This manual is dedicated to the memory of

Diti Hengchaovanich

Geotechnical Engineer

of

Thailand.

He pioneered the use of vetiver on a large scale for highway stabilization, and for many years was a very valuable contributor to The Vetiver Network International. Diti will be remembered with gratefulness by many.

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VETIVER SYSTEM APPLICATIONS
TECHNICAL REFERENCE MANUAL

PREFACE

Few existing plants have the unique attributes of multiple uses, environmentally friendly, effective and simple to use as vetiver grass. Few existing plants that have been known and used quietly over centuries, have suddenly been promoted and widely used world wide in the last 20 years as has vetiver grass. And fewer plants still have been idolized as Miracle Grass, Wonder Grass with capacity to create a living wall, a living filter strip and “live nail” reinforcement.

The Vetiver System (VS) is dependent on the use of a very unique tropical plant, vetiver grass – recently reclassified as *Chrysopogon zizanioides*. 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, semi-tropical, 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.

The species of *Chrysopogon zizanioides*, that is promoted in nearly 100 countries for VS applications, originates in south India, is sterile, non invasive and has to be propagated by clump subdivision. Generally 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 three months. Nursery clumps are divided into planting slips of about 3 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 down slope water flow, and a filter to sediment. A good hedge will reduce rainfall run off 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, labour intensive technology (linked to the cost of labour) 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 liken the vetiver root to a "Living Soil Nail" with an average tensile strength of 1/6 of mild steel.

Vetiver grass can be used directly as a farm income earning product, or it can be used for applications that will protect river basins and watersheds against environmental damage, particularly point source environmental problems relating to: 1. sediment flows and 2. excess nutrients, heavy metals and pesticides in leachate from toxic sources. The two major uses are closely linked.

Results of numerous trial and mass applications of vetiver grass in the last 20 years in many countries also show that the grass is particularly effective in natural disaster reduction (flood, landslide, road batter failure, river bank, 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. All these applications can directly or indirectly impact on the rural poor through either protection or rehabilitation of farm land, providing better moisture retention and provision of direct farm income, or indirectly by protecting rural infrastructure.

The Vetiver Systems can be used by most of the sectors involved in rural and community development; its use should be incorporated, where appropriate, into the development plans for community, district or region. If all the sectors use it, there is then an opportunity for vetiver grass producers, both small and big to get involved with VS as an income generating enterprise, whether it be producing planting material, contracting as landscapers for slope stabilization and other needs, or selling vetiver by-products such as handicrafts, mulch, thatch, forage and other material. Hence it is technology that could "kick start" a significant climb out of poverty for a large segment of the community. The technology is in the public domain and the information is free.

Nevertheless, the potential for vetiver usage remains huge, and awareness about its application needs to be made available to the public. In addition there remains some reluctance, concern, even doubt about the values and effectiveness of vetiver grass. In most cases, failure in the use of vetiver grass is due to improper understanding or incorrect applications rather than Vetiver System itself.

This manual is comprehensive, detailed and practical. It draws on ongoing vetiver work in Vietnam and elsewhere in the world. Its technical recommendations and observations are based on real life situations, problems and solutions. The manual is expected to be used widely by people using and promoting the Vetiver System, and we hope it will be translated into many languages. We have to thank the authors for a job well done!

The manual was first compiled in both Vietnamese and English, but opportunity for the printing of its Vietnamese version came first; both versions are now being published. There are commitments to translate this manual to Chinese, French and Spanish in the near future.

Dick Grimshaw
Founder and Chairman of The Vetiver Network International.

FORWARD

Based on the review of the huge volume of research and application results of vetiver grass, the authors felt it was time to compile a newer version to replace the first World Bank published handbook (1987), Vetiver Grass - A Hedge Against Erosion (commonly known as the Green Book), prepared by John Greenfield. The new manual would cover a wider range of vetiver grass applications. The authors have exchanged this idea and received an enthusiastic support of The Vetiver Network International - TVNI. The Vietnamese and English editions will be printed first.

This Manual combines the applications of VS in land stabilization and infrastructure protection, treatment and disposal of waste and polluted water and rehabilitation and phytoremediation of contaminated lands. Similar to the Green Book, this manual shows the principles and methods of various VS applications in the above uses. This manual also includes the most up to date R&D results for those applications and numerous examples of highly successful results around the world. The main aim of this manual is to introduce VS to planners and design engineers and other potential users, who often are unaware of the effectiveness of bioengineering and phytoremediation methods.

Paul Truong, Tran Tan Van and Elise Pinners,
The authors.

AUTHORS

Dr Paul Truong
Director, The Vetiver Network International, responsible for Asia and Pacific Region, and Director of Veticon Consulting. In the last 18 years he has conducted extensive R&D and Application of the Vetiver System for environmental protection purposes. His pioneering research on vetiver grass tolerance to adverse conditions, heavy metal tolerance and pollution control has established the benchmark for VS applications in toxic wastes, mine rehabilitation and wastewater treatment, for which he has won several World Bank and the King of Thailand Awards.

Dr Tran Tan Van
Coordinator of the Vetiver Network in Vietnam (VNVN). As Vice-Director of the Vietnam Institute of Geosciences and Mineral Resources (VIGMR) in Vietnam, he is in charge of recommendations for natural disaster mitigation. Since being introduced to the Vetiver Systems six years ago, he has become not only an excellent practitioner of Vetiver Systems, but also a strategic leader, as coordinator of the Vetiver Network in Vietnam (VNVN). In these six years he contributed enormously to the widespread adoption of Vetiver Systems in Vietnam, now in nearly 40 out of the 64 provinces, promoted by different ministries, NGOs, and companies. His introduction of Vetiver Systems started with stabilization of coastal sand dunes, and now includes flood damage mitigation on coastal and river banks, sea dikes, anti-salinity dikes and river dikes, protection of slopes and roadsides against erosion and landslides, and applications to mitigate soil and water pollution. He was awarded the prestigious prize of Vetiver Champion by The Vetiver Network International in 2006 at the Fourth International Vetiver Conference in Caracas, Venezuela.

Ir. Elise Pinners
Associate Director of The Vetiver Network International, who started working with Vetiver Systems in NW Cameroon in late nineties, working in agriculture and rural roads projects. Since her arrival in Vietnam in 2001, as an Advisor to VNVN she contributed to the development and promotion of VNVN in Vietnam and internationally, with organisational advice, fund-raising support, and by introducing VS to the world-renowned Dutch coastal engineers. She participated in the implementation of VNVN's first project, funded by the Royal Netherlands Embassy, on coastal dune stabilisation and other applications in Quang Binh and Da Nang. In the last year and half she worked for Agrifood Consulting International (ACI) in Hanoi. Moving to Kenya in summer 2007, she intends to continue her contribution to the promotion and development of Vetiver System.

Although all three authors contributed to the writing and editing of all five parts of the Manual, the leading authors are:

- Part 1, 2 and 4 - Paul Truong
- Part 3 - Tran Tan Van and
- Part 5 - Elise Pinners.

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CONTENTS

This manual has five separate parts. It is possible to use only one part for a specific group of applications, but it is highly recommended to always include Part 1, as other parts frequently refer to Vetiver characteristics, that are relevant for different applications. In most cases it is useful to include also Part 2.

For more up to date details on any of the subjects in this manual, please log on www.vetiver.org, which has numerous links to all relevant subjects.

PART 1 - THE VETIVER PLANT

CONTENTS

1. INTRODUCTION

The Vetiver System (VS), which is based on the application of vetiver grass (*Vetiveria zizanioides* L Nash, now reclassified as *Chrysopogon zizanioides* L Roberty), was first developed by the World Bank for soil and water conservation in India in the mid 1980s. While this application still plays a vital role in agricultural land management, R&D conducted in the last 20 years has clearly demonstrated that, due to vetiver grass' extraordinary characteristics, VS can be now being used as a bioengineering technique for steep slope stabilization, wastewater disposal, phyto-remediation of contaminated land and water, and other environmental protection purposes.

What does the Vetiver System do and how does it work?
VS is a very simple, practical, inexpensive, low maintenance and very effective means of soil and water conservation, sediment control, land stabilization and rehabilitation, and phyto-remediation. Being vegetative it is also environmental friendly. When planted in single rows vetiver plants will form a hedge which is very effective in slowing and spreading run off water, reducing soil erosion, conserving soil moisture and trapping sediment and farm chemicals on site. Although any hedges can do that, vetiver grass, due to its extraordinary and unique morphological and physiological characteristics mentioned 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.

