phytoremediation and bioremediation* – Phytoremediation (Greek: phyton, plant; Latin: remediare, remedy) refers to a green technology that uses plants to decontaminate polluted soils and water. It has gained popularity by leaps and bounds during the last few years because of the rediscovery of the vast potential of plants to do very effective jobs at such low costs compared to the "conven-

tional" cleanup solutions, using mechanical or chemical means. Vetiver grass has been shown to enhance the degradation of heavy metals such as aluminum, cadmium, chromium, copper, lead, and nickel and polycyclic aromatic hydrocarbons in the soil. It is used for wastewater treatment and rehabilitation of old mines.

- *Treat liquid wastes* – Nutrient removal via massive, fibrous root system and rapid biomass production, removes other pollutants including some heavy metals in leachates.
- *Bio-nailing of slopes* – Soil bioengineering, in the context of slope protection and erosion reduction, combines mechanical, biological, and ecological concepts to arrest and prevents shallow slope failures and erosion. Root system increases drainage and permeability which results in a decrease of excess pore pressures The root system increases soil shear strength via apparent cohesion and therefore the probability of the occurrence of a landslide is reduced. The tensile strength of the roots hinders crack forming. The tensile strength of the roots hinders pushing off of aggregates of soil. Bio-nailing measures such as live crib walls and brush layering are relatively complex and must be tailored carefully to specific soil and site conditions.

19.11 Suitability of Vetiver System

- It is a perennial plant that does not produce viable seed, stolons, or rhizomes but has a very fibrous and deep root system. It is noninvasive.
- The major advantage of VS over conventional engineering measures is its low cost and longevity. For slope stabilization in China, for example, savings are in the order of 85–90% (Xie 1997; Xia et al. 1999). In Australia, the cost advantage of VS over conventional engineering methods ranges from 64% to 72%, depending on the method used (Bracken and Truong 2000). Its maximum cost is only 30% of the cost of traditional measures. In addition, annual maintenance costs are significantly reduced once vetiver hedgerows are established.
- Vetiver System can be used effectively to control surface erosion and shallow failure of road batter.
- Vetiver System can be used effectively at slope between 30 and 60°.
- Vetiver System could be applied by road authorities to cope with erosion and shallow failure of road slope.
- At road slope >60°, Vetiver Technology is not recommended to be applied solely (must be combined with geotextiles and/or mechanical methods).
- As with other bioengineering technologies, VS is a natural, environment-friendly way to control erosion control and stabilize land that "softens" the harsh look of conventional rigid engineering measures such as concrete and rock structures. This is particularly important in urban and semirural areas where local communities decry the unsightly appearance of infrastructure development.

- Long-term maintenance costs are low. In contrast to conventional engineering structures, green technology improves as the vegetative cover matures. VS requires a planned maintenance program in the first 2 years; however, once established, it is virtually maintenance-free. Therefore, the use of vetiver is particularly well suited to remote areas where maintenance is costly and difficult.
- Vetiver is very effective in poor and highly erodible and dispersible soils.
- VS is particularly well suited to areas with low-cost labor forces.
- Vetiver hedges are a natural, soft bioengineering technique, an eco-friendly alternative to rigid or hard structures.

19.12 Limitation of Vetiver System

- The main disadvantage of VS applications is the vetiver's intolerance to shading, particularly within the establishment phase. Partial shading stunts its growth; significant shading can eliminate it in the long term by reducing its ability to compete with more shade-tolerant species. However, this weakness could be desirable in situations where initial stabilization requires a pioneer to improve the ability of the microenvironment to host the voluntary or planned introduction of native endemic species.
- Constraints on planting times or the availability of the required quantities of suitable plant materials during allowable planting times may limit the usefulness of VS.
- The Vetiver System is effective only when the plants are well established. Effective planning requires an initial establishment period of about 2–3 months in warm weather and 4–6 months in cooler times. This delay can be accommodated by planting early and in the dry season.
- The biotechnical usefulness of vetiver grass would be limited on slopes that are exposed to high-velocity water flow or constant inundation during initial phase.
- Vetiver hedges are fully effective only when plants form closed hedgerows. Gaps between clumps should be timely replanted.
- It is difficult to plant and water vegetation on very high or steep slopes.
- Because of the harsh environment on dune, beaches, and anti-salt dikes, planting bare-root slips should be avoided as the survival rate is slow and the plants are slower to take hold.
- Vetiver requires protection from livestock during its establishment phase.

