VETIVER SYSTEM FOR EROSION AND SEDIMENT CONTROL

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Abstract

The Vetiver System (VS) is based on the use of vetiver grass (*Vetiveria zizanioides* L.) for various applications in erosion and sediment control. VS was first developed by the World Bank for soil and water conservation in India in the 1980s. Research and Development conducted in Queensland and overseas since then have also shown VS to be a very effective in:

- Water erosion control in agricultural lands such as flood erosion control Darling Downs, where it has been used to replace strip crop layouts, in contour bank substitution and in gully stabilisation. As well, recent research on the use of vetiver grass to control erosion of drains in acid sulfate soils and to improve water quality will be discussed.
- Erosion and sediment control on steep slopes as a bioengineering technique. It has been used successfully for steep batter stabilisation on highway and railway constructions, and for protection of mine infrastructure such as steep outer batter slopes on dams.
- Mine rehabilitation, vetiver grass is highly tolerant to heavy metals as well as to extreme edaphic and climatic conditions. This makes it an ideal species for colonising and ameliorating landfills and tailings dams.

Additional Keywords: soil, water, conservation, mine, phytoremediation.

Introduction

Vetiver System (VS) is based on the use of Vetiver grass (*Vetiveria zizanioides* L. Nash), which was first developed by the World Bank for soil and water conservation in India in the 1980s. In addition to this very important application in agricultural lands, scientific research conducted in the last 15 years has clearly demonstrated that VS has much wider applications. This is due to its unique morphological, physiological and ecological characteristics that permit it to adapt to a wide range of climatic and soil conditions (Truong 2002).

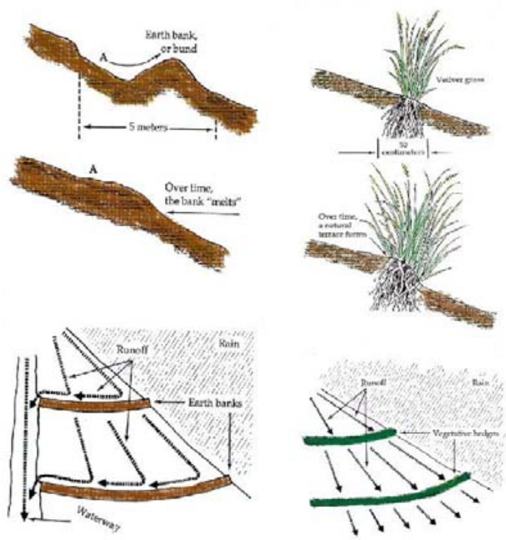
Current applications include soil and water conservation in agricultural lands, steep slope stabilisation, mine, contaminated and saline lands rehabilitation (Truong 1999a) and recently wastewater treatment (Truong and Hart 2001). As a result, VS is now increasingly being used for these purposes in over 120 countries.

Because its remarkable characteristics permit it to survive where other plants cannot, vetiver grass often acts as a pioneer plant; establishing itself in hostile conditions and creating micro-climates that permit a variety of other indigenous plants to prosper.

Vegetative flow-through versus conventional engineering soil conservation systems

A review conducted for the World Bank comparing the effectiveness and practicality of different soil and water conservation systems found that constructed measures must be site specific and require detailed and accurate engineering and design. Furthermore, all structured systems require regular maintenance. Most of the evidence also suggests that constructed works reduce soil losses, but do not reduce runoff significantly and in some cases have a negative impact on soil moisture (Grimshaw 1988). The vegetative conservation system, on the other hand, when planted on the contour, forms a protective barrier across the slope, which slows the runoff water causing sediment to be deposited. Since the barriers only filter the runoff and do not convey it, water seeps through the hedge, reaching the bottom of the slope at lower velocity without causing any erosion and without being concentrated in any particular area. This is known as the flow- through system (Greenfield 1989). This is in sharp contrast with the contour terrace/waterway system in which runoff water is collected by the terraces and diverted as quickly as possible from the field to reduce its erosive potential. All runoff water is therefore collected and concentrated in the waterways where most erosion occurs in agricultural lands, particularly on sloping lands, and this water is lost from the field. With the flow-through system, not only is this water conserved but also no land is wasted on the waterways (Fig.1).

Figure 1: Comparison between conventional terrace/contour system and VS in soil and water conservation (Greenfield 1989).



Ideally, species to be used as barriers for effective erosion and sediment control should have the following features (Smith and Srivastava 1989).

- Form an erect, stiff and uniformly dense hedge so as to offer high resistance to overland water flow and have extensive and deep roots, which bind soil to prevent rilling and scouring near the barrier.
- Ability to survive moisture and nutrient stress and to re-establish top growth quickly after rain.
- Minimum loss of crop yield implying that the barrier should not proliferate as a weed, not compete for moisture, nutrients and light and not be a host for pests and diseases.
- Preferably require only a narrow width to be effective and supply products of economic value to farmers.