The Extension Workers Manual, or the Little Green Book
Complementing this technical manual is the slim green extension workers pocket book, first published by the World Bank in 1987,Vetiver Grass - A Hedge Against Erosion, or more commonly known the "little green book" by John Greenfield. This present manual is far more technical in its description of the Vetiver System and is aimed at technicians, academics, planners and Government officials and land developers. For the farmer and the extension worker in the field the little green book that can fit in to a shirt pocket is still the ideal field manual.

2. SPECIAL CHARACTERISTICS OF VETIVER GRASS

2.1 Morphological characteristics:

- 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 3-4m in the first year. This deep root system makes vetiver plant extremely drought tolerant and difficult to dislodge by strong current.
- Stiff and erect stems, which can stand up to relatively deep water flow - photo 1.
- Highly resistance to pests, diseases and fire - photo 2.
- 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 will continue to grow up with the deposited silt eventually forming terraces, if trapped sediment is not removed.

Photo 1: Erect and stiff stems form a dense hedge when planted close together.

2.2 Physiological characteristics

- Tolerance to extreme climatic variation such as prolonged drought, flood, submergence and extreme temperature from -15ºC to +55ºC.
- Ability to re-grow 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 3.3 to 12.5 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.
- Highly tolerant to growing medium high in acidity, alkalinity, salinity, sodicity and magnesium.
- Highly tolerant to Al, Mn and heavy metals such as As, Cd, Cr, Ni, Pb, Hg, Se and Zn in the soils.

2.3 Ecological characteristics

Although vetiver is very tolerant to some extreme soil and climatic conditions mentioned above, as typical tropical grass, it is intolerant to shading. Shading will reduce its growth and in extreme cases, may even eliminate vetiver in the long term. Therefore vetiver grows best in the open and weed free environment, weed control may be needed during establishment phase. On erodible or unstable ground vetiver first reduces erosion, stabilizes the erodible ground (particularly steep slopes), then because of nutrient and moisture conservation, improves its micro-environment so other volunteered or sown plants can establish later. Because of these characteristics vetiver can be considered as a nurse plant on disturbed lands.

Photo 2: Vetiver grass surviving forest fire (left) and two months after the fire (right).

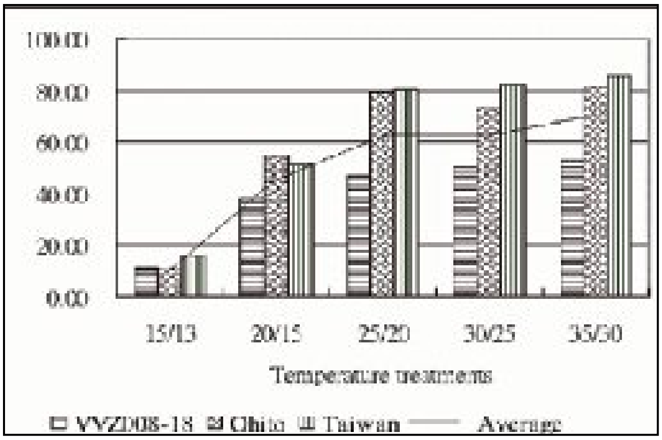
Photo 3: On coastal sand dunes in Quang Bình (left) and saline soil in Gò Công Province (right).

Photo 4: On extreme acid sulfate soil in Tân An (left) and alkaline and sodic soil in Ninh Thun (right).

2.4 Cold weather tolerance of vetiver grass

Although vetiver is a tropical grass, it can survive and thrive under extremely cold conditions. Under frosty weather its top growth dies back or becomes dormant and 'purple' in colour under frost conditions but its underground growing points survived. In Australia, vetiver growth was not affected by severe frost at –14ºC and it survived for a short period at –22ºC (-8ºF) in northern China. In Georgia (USA), vetiver survived in soil temperature of -10ºC but not at –15ºC. Recent research showed that 25ºC was optimal soil temperature for root growth, but vetiver roots continued to grow at 13ºC. Although very little shoot growth occurred at the soil temperature range of 15ºC (day) and 13ºC root growth continued at the rate of 12.6cm/day, indicating that vetiver grass was not dormant at this temperature and extrapolation suggested that root dormancy occurred at about 5ºC (Fig.1).

Figure 1: The effect of soil temperature on the root growth of vetiver.



2.5 Summary adaptability range

The summary of vetiver adaptability range is shown on table 1.

Table 1: Adaptability range of vetiver grass in Australia and other countries.

Condition characteristic	Australia	Other Countries
Adverse Soil Conditions		
Acidity (pH)	3.3-9.5	4.2-12.5 (high level soluble Al)
Salinity (50% yield reduction)	17.5 $mScm^{-1}$	
Salinity (survived)	47.5 $mScm^{-1}$	
Aluminium level (Al Sat. %)	Between 68% - 87%	
Manganese level	> 578 $mgkg^{-1}$	
Sodicity	48% (exchange Na)	
Magnesicity	2400 $mgkg^{-1}$ (Mg)	
Fertilizer		
Vetiver can be established on very infertile soil due to its strong association with mycorrhiza	N and P (300 kg/ha DAP)	N and P, farm manure

Continued ..... next page.

Condition characteristic	Australia	Other Countries
Heavy Metals		
Arsenic (As)	100 - 250 $mgkg^{-1}$	
Cadmium (Cd)	20 $mgkg^{-1}$	
Copper (Cu)	35 - 50 $mgkg^{-1}$	
Chromium (Cr)	200 - 600 $mgkg^{-1}$	
Nickel (Ni)	50 - 100 $mgkg^{-1}$	
Mercury (Hg)	> 6 $mgkg^{-1}$	
Lead (Pb)	> 1500 $mgkg^{-1}$	
Selenium (Se)	> 74 $mgkg^{-1}$	
Zinc (Zn)	>750 $mgkg^{-1}$	
Location	15^0S to 37^0S	41^0N - 38^0S
Climate		
Annual Rainfall (mm)	450 - 4000	250 - 5000
Frost (ground temp.)	-11^0C	-22^0C
Heat wave	45^0C	55^0C
Drought (no effective rain)	15 months	
Palatability	Dairy cows, cattle, horse, rabbits, sheep,	Cows, cattle, goats, sheep, pigs, carp
Nutritional Value	N = 1.1 % P = 0.17% K = 2.2%	Crude protein 3.3% Crude fat 0.4% Crude fibre 7.1%

Genotypes: VVZ008-18, Ohito, and Taiwan, the latter two are basically the same as Sunshine. Temperature treatments: day 15ºC /night 13ºC. (PC: Y.W .Wang).

2.6 Genetic characteristics

Three vetiver species are used for environmental protection purposes.

2.6.1 Vetiveria zizanioides L reclassified as Chrysopogon zizanioides L

There are two species of vetiver originating in the Indian subcontinent: *Chrysopogon zizanioides* and *Chrysopogon lawsonii*. *Chrysopogon zizanioides* has many different accessions. Generally those from south India have been cultivated and have large and strong root systems. These accessions tend towards polyploidy and show high levels of sterility and are not considered invasive. The north Indian accessions, common to the Gangetic and Indus basins, are wild and have weaker root systems. These accessions are diploids and are known to be weedy, though not necessarily invasive. These north Indian accessions are NOT recommended under the Vetiver System. It should also be noted that most of the research into different vetiver applications and field experience have involved the south Indian cultivars that are closely related (same genotype) as Monto and Sunshine. DNA studies confirm that about 60% of *Chrysopogon zizanioides* used for bio-engineering and phytoremediation in tropical and subtropical countries are of the Monto/Sunshine genotype.

2.6.2 Chrysopogon nemoralis

This native vetiver species are wide spread in the highlands of Thailand, Laos, and Vietnam and most likely in

Cambodia and Myanmar as well. It is being widely used in Thailand for thatching purpose. This species is not sterile, the main differences between *C. nemoralis* and *C. zizanioides*, are that the latter is much taller and has thicker and stiff stems, *C. zizanioides* has a much thicker and deeper root system and its leaves are broader and has a light green area along the mid ribs, as shown on the photos below - photos 5-8.