19.13 Status of Vetiver Technology

Based on the feedback by the vetiver users around the world, the responses are adapted as below (Grimshaw 2008):

(a) *Lack of knowledge and technology dissemination*: This covers a wide range including ignorance of the technology by administrators, policy makers and planners, uninformed technical professionals and lack of profession endorsement, teaching and learning limitations in universities and schools, limited press coverage, absence of mass marketing, lack of publications, language barriers, and not using modern marketing tools.
(b) *Leadership*: New technology introduction requires farsighted leadership with vision and commitment. A committed lead organization is required. Good NGOs and private sector companies can often do this best. Commitment is rarely found in government organizations.
(c) *Low-cost solution and problems thereof*: Not always, but generally VS is seen as a low-cost technology that does not attract high budget allocations, and therefore the opportunities and attractiveness for corrupt practices are much less than for high-cost alternatives.
(d) *Technology*: Majority of solutions have in the past an engineering base. Most engineers have not been trained in bioengineering solutions, particularly those that are low cost. Low-cost biological solutions are often seen as too simple and as such are unattractive. Again applying low-cost solutions results in lower fees for designers and executing contractors. Many higher-cost engineering solutions do not always last long and have to be replaced.
(e) *Specifications*: Specifications and standards should be followed; bad application generally results in failure and detracts potential users. Site specification is important. Often rather general standards are given and followed, and if not properly supervised and fine-tuned, it can lead to failure.
(f) *Multipurpose use*: For some potential user groups such as railway and highway engineers, it is best to have narrowly focused workshops and training on the application at hand. For other users such as farmers and rural planners, there is a need to look at the wider aspects and the multi-benefits that are possible from VS.
(g) *Plant propagation*: Because vetiver has to be vegetatively propagated, an upfront investment and lead time are required. This can be detraction. However, there are plenty of demonstrations showing that small farmer private nurseries can be quickly established if there is a guaranteed market.
(h) *Invasive species and native plant syndrome*: This is more of a problem in developed countries. Sometimes deliberate miscasting of vetiver as an invasive species. Many government projects in the United States will only use native plants. Also entrenched vested interests in other more "profitable" technology work hard to keep VS out, and the "invasive" slur is a handy tool to frighten unaware decision-makers.
(i) *Research*: Some research has been very adequate, but more has to be done for field application.
(j) *Maintenance requirements*: Once vetiver is well established on the selected site, usually within one growing season, it generally becomes self-repairing by regeneration and growth and requires little maintenance. However, a newly installed project will require careful periodic inspections until it is established.

Established vegetation is vulnerable to trampling, drought, grazing, nutrient deficiencies, toxins, and pests and may require special management measures at times.

(k) *Limitation*: Vetiver System (VS) measures should not be viewed as a panacea or solution for all slope failure and surface erosion problems. VS has unique attributes, but is not appropriate for all sites and situations. In certain cases, a conventional vegetative treatment (e.g., grass seeding and hydro-mulching) works satisfactorily at less cost. In other cases, the more appropriate and most effective solution is a structural retaining system alone or in combination with soil bioengineering.

(l) *Vetiver growth*: Vetiver plantation is suitable for protecting slopes in different geographic areas with different soils and climatic conditions. However, the growth of vetiver roots and shoot varies in different areas. These are due to the differences in soil type, nutrient content, salinity, and climatic conditions. Even in high saline zone area, vetiver plantation is a suitable solution to protect the side slopes of shrimp ponds from flood and wave actions.