Vetiver grass exhibits all these characteristics and it is unique in that it can thrive in arid and humid conditions, growing under some extreme soil conditions and survives wide temperature ranges (Grimshaw 1988).

Some Special Characteristics of Vetiver Grass

Morphological Characteristics

- Vetiver grass does not produce above or underground runners. The plant has a strong and massive root system, which is vertical in nature descending 2-3 meters in the first year, ultimately reaching some five meters under tropical conditions. The depth of root structure provides the plant with great tolerance to drought, permits excellent infiltration of soil moisture and penetrates through compacted soil layers (hard pans).
- Above ground, the shoots can grow to two meters and when planted close together it forms a solid vegetative barrier that retards water flow and filters and traps sediment in runoff water. Growth occurs from the crown, which rises relative to soil build-up. It is also highly resistant to pests, diseases, fire and heavy grazing pressure.

Physiological Characteristics

- Tolerance to extreme climatic variations such as prolonged drought, flood, submergence and temperature levels ranging from -20ºC to 55ºC.
- Vetiver has been found to thrive under rainfall ranging from 300 mm to 6000 mm per annum.
- Ability to regrow rapidly after being affected by drought, frost, fire, saline and other adverse conditions when the adverse effects are removed.
- Adaptability to a wide range of soil types (pH 3.0 to 10.5) (Truong and Baker 1998).
- Highly tolerant to growing media that are high in acidity, alkalinity, salinity, sodicity and magnesium (Truong 1994; Truong *et al*. 2003).
- Highly tolerant to Al, Mn, As, Cd, Cr, Ni, Pb, Hg, Se and Zn in the soil (Truong and Baker 1998).

Ecological Characteristics

- Although vetiver is tolerant to extreme soil and climatic conditions, it is intolerant to heavy shade. Shading will reduce growth and, in extreme cases, may result in plant failure.
- It is considered as a pioneer plant. When the planted or invading indigenous species of trees and shrubs eventually form into a heavy canopy above vetiver, its growth will be reduced, and, if desired, it will die out under prolonged shading. Thus, vetiver is a valuable pioneer agent for land rehabilitation and the establishment of native plants or in the context of forestry establishment on steeply sloping lands.

- Whilst vetiver originates as a tropical grass, its adaptability permits it to thrive in climatic circumstances outside the tropical and sub-tropical zones. Vetiver has been shown to grow well at latitudes of 40ºN in China and Southern Europe where it thrives in the Mediterranean countries, particularly in the hot and dry climate of southern Spain, Portugal and Italy (Pease and Truong 2000).

Potential for Invasiveness

- Most of the cultivars of *Vetiveria zizanioides* that are now distributed globally have closely similar DNA characteristics and only a few have been shown to produce viable seeds (Truong and Creighton 1994; Adams and Dafforn 1997).
- In Queensland a sterile cultivar was selected and rigorously monitored and tested over an eight-year period commencing in 1989. This cultivar produced no caryopses when grown under glasshouse and field conditions and in dryland, irrigated and wetland habitats. It is registered as ***Monto Vetiver*** in Queensland.
- In Australia, Monto vetiver has been successfully established in Northern Territory, New South Wales, Victoria and south west of Western Australia.
- There are a number of seeded cultivars in Australia including a number from the Kimberley and New South Wales, which should not be used for the above applications.

Vetiver System for Erosion and Sediment Control

Effectiveness of Vetiver Hedges in Soil and Water Conservation and Crop Yield
In India on cropping land with 1.7% slope, Vetiver contour hedges reduced runoff (as percentage of rainfall) from 23.3% (control) to 15.5%, soil loss from 14.4 t/ha to 3.9 t/ha and sorghum yield increased from 2.52 t/ha to 2.88 t/ha over a four year period. The yield increase was attributed to mainly *in situ* soil and water conservation over the entire toposequence under the Vetiver hedge system (Truong 1993). Under small plot conditions at the International Crops Research Institute for the Semi-Arid Tropics vetiver hedges gave more effective runoff and soil loss control than lemon grass or stone bunds. Runoff from the Vetiver plots was only 44% of that of the control plots on 2.8% slope and 16% on 0.6% slope. Relative to control plots, average reductions of 69% in runoff and 76% in soil loss were recorded from Vetiver plots (Rao *et al*. 1992).