Photo 5: Vetiver leaves: *C. zizanioides* (left) and *C. nemoralis* (right).

Photo 6: Vetiver shoots: *C. nemoralis* (left) and *C. zizanioides* (right).

Photo 7: Difference between *C. zizanioides* (upper) and *C. nemoralis* roots (lower).

Although *C. nemoralis* is not as effective as *C. zizanioides,* farmers have also recognized the usefulness of *C. nemoralis* in soil conservation; they have used it in the Central Highlands as well as in some coastal provinces of Central Vietnam such as Quang Ngai to stabilize dikes in rice fields - photo 9.

Photo 8: Vetiver roots in soil (left and middle) and when grown on floats in water (right).

Photo 9: *C. nemoralis* on a rice field bund in Quang Ngai (left) and in the wild - Central Highlands (right).

Photo 10: *Chrysopogon nigritana* in Mali, West Africa.

2.6.3 Chrysopogon nigritana

This species is native to Southern and West Africa, its application is mainly restricted to the sub continent, and as it produces viable seeds its application should be restricted to their home lands (Picture 10).

2.7 Weed potential

Vetiver grass cultivars derived from south Indian accessions are non-aggressive; they produce neither stolons nor rhizomes and have to be established vegetatively by root (crown) subdivisions. It is imperative that any plants used for bioengineering purposes will not become a weed in the local environment; therefore sterile vetiver cultivars (such as Monto, Sunshine, Karnataka, Fiji and Madupatty) from south Indian accessions are ideal for this application. In Fiji, where vetiver grass was introduced for thatching more than 100 years ago, it has been widely used for soil and water conservation purposes in the sugar industry for over 50 years without showing any signs of invasiveness. Vetiver grass can be destroyed easily either by spraying with glyphosate (Roundup) or by cutting off the plant below the crown.

3. CONCLUSION

Due to *C. nemoralis* low growth forms and most importantly very short root system it is not suitable for steep slope stabilization works. In addition, no research has been conducted on its wastewater disposal and treatment, and phyto-remediation capacities, it is recommended that only *C. zizanioides* be used for applications listed in this manual.

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PART 2 - METHODS TO PROPAGATE VETIVER

CONTENTS

1. INTRODUCTION

Since most major applications require a large number of plants, the quality of the planting material is important the successful application of the Vetiver System (VS). This requires nurseries capable of producing large quantities of high quality, low cost plant materials. The exclusive use of only sterile vetiver cultivars (*C. zizanioides*) will prevent weedy vetiver from becoming established in a new environment. DNA tests prove that the sterile vetiver cultivar used around the world is genetically similar to Sunshine and Monto cultivars, both of which originate in southern India. Given its sterility, this vetiver must be propagated vegetatively.

2. VETIVER NURSERY

Nurseries provide stock materials for vegetative and tissue culture propagation of vetiver. The following criteria will facilitate the establishment of productive, easily managed vetiver nurseries:

- ***Soil type***: Sandy loam nursery beds ensure easy harvesting and minimal damage to plant crowns and roots. Although clay loam is acceptable, heavy clay is not.
- ***Topography***: Slightly sloping land avoids water-logging in case of over watering. Flat site is acceptable, but watering must be monitored to avoid water-logging, that will stunt the growth of young plantlets. Mature vetiver, however, thrives under waterlogged conditions.
- ***Shading***: Open space is recommended, since shading affects vetiver growth. Partially shaded areas are acceptable. Vetiver is a C4 plant and likes plenty of sun.
- ***Planting layout***: Vetiver should be planted in long, neat rows across the slope for easy mechanical harvesting.
- ***Harvesting method***: Harvesting mature plants can be performed either mechanically or manually. A machine should uproot the mature stock 20-25cm (8-10'') below ground. To avoid damaging the plant crown use a single blade mouldboard plough or a disc plough with special adjustment.
- ***Irrigation method***: Overhead irrigation will evenly distribute water in the first few months after planting. More mature plants welcome flood irrigation.
- ***Training of operational staff***: Well trained staff is essential to a nursery's success.
- ***Mechanical planter***: A modified seedling planter or mechanical transplanter can plant large numbers of

vetiver slips in the nursery.

- ***Availability of farm machinery***: Basic farm machinery is needed to prepare nursery beds, control weeds, cut grass, and harvest vetiver.

Photo 1: Machine planting (left) and manual planting (right).

3. METHODS OF PROPAGATION

The four common ways to propagate vetiver are:

- Splitting mature tillers from vetiver clump or mother plants, which yields bare root slips for immediate planting or propagating in polybags.
- Using various parts of a mother vetiver plant
- Bud multiplication or in vitro micro propagation for large scale propagation
- Tissue culture, using a small part of the plant to propagate on a large scale.

3.1 Splitting mature plants to produce bare root slips

Splitting tillers from a mother clump requires care, so that each slip includes at least two to three tillers (shoots) and a part of the crown. After separation, the slips should be cut back to 20 cm (8'') length (Figure 1). The resulting bare root slips can be dipped in various treatments, including rooting hormones, manure slurry (cow or horse tea), clay mud, or simple shallow water pools, until new roots appear. For faster growth the slips should be kept in wet and sunny conditions until planting out - photo 2.

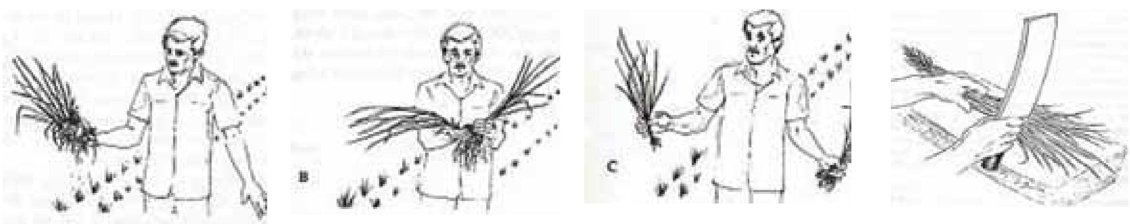

Figure 1: How to split vetiver slips.

3.2 Propagating vetiver from plant parts

Three parts of the vetiver plant are used for propagation - photos 3 & 4:

- Tillers or shoots.
- Crown (corm), the hard part of the plant between the shoots and the roots.
- Culms.


Photo 2: Bare root slips ready for planting out (left) and being dipped in clay mud or manure slurry sometimes known as "cow tea" (right).

A culm is the stem or stalk of a grass. The vetiver culm is solid, stiff, and hard; it has prominent nodes with lateral buds that can form roots and shoots when exposed to moist conditions. Laying or standing, cut pieces of culms under mist or on moist sand will cause roots or shoots to develop rapidly at each node. Le Van Du, Agro-Forestry University, Ho Chi Minh City, developed the following four-step method of propagating vetiver from cuttings:

- Prepare vetiver cuttings.
- Spray the cuttings with a 10% water hyacinth solution.
- Use plastic bags to cover the cuttings completely, and leave it alone for 24 hours.
- Dip in clay mud or manure slurry, and plant in a good bed.

3.2.1 Preparing vetiver cutting


Photo 3: Old tillers (left) and young tillers (right).

V***etiver culms:***
Select old culms, which have more mature buds and more nodes than young ones. Cut culms in 30-50mm (1-2") lengths, including 10-20mm (4-8") below the nodes, and strip off the old leaf covers. Expect new shoots to emerge about one week after planting.
Vetiver tillers:

- Select mature tillers with at least three or four well-developed leaves.
- Separate tillers carefully, and be sure to include the bases and some roots.

Vetiver crown or corms:
The crown (corm) is the base of a mature vetiver plant from which new shoots sprout. Use only the top part of the mature crown.

Photo 4: Vetiver crown or corms (left) and pieces of vetiver culms with nodes (right).

3.2.2 Preparing water hyacinth solution

Water Hyacinth solution contains many hormones and growth regulators, including gibberellic acid and many Indol-Acetic compounds (IAA). To prepare rooting hormone from Water Hyacinth:

- Remove Water Hyacinth plants from lakes or canals
- Put plants into 20 litre plastic bag, and tie it closed
- Leave the bag for about one month until the plant material has decomposed
- Discard the solid parts and keep only the solution.
- Strain the solution and maintain in a cool place until use.