(m) *Livelihood propagation*: Vetiver grass is traditionally used by communities (Fig. 19.8) for livelihoods, however facilitation of Vetiver products across the country needs motivation and cooperation from government.

As a way forward after the Sixth International Conference on Vetiver (ICV), held in May 2015, Vietnam, it was opined that this VS technology must be used across sectors by communities to resolve a number of climate change issues without having to resort to external funding or assistance thus enabling communities to sustain and improve their quality of life through betterment of their environment (Truong 2015) (Fig. 19.9).

19.14 Conclusions

Vetiver Grass Technology (VGT) has so far been applied as soil conservation technique, and it is being used a bioengineering tool which involves significant engineering design and construction that requires an understanding of biology, soil science, hydraulics, hydrology, and geotechnical principles. The layout design varies with slope gradient, cut or fill slope, soil types, and rainfall of a particular site. It has been playing role in soil and water conservation, infrastructure stabilization, pollution control, wastewater treatment, mitigation and rehabilitation, sediment control, prevention of storm damage, and many other environmental protection applications through bioengineering and phytoremediation. Vetiver, although known as a grass, does possess several treelike features. It therefore becomes an attractive alternative to trees or shrubs when it comes to bioengineering applications. Some of the potential applications of Vetiver System across the 100+ countries demonstrate that this plant, even though originated in India, needs extensive research and development in Indian context. Parting with traditional ways to slope

(a)

(b)

Fig. 19.8 (**a**) Application of geotextile mat (GeoMat) for riverbank erosion control and (**b**) use of Vetiver System at a site in Assam state, India

stabilization, there are several modern earth reinforcing techniques that have been applied to India, which are mostly propitiated by select few industries but not formalized in codal practices in India. Excepting a mere mention in the recent IRC code for the application of vetiver system, many nodal organizations are hesitant to adopt VS. However, a combination of modern techniques with Vetiver System has

Fig. 19.9 Utilization of vetiver grass (khus) after extracting oil for the livelihood regeneration, India

to be emphasized and in order to harness that geo-professional practices needs to evolve technique to apply bioengineering solution in soil erosion and landslide problems. Following considerable research and the successes of the many applications presented elsewhere, it is now established that vetiver, with its many advantages and very few disadvantages, is a very effective, economical, community-based, and environment-friendly sustainable bioengineering tool that protects infrastructure and mitigates natural disasters. Once established, the vetiver plantings will last for decades with little, if any, maintenance. However, it must be stressed that the most important keys to success are good-quality planting material, proper design, and correct planting techniques. By all count vetiver is the new-generation green technology everyone is going to adopt for the future.

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References

Bracken N, Truong PN (2000) Application of Vetiver grass technology in the stabilization of road infrastructure in the wet tropical region of Australia. Proc. Second International Vetiver Conf. (ICV-2), Thailand

Danh LT, Truong P, Mammucari R, Tran T, Foster N (2009) Vetiver grass, Vetiveria zizanioides: a choice plant for phytoremediation of heavy metals and organic wastes. Int J Phytoremediat 11(8):664–691. doi:10.1080/ 15226510902787302

Gray DH (1994) Influence of vegetation on stability of slopes. In: Vegetation and slopes. Institution of Civil Engineers, London, pp 2–25

Greenfield JC (1990) Vetiver grass -the hedge against erosion, 3rd edn. The World Bank, Washington, DC

Grimshaw RG (1993) Soil and moisture conservation in central America, vetiver grass technology, Observations from visits to Panama, Costa Rica, Nicaragua, El Salvador, Honduras, and Guatemala. Asia Technical Department, The World Bank, Washington, DC

Grimshaw D (2008) An annual report of Vetiver system. http://vetivernetinternational.blogspot.in/

Hengchaovanich D (1998) Vetiver grass for slope stabilization and erosion control. Tech. Bull. No.1998/2, PRVN / ORDPB, Bangkok, Thailand