In Nigeria, vetiver strips were established on 6% slopes for three growing seasons to assess effects of vetiver grass on soil and water loss, soil moisture retention and crop yields. Results showed that soil physical and chemical conditions were ameliorated behind the vetiver strip for a distance of 20m. Crop yields were increased by a range 11 – 26% for cowpea and by about 50% for maize under vetiver management. Soil loss and runoff water at the end of 20m runoff plots were 70% and 130% higher respectively in non-vetiver plots than vetiver plots. Vetiver strips increased soil moisture storage by a range of 1.9% to 50.1% at various soil depths. Eroded soils on non-vetiver plots were consistently richer in nutrient contents than on vetiver plots. Nitrogen use efficiency was enhanced by about 40%. This work demonstrates the usefulness of vetiver grass as a soil and water conservation measure in the Nigerian environment (Babola *et al.* 2003).

Similar results were also reported on a range of soil types, land slopes and crops in Venezuela and Indonesia In Natal, South Africa, vetiver hedges have increasingly replaced contour banks and waterways on steep canelands, where farmers have found that the Vetiver system is the most effective and low cost form of soil and water conservation in the long term (Grimshaw 1993). Results of a cost benefit analysis conducted on the Maheswaran watershed in India where both engineering structures and vegetative barriers with Vetiver grass were used, showed that Vetiver systems are more profitable even during the initial stages due to their efficiency and low cost (Rao 1993).

In Queensland, Australia vetiver grass R & D over the last 16 years have confirmed overseas findings, particularly its effectiveness in soil and water conservation, gully stabilisation, degraded land rehabilitation and trapping sediment in waterways and depressions. In addition to these applications, three contributions of significant importance to the versatility of vetiver applications are:

- Flood erosion control on the flood plains of the Darling Downs
- Erosion control in acid sulfate soil
- Contour bank replacement in steep sugar cane lands in North Queensland.

Table 1. Effects of the Vetiver System on soil loss and runoff in agricultural lands (Rodriguez 1993.)

Countries	Soil loss (t/ha)			Runoff (% of rainfall)		
	Control	**Conventional**	**VS**	**Control**	**Conventional**	**VS**
Thailand	3.9	7.3	2.5	1.2	1.4	0.8
Venezuela	95.0	88.7	20.2	64.1	50.0	21.9
Venezuela (15%)*	16.8	12.0	1.1	88	76	72
Venezuela (26%)*	35.5	16.1	4.9			
Vietnam	27.1	5.7	0.8			
Bangladesh		42	6-11			
India		25	2			
		14.4	3.9		23.3	15.5

* Land slope

<u>Flood erosion control</u>. On the flood plains of the Darling Downs and on the northwestern slopes of New South Wales, strip-cropping is used to mitigate floodwater damage to crops and to control soil erosion on low gradient lands subject to deep overland flooding. Crops are planted on the contour in a sequence of crop, stubble and fallow strips of uniform width arranged perpendicular to the flood flow direction with the aim of spreading the flood waters laterally, thus reducing the depth, velocity and consequently the erosivity of flow. Strip cropping uses a similar "flow-through" system as that of Vetiver grass hedges. Strip cropping requires a strict sequence of crop rotation but at times provides little protection from erosion during drought or when low stubble producing crops such as sunflower or cotton are grown in alternate strips.

In a large field trial at Jondaryan, in December 1993 six rows of vetiver totaling over 3000m were planted on the contour at 90m spacing. These rows developed into substantial hedges averaging 1.7m in height in 10 months, providing permanent protection against flood waters. Data collected from a small flow over the site show that the hedges reduce significantly the depth and therefore energy of flow through the hedges. At a low depression, 7.25 tonnes of sediment was trapped by one hedge.

Results over the last several years, (including several major flood events) have shown that VS is very successful in reducing flood velocity and limiting soil movement, with very little erosion in fallow strips (Truong *et al.* 1996, Dalton *et al.* 1996a and Dalton *et al.* 1996b).The results of this trial demonstrated that VS can be considered as an alternative to strip cropping practice on the flood plains of Australia.

<u>Erosion control in acid sulfate soil.</u> Due to its high tolerance level to Al and Mn toxicity, vetiver has been used successfully for the stabilisation of drainage channel bank in acid sulfate soils (actual soil pH around 3.5 and oxidised pH is as low as 2.8) in Cairns and the Gold Coast (Truong *et al*. 2003).

<u>Replacing contour banks</u>. Because of steep and broken slopes, cane growers in the Innisfail area of the wet tropical coast are reluctant to adopt the conventional contour bank system, which can be dangerous for harvesters and heavy machinery. Replacement of contour banks with thin lines of vegetation such as vetiver hedges could offer a solution to the problem. Two contour banks totaling 800m on a sugar cane farm near Innisfail were replaced by vetiver hedges in 1993. Even during the first year when the hedges had not been fully established the benefit of vetiver contour hedges was evident by trapping a considerable amount of sediment. This trial demonstrated clearly that vetiver contour hedges are effective in preventing erosion and trapping sediment on site. More importantly, sugarcane growers in this region considered vetiver contour hedges more acceptable to their local farming practices than the old earthen contour banks, because of their effectiveness and because virtually no maintenance was needed for the vetiver contour hedges.