3.2.3 Treatment and planting

Photo 5: Spraying cuttings with 10% water hyacinth solution (left) and cover cuttings completely with plastic bags, and leave them for 24 hours (right).

3.2.4 Advantages of using bare root slips and culm slips

Advantages:

- Efficient, economic, and a quick way to prepare the planting material.
- Small volume results in lower transportation cost.
- Easy to plant by hand.
- Large numbers can be mechanically planted in large areas.

Photo 6: Plant with manure, in a good nursery bed.

Disadvantages:

- Vulnerable to drying and extreme temperatures.
- Limited on-site storage time.
- Requires planting in moist soil.
- Needs frequent irrigation in the first few weeks.
- Recommended for good nursery sites with easy access to irrigation.

3.3 Bud multiplication or micro propagation

Dr. Le Van Be of Can Tho University, Can Tho City, Vietnam has developed a very practical and simple method to multiply buds (Lê Van Bé et al, 2006). His protocol consists of four micro-propagation stages, all in liquid medium:

- Inducing lateral bud development.
- Multiplying new shoots.
- Promoting root development on new shoots.
- Promoting growth in shade house or glasshouse.

3.4 Tissue culture

Tissue culture is another way to propagate vetiver planting materials in quantity, using special tissues (root tip, young flower inflorescence, nodal bud tissues) of the vetiver plant. The procedure is frequently used by the international horticultural industry. Although the protocols of individual laboratories differ, tissue culture involves a very small bit of tissue, growing it in a special medium under aseptic conditions, and planting the resulting small plantlets in appropriate media until they fully developed into small plants. More details are found in Truong (2006).

4. PREPARING PLANTING MATERIAL

To increase the establishment rate under hostile conditions, when the plantlets produced by the above methods are mature enough or bare root slips are ready, they can be prepared for planting out by:

- polybags or tubestock.
- planting strip.

4.1 Polybags or tube stock

Plantlets and bare root slips are planted in small pots or small plastic bags containing half soil and half potting mix and maintained in the containers for three to six weeks, depending on the temperature. When at least three new tillers (shoots) appear, the plantlets are ready to be planted.

Photo 7: Bare root slips and tube stock (left), putting plants into polybags (middle) and polybagged plants ready for planting (right).

4.2 Planting strip

Planting strips are a modified form of polybags. Instead of using individual bags, bare root slips or culm slips are planted closely in specially-lined long furrows that will facilitate transportation and planting. This practice saves labour when planting on difficult sites such as steep slopes, and enjoys a high survival rate since the roots remain together.

Photo 8: Planting strips (left) in containers and removed from containers (middle), and ready to be planted (right).

4.2.1 Advantages and disadvantages of polybags and planting strips

Advantages:

- Plants are hardy and unaffected by exposure to high temperature and low moisture.
- Lower irrigation frequency after planting.
- Faster establishment and growth after planting .
- Can remain on site for longer before being planted .
- Recommended for harsh and hostile conditions.

Disadvantages:

- More expensive to produce.
- Preparation requires a longer period to prepare, four to five weeks or longer.
- Transporting large volume and increased weight is expensive.
- Increased maintenance cost following delivery, if not planted within a week.

5. NURSERIES IN VIETNAM

Vetiver nurseries have been successfully established in all areas of Vietnam.


Photo 9: In the south: Can Tho University (left) and An Giang province (right).


Photo 10: In the centre south: Quang Ngai (left) and Binh Phuoc (right).


Photo 11: In the centre north: Quang Binh (left) and along HCM highway (right).



Photo 12: In the north: Bac Ninh (left) and Bac Giang (right).

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PART - 3 VETIVER SYSTEM FOR NATURAL DISASTER REDUCTION AND INFRASTRUCTURE PROTECTION

CONTENTS

1. TYPES OF NATURAL DISASTERS THAT CAN BE REDUCED BY USING THE VETIVER SYSTEM (VS)

Besides soil erosion, the Vetiver System (VS) can reduce or even eliminate many types of natural disasters, including landslides, mud slides, road batter instability, and erosion (river banks, canals, coastlines, dikes, and earth-dam batters).

When heavy rains saturate rocks and soils, landslides and debris-flows occur in many mountainous areas of Vietnam. Representative examples are the catastrophic landslides, debris flows and flash flooding in the Muong Lay district, Dien Bien province (1996), and the landslide on the Hai Van Pass (1999) that disrupted North-South traffic for more than two weeks and cost more than US $1 million to remedy. Vietnam's largest landslides, those larger than one million cubic meters (among them Thiet Dinh Lake, Hoai Nhon district, Binh Dinh province, in An Nghiêp and An Linh communes, Tuy An district, and Phu Yen province), caused loss of life as well as property damage.

River bank and coastal erosion, and dike failures happen continually throughout Vietnam. Typical examples include: river bank erosion in Phu Tho, Hanoi, and in several central Vietnam provinces (including Thua Thien Hue, Quang Nam, Quang Ngai and Binh Dinh); coastal erosion in Hai Hau district, Nam Dinh province, and; riverbank and coastal erosion in the Mekong Delta. Although these events and flooding/storm disasters usually occur during the rainy season, sometimes riverbank erosion takes place during the dry season, when water drops to its lowest level. This happened in Hau Vien village, Cam Lo district, in Quang Tri province.

Landslides are more common in areas where human activities play a decisive role. Almost 20 percent or 200 km (124 miles) of more than 1000 km (621 miles) of the Ha Tinh - Kon Tum section of the Ho Chi Minh Highway is highly susceptible to landslide or slope instability, mainly because of poor road construction practices and an underlying failure to understand the unfavorable geological conditions. Recent landslides in the towns of Yen Bai, Lao Cai, and Bac Kan followed municipal decisions to expand housing by allowing cutting at increased slope gradients.

Major earthquakes have also generated landslides in Vietnam, including the 1983 slide in Tuan Giao district, and the 2001 slide along the route from Dien Bien town to Lai Chau district.

From a strictly economic point of view, the cost of remediating these problems is high, and the State budget for such works is never sufficient. For example, river bank revetment usually costs between US $200,000-300,000/km, sometimes running as high as US $700,000-$1 million/km. The Tan Chau embankment in the Mekong Delta is an extreme case that cost nearly US $7 million/km. River bank protection in Quang Binh province alone is estimated to require an expenditure of more than US $20 million the annual budget is only US $300,000.

Construction of sea dikes usually costs between US $700,000-$1 million/km, but more expensive sections can cost upwards of US $2.5 million/km, and are not uncommon. After storm No. 7 in September 2005 washed away many improved dike sections, some dike managers concluded that even sections engineered to withstand storms up to the 9th level are too weak, and began to seriously consider constructing sea dikes capable of withstanding storms of up to the 12th level that would cost between US $7-$10 million/km.

Budget constraints always exist, which confines rigid structural protection measures to the most acute sections, never to the full length of the river bank or coastline. This bandage approach compounds the problems.

Each of these events represents a type of slope failure or mass wasting, reflecting the down slope movement of rock debris and soil in response to gravitational stresses. This movement can be very slow, almost imperceptible, or devastatingly rapid and apparent within minutes. Since many factors influence whether natural disasters will occur, we should understand the causes as well as some basic principles of slope stabilisation. This information will allow us to effectively employ VS bioengineering methods to reduce their impact.

2. GENERAL PRINCIPLES OF SLOPE STABILITY AND SLOPE STABILISATION

2.1 Slope profile

Some slopes are gradually curved, and others are extremely steep. The profile of a naturally-eroded slope depends primarily on its rock/soil type, the soil's natural angle of repose, and the climate. For slip resistant rock/soil, especially in arid regions, chemical weathering is slow compared to physical weathering. The crest of the slope is slightly convex to angular, the cliff face is nearly vertical, and a debris slope is present at a 30-35° angle of repose, the maximum angle at which loose material of a specific soil type is stable.

Non-resistant rock/soil, especially in humid regions, weathers rapidly and erodes easily. The resulting slope contains a thick soil cover. Its crest is convex, and its base is concave.

2.2 Slope stability

2.2.1 Upland natural slope, cut slope, road batter etc.

The stability of such slopes is based on the interplay between two types of forces, driving forces and resisting forces. Driving forces promote down slope movement of material, while resisting forces deter movement. When driving forces overcome resisting forces, these slopes become unstable.