Hengchaovanich D, Nilaweera N (1996) An assessment of strength properties of Vetiver grass roots in relation to slope stabilization, Proceedings of the first International Conference on vetiver (ICV-1), Bangkok edn. Office of the Royal Development Projects Board, pp 153–158

Islam MN (2000) Embankment erosion control: towards cheap and simple practical solutions for Bangladesh. Proceedings of the Second International Conference on Vetiver. Office of the Royal Development Projects Board, Bangkok. Pp.307–321

Islam MN (2003) Role of Vetiver in controlling water-borne erosion with particular reference to Bangladesh coastal region. In: Proceedings of the 3rd International Conference on Vetiver (ICV-3), Guangzhou, China, pp 358–367

Islam MN (2011) Riverbank erosion and sustainable protection strategies. J Eng Sci 2., 2011:63–72

Islam MS, Nasrin S, Islam MS, Moury FR (2013a) Use of vegetation and geo-jute in erosion control of slopes in a sub-tropical climate. World Acad Sci Eng Technol 73:1162–1170

Islam MS, Shahriarl BAM, Shahin H (2013b) Study on growth of Vetiver grass in tropical region for slope protection Int. J GEOMATE 5(2):729–734

Luqman S (2011) Investigations on biological activity of Vetiveria zizanioides L. Nash, a palin genesis of some important findings in miracle grass. Proceeding of The Fifth International Conference on Vetiver (ICV-5), Lucknow, India

Madhu AK, Haridas P (2011) Protection of river banks by using Vetiver system technology in Malappurum district of Kerala, Proc. Fifth International Vetiver Conf. (ICV-5), Lucknow, India

Man Tran Van, Elise Pinners, Truong P (2003) Some results of the trial application of Vetiver grass for sand fly, sand flow and river bank erosion control in Central Vietnam. Proc. Third International Vetiver Conf. (ICV-3) China

Man Tran Van, Huynh Van Thang, Truong P (2011) VST in river and canal bank stabilisation in central Vietnam: successes and failures ten years later, Proc. Fifth International Vetiver Conf. 9ICV-5, Lucknow, India

National Research Council (1993) Vetiver grass: a thin green line against erosion. National Academy Press, Washington, DC

Truong P (1999) Vetiver grass technology for land stabilisation, erosion and sediment control in the Asia Pacific region. Proc. First Asia Pacific Conference on Ground and Water Bioengineering for Erosion Control and Slope Stabilization, Manila, the Philippines

Truong P (2015) Summary and highlights of papers Submitted to ICV-6, Source: http://www.vetiver.org/g/conferences.htm, 28 pages

Truong P, Baker D (1998) Vetiver grass system for environmental protection. Technical Bulletin 1998/1. Pacific Rim Vetiver Network, Office of the Royal Development Projects Board, Bangkok, Thailand

Truong P, Gawander JS (1996) Back from the future: do's and don'ts after 50 years of vetiver utilisation in Fiji. Proc. of the First International Conference on vetiver (ICV-1). Office of the Royal Development Projects Board, Bangkok, pp 12–17

Truong P, Gordon I, Baker D (1996) Tolerance of vetiver grass to some adverse soil conditions. Proc. first International vetiver Conf. (ICV-1), Thailand

Le Van Du, Truong P (2003) Vetiver system for erosion control on drainage and irrigation channels on severe acid sulfate soil in Southern Vietnam. Proc. Third International Vetiver Conf. (ICV-3), China

World Bank (1995) Vetiver grass for soil and water conservation. Technical Paper No. 273, RG Grimshaw (ed), Washington DC, USA

Xia HP, Ao HX, Liu SZ, He DQ (1999) Application of the Vetiver grass bio-engineering technology for the prevention of highway slippage in southern China. International Vetiver Workshop, Fuzhou, China, October 1997

Xie FX (1997) Vetiver for highway stabilization in Jian Yang County: Demonstration and Extension. Proceedings International Vetiver Workshop, Fuzhou, China, October 1997