Vetiver System for Steep Slope Stabilisation

Land disturbance by construction activities has resulted in soil erosion increases from two to 40 000 times the pre construction rates with sediment being the principal transport mechanism for a range of pollutants entering water courses (Truong 1999a).

Vetiver grass' morphological, physiological and ecological characteristics including its tolerance to highly adverse growing conditions provide a unique bio-engineering tool for land stabilisation, soil erosion and sediment control. The main reasons for slope instability are surface erosion and structural weakness of the slope. While surface erosion often leads to rill and gully erosion, structural weakness will cause mass movement or landslip.

Tensile strength and shear strength of vetiver roots.
Research conducted by Hengchaovanich and Nilaweera (1996) showed that the tensile strength of vetiver roots increases with the reduction in root diameter. The tensile strength of vetiver roots varies between 40-180 Mpa for the range of root diameter between 0.2-2.2 mm. The mean design tensile strength is about 75 Mpa (equivalent to approximately one sixth of mild steel) at 0.7-0.8 mm root diameter, which is the most common size for vetiver roots. This indicates that vetiver roots are as strong as, or even stronger than that of many hardwood species, which have been proven positive for root reinforcement in steep slopes. In a soil block shear test, the root penetration of a two year old vetiver hedge with 15cm plant spacing can increase the shear strength of soil in adjacent 50 cm wide strip by 90% at 0.25 m depth. Vetiver can grow vertically on slopes steeper than 150%. It is faster growing and imparts more reinforcement, making it a better candidate for slope stabilisation than other plants

Steep slope stabilisation with VS.
Presently vetiver grass has been widely used for erosion and sediment control on steep slopes around the world: including Africa, Asia, central and south America, southern Europe and Australia where it has been used successfully to stabilise steep batters of road and railway in north, central and south east Queensland. In China, VS has been used for erosion and sediment control on more than 150000 km of railway, highway and road batters in the last 5 years.

Vetiver System for Mine Rehabilitation and Phytoremediation.

With its extraordinary morphological and physiological characteristics mentioned above, vetiver grass has been used successfully for rehabilitation and phytoremediation of mine tailings in Australia and several other countries.

Tolerance to High Acidity, Aluminium and Manganese Toxicity
Truong (2000b) reported that with adequate N and P supply, vetiver growth was not affected even under extremely acidic conditions (pH = 3.0) and at a soil Aluminium Saturation Percentages between 83-87%, which is extremely high as growth of most plants is affected at Al Saturation Percentages less than 30%. In addition, vetiver growth was not affected when extractable manganese in the soil reached 578 mg/Kg and plant manganese content was as high as 890 mg/Kg.

Tolerance to High Soil Salinity and Sodicity: With a salinity threshold level at EC_{se} = 8 dS/m, vetiver grass compares favorably with some of the most salt tolerant crop and pasture species grown in Australia such as Bermuda Grass (*Cynodon dactylon)* with a threshold at 6.9 dSm^{-1}; Rhodes Grass (*Chloris guyana*) at 7.0 dS/m ; Wheat Grass (*Thynopyron elongatum*) at 7.5 dS/m and barley (*Hordeum vulgare*) at 7.7 dS/m. Vetiver grew satisfactorily on a sodium bentonite tailings with Exchangeable Sodium Percentage (ESP) of 48% and a coalmine overburden with an ESP of 33%.

Tolerance and Distribution of Heavy Metals in Vetiver Plant: Vetiver is highly tolerant to As, Cd, Cr, Cu, Hg, Ni, Pb, Se and Zn (Table 2). The distribution of heavy metals in vetiver plant can be divided into three groups:

- Very little of the As, Cd, Cr and Hg absorbed was translocated to the shoots (1% to 5%)
- A moderate proportion of Cu, Pb, Ni and Se was translocated (16% to 33%) to the top and
- Zn was almost evenly distributed between shoot and root (40%). Truong (2000b)

Some examples of VS application in mine rehabilitation and phytoremediation are (Loch *et al.* 2000):

<u>Mine waste.</u> VS has been used to rehabilitate mine waste in South Africa, China, Thailand and Australia where it was used for erosion and sediment control of overburden of coal mines in central and south east Queensland, for wind erosion control in gold mine in north Queensland.

<u>Mine tailings</u>. VS is highly effective as a pioneer plant in the rehabilitation of coal tailings in central Queensland, both new and old gold tailings in north Queensland and Bentonite tailings in south Queensland.

Table 2: Threshold levels of heavy metals to vetiver growth as compared with other species

Heavy Metals	Threshold levels in soil (mg/Kg)		Threshold levels in plant (mg/Kg)	
	Vetiver	**Other plants**	Vetiver	**Other plants**
Arsenic	100-250	2.0	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	>1 500	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

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