2.2.2 River bank, coastal erosion and instability of water retaining structures

Some hydraulic engineers may argue that bank erosion and unstable water retaining structures should be treated separately from other types of slope failure because their respective loads are different. In our opinion, however, both are subject to the same interaction between "driving forces" and "resisting forces". Failure results when the former overcomes the latter.

However, erosion of banks and the instability of water retaining structures are slightly more complicated; they result from interactions between hydraulic forces acting at the bed and toe and gravitational forces affecting the in-situ bank material. Failure occurs when erosion of the bank toe and the channel bed adjacent to the bank have increased the height and angle of the bank to the point that gravitational forces exceed the shear strength of the bank material. After failure, failed bank material may be delivered directly to the flow and deposited as bed material, dispersed as wash load, or deposited along the toe of the bank either as intact block, or as smaller, dispersed aggregates.

Fluvial controlled processes of bank retreat are essentially twofold. Fluvial shear erosion of bank materials results in progressive incremental bank retreat. Additionally, a rise in bank height due to near-bank bed degradation or an increase in bank steepness due to fluvial erosion of the lower bank may act alone or together to decrease the stability of the bank with respect to mass failure. Depending on the constraints of its material properties and the geometry of its profile, a bank may fail as the result of any one of several possible mechanisms, including planar, rotational, and cantilever type failures.

Non-fluvial controlled mechanisms of bank retreat include the effects of wave wash, trampling, and piping- and sapping-type failures, associated with stratified banks and adverse groundwater conditions.

2.2.3 Driving forces

Although gravity is the main driving force, it cannot act alone. Slope angle, angle of repose of specific soil, climate, slope material, and especially water, contribute to its effect:

- Failure occurs far more frequently on steep slopes than on gentle slopes.
- Water plays a key role in producing slope failure especially at the toe of the slope:

- In the form of rivers and wave action, water erodes the base of slopes, removing support, which increases driving forces.
- Water also increases the driving force by loading, that is, filling previously empty pore spaces and fractures, which adds to the total mass subjected to gravitational force.
- The presence of water results in pore water pressure that reduces the shear strength of the slope material. Importantly, abrupt changes (dramatic increases and decreases) in pore water pressure may play the decisive role in slope failure.
- Water's interaction with surface rock and soil (chemical weathering) slowly weakens slope material, and reduces its shear strength. This interaction reduces resisting forces.

2.2.4 Resisting forces

The main resisting force is the material's shear strength, a function of cohesion (the ability of particles to attract and hold each other together) and internal friction (friction between grains within a material) that opposes driving forces. The ratio of resisting forces to driving forces is the safety factor (SF). If SF >1 the slope is stable. Otherwise, it is unstable. Usually a SF of 1.2-1.3 is marginally acceptable. Depending on the importance of the slope and the potential losses associated with its failure, a higher SF should be ensured. In short, slope stability is a function of: rock/soil type and its strength, slope geometry (height, angle), climate, vegetation and time. Each of these factors may play a significant role in controlling driving or resisting forces.

2.3 Types of slope failure

Depending on the type of movement and the nature of the material involved, different types of slope failure may result:

Table 1: Types of slope failure.

Type of movement		***Material involved***	
		Rock	***Soil***
Falls		Rock fall	soil fall
Slides	Rotational	Rock slump block	soil slump blocks
	Translational	Rock slide	debris slide
Flows	Slow	Rock creep	soil creep
			saturated & unconsolidated material
			earth flow
			mudflow (up to 30% water)
	Fast		debris flow
			debris avalanche
Complex	Combination of two or more types of movement		

In rock, usually falls and translational slides (involving one or more planes of weakness) will occur. Since soil is more homogenous and lacks a visible plane of weakness, rotational slides or flows occur. In general, mass wasting involves more than one type of movement, for example, upper slump and lower flow, or upper soil slide and lower rock slide.

2.4 Human impact on slope failure

Landslides are natural occurring phenomena known as geological erosion. Landslides or slope failures occur whether people are there or not! However, human land use practices play a major role in slope processes. The combination of uncontrollable natural events (earthquakes, heavy rainstorms, etc.) and artificially altered land (slope excavation, deforestation, urbanization, etc.) can create disastrous slope failures.

2.5 Mitigation of slope failure

Minimizing slope failure requires three steps: identification of potentially unstable areas; prevention of slope failure, and; implementation of corrective measures following slope failure. A thorough understanding of geological conditions is critically important to decide the best mitigation practice.

2.5.1 Identification

Trained technicians identify prospective slope failure by studying aerial photographs to locate previous landslide or slope failure sites, and conducting field investigations of potentially unstable slopes. Potential mass-wasting areas can be identified by steep slopes, bedding planes inclined toward valley floors, hummocky topography (irregular, lumpy-looking surfaces covered by younger trees), water seepage, and areas where landslides have previously occurred. This information is used to generate a hazard map showing the landslide-prone unstable areas.

2.5.2 Prevention

Preventing landslides and slope instability is much more cost effective than correction. Prevention methods include controlling drainage, reducing slope angle and slope height, and installing vegetative cover, retaining wall, rock bolt, or shotcrete (finely-aggregated concrete, with admixture for fast solidifying, applied by a powerful pump). These supportive methods must be correctly and appropriately applied by first ensuring that the slope is internally and structurally stable. This requires a good understanding of local geological conditions.

2.5.3 Correction

Some landslides can be corrected by installing a drainage system to reduce water pressure in the slope, and prevent further movement. Slope instability problems bordering roads or other important places typically require costly treatment. Done timely and properly, surface and subsurface drainage would be very effective. However, since such maintenance is usually deferred or neglected entirely, much more rigorous and expensive corrective measures become necessary.

In Vietnam, rigid structural protection methods (concrete or rock riprap bank revetment, groins, retaining walls, etc.) are commonly used to stabilize slopes and riverbanks and to control coastal erosion. Nevertheless, despite their continuous use for decades, slopes continue to fail, erosion worsens, maintenance costs increase. So what are the main weaknesses of these measures? From a strictly economic point of view, rigid measures are very expensive, and state or municipal budgets for such projects are never sufficient. A technical and environmental analysis raises the following concerns:

- Mining of the rock/concrete occurs elsewhere, where it undoubtedly wreaks environmental havoc.
- Localized rigid structural devices do not absorb flow/wave energy. Since rigid structures cannot follow the local settlement, they cause strong gradients. Strong gradients generate additional turbulence, which creates more erosion. Moreover, since the devices are localized, they frequently end abruptly; they do not transit gradually and smoothly to the natural bank. Thus, they simply transfer erosion to another place, to the opposite side or downstream, which aggravates the disaster, rather than reducing it for the river as a whole. Examples of these abound in several Central Vietnam provinces.

- Structural, rigid measures introduce considerable amounts of stone, sand, cement into the river system, displacing and disposing large volumes of bank soil into the river. As the river becomes silted up, its dynamics change, its bed rises, and flood and bank erosion problems increase. This problem is particularly grave in Vietnam where workers throw waste soil directly into the river as they re-shape the bank. Often they dump stone directly into the river to stabilize the toe of unstable bank, or try to lay rock pieces on the riverbed, which reduces the flow depth (channel) considerably. When the embankments ultimately fail, scraps of rock baskets, groins, etc. remain scattered in the water causing man-made aggradation of the river bed.
- Rigid structures are unnatural and are incompatible with the soft ground of eroding or erodible soils. As the ground is consolidated and/or eroded and washed away, it undercuts and undermines the upper rigid layer. Examples include the right bank immediately downstream of the Thach Nham Weir (Quang Ngai province) that cracked and collapsed. Engineers who replace concrete plates with rock riprap with or without concrete frames leave unsolved the problem of subsurface erosion. Along the Hai Hau sea dike, the whole section of rock riprap collapsed as the foundation soil underneath was washed away.
- Rigid structures only temporarily reduce erosion. They cannot help stabilize the bank when big landslides with deep failure surface.
- Concrete or rock retaining walls are probably the most common engineering method employed to stabilize road batters in Vietnam. Most of these walls are passive, simply waiting for the slopes to fail. When the slopes do fail, the walls also fail, as seen in many areas along the Ho Chi Minh Highway. These structures are also destroyed by earthquakes.

Although rigid structures like rock embankments are obviously unsuitable for certain applications, such as sand dune stabilisation, they are still being built, as can be observed along the new road in central Vietnam.

2.6 Vegetative slope stabilisation

Vegetation has been used as a natural bioengineering tool to reclaim land, control erosion and stabilize slopes for centuries, and its popularity has increased markedly in the last decades. This is partly due to the fact that more information about vegetation is now available to engineers, and also partly due to the cost-effectiveness and environment-friendliness of this "soft" engineering approach.

Under the impact of the several factors presented above, a slope will become unstable due to: (a) surface erosion or 'sheet erosion'; and (b) internal structural weaknesses. Sheet erosion when not controlled often leads to rill and gully erosion that, over time, will destabilize the slope; structural weakness will ultimately cause mass movement or landslip. Since sheet erosion can also cause slope failure, slope surface protection should be considered as important as other structural reinforcements but its importance is often over looked. Protecting the slope surface is an effective, economical, and essential preventive measure. In many cases, applying some preventive measures will ensure continued slope stability, and always cost much less than corrective measures.

The vegetative cover provided by grass seeding, hydro-seeding or hydro-mulching normally is quite effective against sheet erosion and small rill erosion, and deep-rooted plants such as trees and shrubs can provide some structural reinforcement for the ground. However, on newly-constructed slopes, the surface layer is often not well consolidated, so even well-vegetated slopes cannot prevent rill and gully erosion. Deep-rooted trees grow slowly and are often difficult to establish in such hostile territory. In these cases, engineers often rue the inefficiency of the vegetative cover and install structural reinforcement soon after construction. In short, traditional slope surface protection provided by local grasses and trees cannot, in many cases, ensure the needed stability.

2.6.1 Pros, cons and limitations of planting vegetation on slope

Table 2: General physical effects of vegetation on slope stability.

Effect	Physical Characteristics
Beneficial	
Root reinforcement, soil arching, buttressing, anchorage, arresting the roll of loose boulders by trees	Root aeration, distribution and morphology; Tensile strength of roots; Spacing, diameter and embedment of trees, thickness and inclination of yielding strata; Shear strength properties of soils
Depletion of soil moisture and increase of soil suction by root uptake and transpiration	Moisture content of soil; Level of ground water; Pore pressure/soil suction
Interception of rainfall by foliage, including evaporative losses	Net rainfall on slope
Increase in the hydraulic resistance in irrigation and drainage canals	Manning's coefficient
Adverse	
Root wedging of near-surface rocks and boulders and uprooting in typhoon	Root area ration, distribution and morphology
Surcharging the slope by large (heavy) trees (sometimes beneficial depending on actual situations)	Mean weight of vegetation
Wind loading	Design wind speed for required return period; mean mature tree height for groups of trees
Maintaining infiltration capacity	Variation of moisture content of soil with depth

Table 3: Slope angle limitations on establishment of vegetation.

Slope angle (degrees)	**Vegetation type**	
	Grass	**Shrubs/Trees**
0 - 30	Low in difficulty; routine planting techniques may be used	Low in difficulty; routine planting techniques may be used
30 - 45	Increasingly difficult for sprigging or turfing; routine application for hydro seeding	Increasingly difficult to plant
> 45	Special consideration required	Planting must generally be on benches

2.6.2 Vegetative slope stabilisation in Vietnam

To a lesser extent, softer, vegetative solutions have also been employed in Vietnam. The most popular bioengineering method to control riverbank erosion is probably the planting of bamboo (which is the worst measure you can take. Once bamboo clumps washout in a flood and go down river they can take out bridges or anything they get caught up in. They have such high tensile strength they do not break up.). To control coastal erosion, mangrove, casuarinas, wild pineapple, and nipa palm are also employed. However, these plants have some major deficiencies, for example:

- Growing in clumps, bamboo which is shallow rooted does not close as a hedgerow. Therefore floodwater concentrates at the gaps between clumps, which increases its destructive power and causes more erosion.
- Bamboo is top heavy. Its shallow (1-1.5 m deep) bunch root system does not balance the high, heavy canopy. Therefore, clumps of bamboo add stress to a river bank, without contributing to its stabilit.
- Frequently the bunch root system of bamboo destabilizes the soil beneath it, encouraging erosion and creating the conditions for larger landslides. Several Central Vietnam provinces display examples of bank failure following installation of extensive bamboo strip.
- Mangrove trees, where they can grow, form a solid buffer that reduces wave power, which, in turn, reduces coastal erosion. However, establishing mangrove is difficult and slow as mice eat its seedling. Typically, of the hundreds of hectares planted, only a small percentage survives to become forest. This has been reported recently in Ha Tinh province.
- Casuarinas trees have long been planted on thousands of hectares of sand dunes in Central Vietnam. Wild pineapple is also planted along banks of rivers, streams and other channels, and along the contour lines of dune slopes. Although they reduce wind power and minimize sand storm, these plants cannot stem sand flow because they have shallow root systems and do not form closed hedgerows. Despite planting casuarinas and wild pineapple trees atop the sand dikes along flow channels in Quang Binh province, sand fingers continue to invade arable land. Moreover, both plants are sensitive to climate; casuarinas seedlings barely survive sporadic but extreme cold winters (less than -15ºC/5ºF), and wild pineapple cannot survive North Vietnam’s blistering summers.

Fortunately, vetiver grows quickly, becomes established under hostile conditions, and its very deep and extensive root system provides structural strength in a relatively short period of time. Thus, vetiver can be a suitable alternative to traditional vegetation, provided that the following application techniques are learned and followed carefully.

3. SLOPE STABILISATION USING VETIVER SYSTEM

3.1 Characteristics of vetiver suitable for slope stabilisation

Vetiver’s unique attributes have been researched, tested, and developed throughout the tropical world, thus ensuring that vetiver is really a very effective bioengineering tool:

- Although technically a grass, vetiver plants used in land stabilisation applications behave more like fast-growing trees or shrubs. Vetiver roots are, per unit area, stronger and deeper than tree roots.
- Vetiver’s extremely deep and massive finely structured root system can extend down to two to three meters (six to nine feet) in the first year. On fill slope, many experiments show that this grass can reach 3.6m (12 feet) in 12 months. (Note that vetiver certainly 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 extremely tolerant to drought.
- 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 Mega Pascal (MPa), which is equivalent to 1/6 of mild steel reinforcement and a shear strength increment of 39% at a depth of 0.5m (1.5 feet).
- 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 run-off. 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 facilitates their re-establishment.
- Vetiver tolerates extreme climatic and environmental variation, including prolonged drought, flooding and submergence, and temperature extremes ranging from -14ºC to 55ºC (7º F to 131ºF) (Truong et al, 1996).
- This grass re-grows 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, sodicity and acid sulfate conditions (Le van Du and Truong, 2003).

Vetiver is very effective when planted closely in rows on the contour of slopes. Contour lines of vetiver can stabilize natural slopes, cut slopes and filled embankments. Its deep, rigorous root system helps stabilize the slopes structurally while its shoots disperse surface run-off, reduce erosion, and trap sediments to facilitate the growth of native species - photo 1.

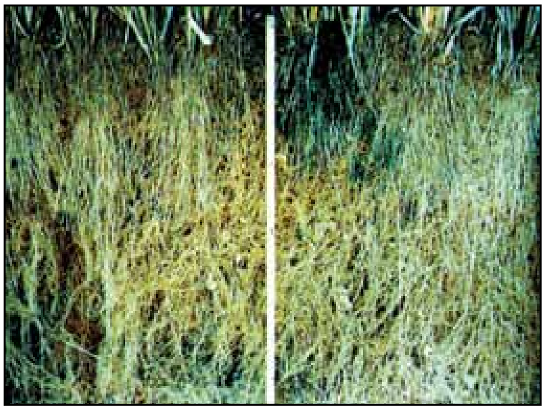


Photo 1: Vetiver forms a thick and effective bio-filter both above (left) and below ground (right).

Hengchaovanich (1998) also observed that vetiver can grow vertically on slopes steeper than 150% (~56º). Its fast growth and remarkable reinforcement make it a better candidate for slope stabilisation than other plants. Another less obvious characteristic that sets it apart from other tree roots is its power of penetration. Its strength and vigor enable it to penetrate difficult soil, hardpan, and rocky layers with weak spots. It can even punch through asphalt concrete pavement. The same author characterizes vetiver roots as living soil nails or 2-3m (6-9 feet) dowels commonly used in 'hard approach' slope stabilisation work. Combined with its ability to become quickly established in difficult soil conditions, these characteristics make vetiver more suitable for slope stabilisation than other plants.

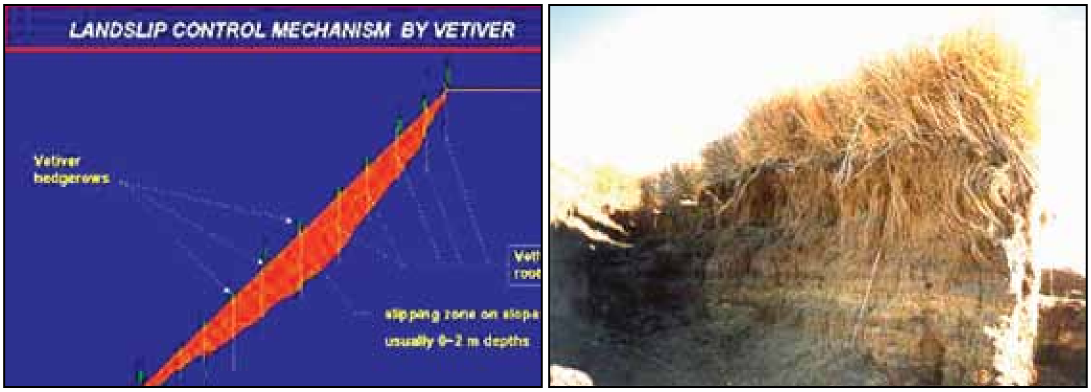


Figure 1: Left: Principles of slope stabilisation by vetiver; right: Vetiver roots reinforcing this dam wall kept it from being washed away by flood.

3.2 Special characteristics of vetiver suitable for water disaster mitigation

To reduce the impact of water related disasters such as flood, river bank and coastal erosion, dam and dike instability, vetiver is planted in rows either parallel to or across the water flow or wave direction. Its additional unique characteristics are very useful:

- Given its extraordinary root depth and strength, mature vetiver is extremely resistant to washouts from high velocity flow. Vetiver planted in north Queensland (Australia) has withstood flow velocity higher than 3.5m/sec (10'/sec) in river under flood conditions and, in southern Queensland, up to 5m/sec (15'/sec) in a flooded drainage channel.
- Under shallow or low velocity flow, the erect and stiff stems of vetiver act as a barrier that reduces flow velocity (i.e. increase hydraulic resistance) and traps eroded sediment. In fact, it can maintain its erect stance in a flow as deep as 0.6-0.8m (24-31").
- Vetiver leaves will bow under deep and high velocity flow, providing extra protection to surface soil while reducing flow velocity.
- When planted on water-retaining structures such as dams or dikes, vetiver hedgerows help reduce the flow velocity, decrease wave run-up (lap-erosion), over-topping, and ultimately the volume of water that flows into the area protected by these structures. These hedgerows also help reduce so-called retrogressive erosion that often occurs when the water flow or wave retreats after it rises over water-retaining structures.
- As a wetland plant, vetiver withstands prolonged submergence. Chinese research shows that vetiver can survive longer than two months under clear water.

3.3 Tensile and shear strength of vetiver roots

Hengchaovanich and Nilaweera (1996) show that the tensile strength of vetiver roots increases with the reduction in root diameter, implying that stronger, fine roots provide greater resistance than thicker roots. The tensile strength of vetiver roots varies between 40-180 MPa in the range of root diameter between 0.2-2.2 mm (.008-.08"). The mean design tensile strength is about 75 MPa at 0.7-0.8 mm (.03") root diameter, which is the most common size of vetiver roots, and equivalent to approximately one sixth of mild steel. Therefore, vetiver roots are as strong or even stronger than those of many hardwood species that have been proven positive for slope reinforcement - Figure 2 and Table 4.

In a soil block shear test, Hengchaovanich and Nilaweera (1996) also found that root penetration of a two-year-old Vetiver hedge with 15cm (6") plant spacing can increase the shear strength of soil in adjacent 50 cm (20") wide strip by 90% at 0.25 m (10") depth. The increase was 39% at 0.50 m (1.5') depth and gradually reduced

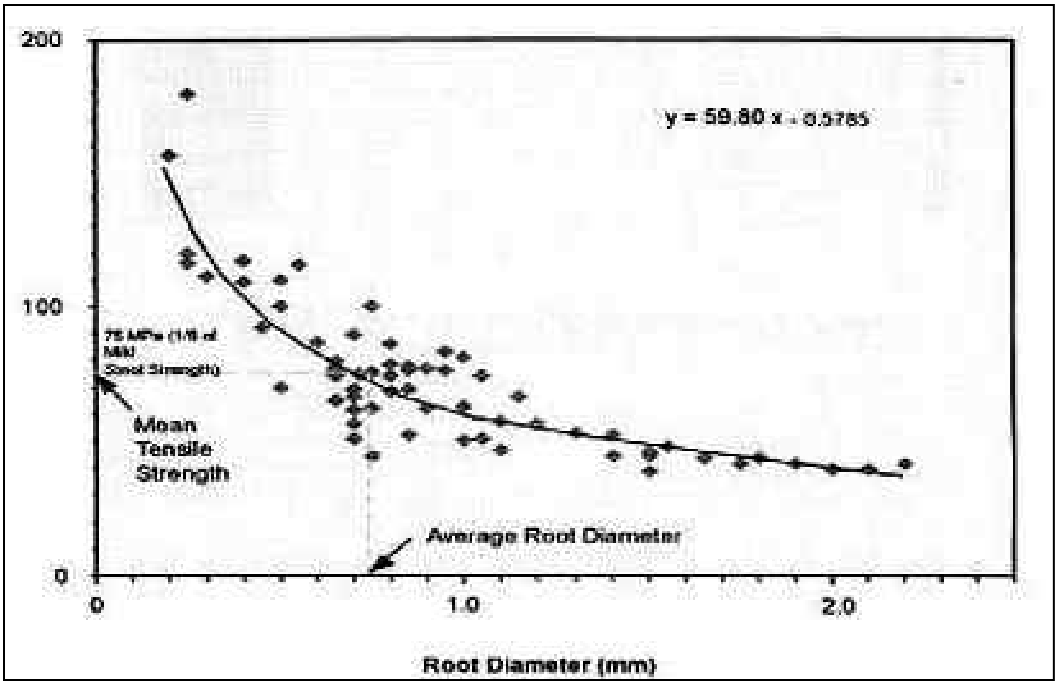


Figure 2: Root diameter distribution

Table 4: Tensile strength of some plant roots

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 sacharinum	Silver maple	15-30
Tsuga heterophylia	Western hemlock	27
Vaccinum spp	Huckleberry	16
Hordeum vulgare	Barley	15-31
	Grass, Forbs	2-20
	Moss	2-7 kPa
Chrysopogon zizanioides	**Vetiver grass**	**40-120 (average 75)**

to 12.5% at one meter (3') depth. Moreover, vetiver's dense and massive root system offers better shear strength increase per unit fibre concentration (6-10 kPa/kg of root per cubic meter of soil) compared to 3.2-3.7 kPa/kg

for tree roots (Fig.3). The authors explained that when a plant root penetrates across a potential shear surface in a soil profile, the distortion of the shear zone develops tension in the root; the component of this tension tangential to shear zone directly resists shear, while the normal component increases the confining pressure on the shear plane.

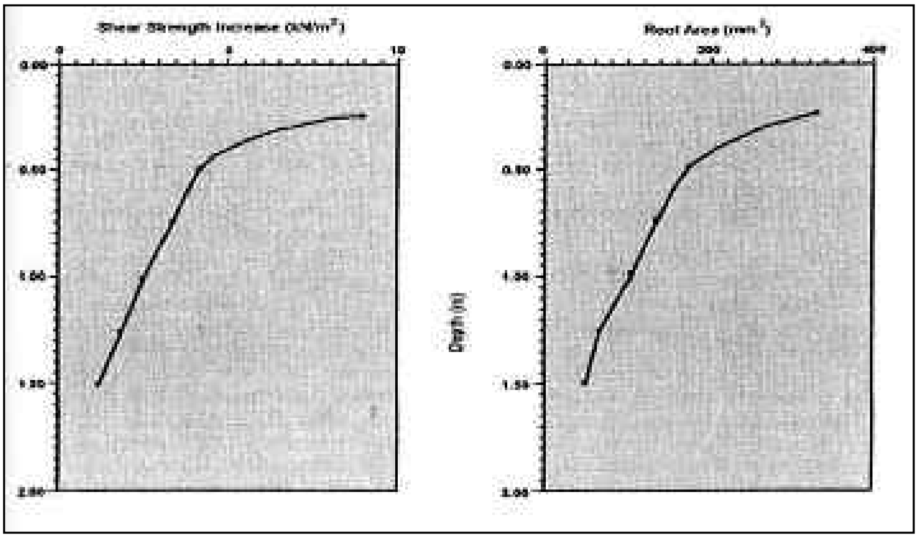


Figure 3: Shear strength of vetiver root.

Table 5: Diameter and tensile root strength of various herbs.

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

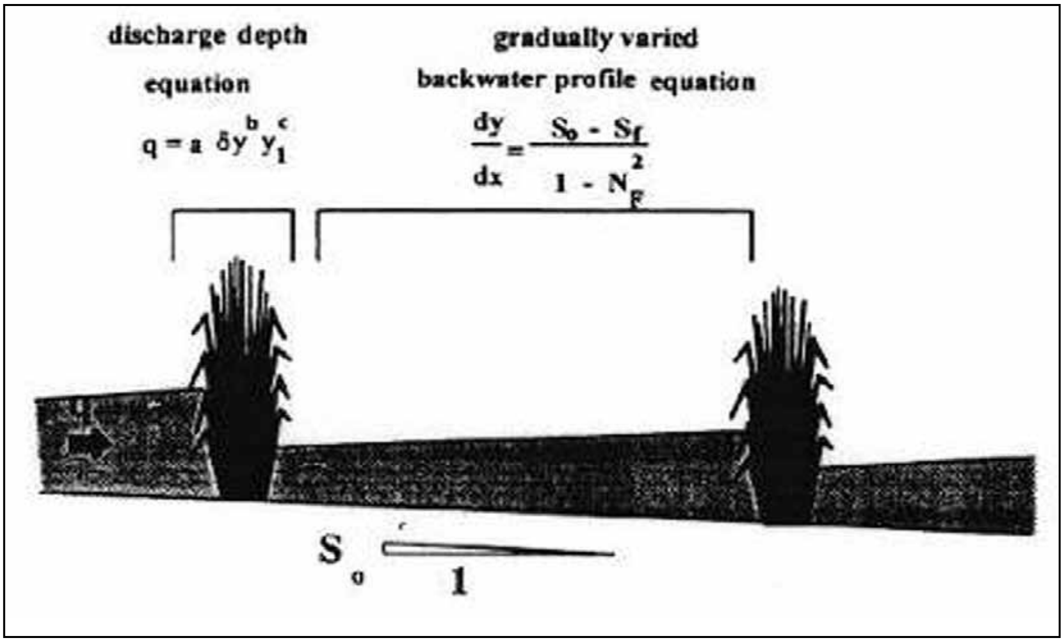
Cheng et al (2003) supplemented Diti Hengchaovanich's root strength research by conducting further tests on other grasses - table 5. Although vetiver has the second finest roots, its tensile strength is almost three times higher than all plants tested.

3.4 Hydraulic characteristics

When planted in rows, vetiver plants form thick hedges; their stiff stems allow these hedges to stand up at least 0.6-0.8m (2-2.6'), forming a living barrier to slow and spread runoff water. Properly planned, these hedges are very effective structures that spread and divert runoff water to stable areas or proper drains for safe disposal.

Flume tests conducted at the University of Southern Queensland to study the design and incorporation of vetiver hedges into strip-cropping layout for flood mitigation confirmed the hydraulic characteristics of vetiver hedges under deep flows. Figure 4. The hedges successfully reduced flood velocity and limited soil movement; fallow strips suffered very little erosion, and a young sorghum crop was completely protected from flood damage (Dalton et al, 1996).

Figure 4: Hydraulic model of flooding through vetiver hedges.



Where:
q = discharge per unit width
y = depth of flow y_1 = depth upstream
S_o = land slope S_f = energy slope N_F = the Froude number of flow

3.5 Pore water pressure

Vegetation cover on sloping lands increases water infiltration. Concerns have been raised that the extra water will increase pore water pressure in the soil and lead to slope instability. However, field observations actually show improvements. First, planted on contour lines or modified patterns of lines that trap and spread runoff water on the slope, vetiver's extensive root system and flow though effect distributes surplus water more evenly and gradually and helps prevent localized accumulation.

Second, the likely increase in infiltration is offset by a higher and gradual rate of soil water depletion by the grass. Research in soil moisture competition in crops in Australia (Dalton et al, 1996) shows that, under low rainfall conditions, this depletion would reduce soil moisture up to 1.5m (4.5') from the hedges. This increases water infiltration in that zone, leading to the reduction of runoff water and erosion rate. From a geotechnical perspective, these conditions help maintain slope stability. On steep (30-60º) slopes, the space between rows at 1m (3') VI (Vertical Interval) is very close. Therefore, moisture depletion would be greater and further improve the slope stabilisation process. However, to reduce this potentially harmful effect of vetiver on steep slopes in very high rainfall areas, as a precautionary measure, vetiver hedges could be planted on a gradient of about 0.5% as in graded contour terraces to divert the extra water to stable drainage outlets (Hengchaovanich, 1998).

3.6 Applications of VS in natural disaster mitigation and infrastructure protection

Given its unique characteristics, vetiver generally is very useful in controlling erosion on both cut and fill batters and on other slopes associated with road construction, and particularly effective in highly erodible and dispersible soils, such as sodic, alkaline, acidic and acid sulfate soils.

Vetiver planting has been very effective in erosion control or stabilisation in the following conditions:

- Slope stabilisation along highways and railways. Especially effective along mountainous rural roads, where the community lacks sufficient funding for road slope stabilisation and where it often takes part in road construction.
- Dike and dam batter stabilisation, 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.
- 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 water mark on big farm dam batters or river banks.
- 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.

Given its unique characteristics, vetiver effectively controls water disasters such as flood, coastal and riverbank erosion, dam and dike erosion, and general instability. It also protects bridges, culvert abutments and interfaces between concrete/rock structures and soil. Vetiver is particularly effective in areas where the embankment fill is highly erodible and dispersible, such as sodic, alkaline, and acidic (including acid sulfate) soils.

3.7 Advantages and disadvantages of Vetiver System

Advantages:

- The major advantage of VS over conventional engineering measures is its low cost and longevity. For slope stabilisation in China, for example, savings are in the order of 85-90% (Xie, 1997 and 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 (Braken and Truong 2001). In summary, 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
- As with other bioengineering technologies, VS is a natural, environmentally-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 semi-rural 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 two 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 labour forces.
- Vetiver hedges are a natural, soft bioengineering technique, an eco-friendly alternative to rigid or hard structures.

Disadvantages:

- 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 stabilisation requires a pioneer to improve the ability of the micro-environment to host the voluntary or planned introduction of native endemic species.
- 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.
- Vetiver hedges are fully effective only when plants form closed hedgerows. Gaps between clumps should be timely re-planted.
- It is difficult to plant and water vegetation on very high or steep slopes.
- Vetiver requires protection from livestock during its establishment phase.

Based on these considerations, the advantages of using VS as a bioengineering tool outweigh its disadvantages, particularly when vetiver is used as a pioneer species.

Worldwide evidence supports the use of VS to stabilize embankments. Vetiver has been used successfully to stabilize roadsides, amongst others, in Australia, Brazil, Central America, China, Ethiopia, Fiji, India, Italy, Madagascar, Malaysia, Philippines, South Africa, Sri Lanka, Venezuela, Vietnam, and the West Indies. Used in conjunction with geotechnical applications, vetiver has been used to stabilize embankments in Nepal and South Africa.

3.8 Combination with other types of remedy
Vetiver is effective both by itself and combined with other traditional methods. For example, on a given section of riverbank or dike, rock or concrete riprap can reinforce the underwater part, and vetiver can reinforce the top part. This tandem application creates a factor of stability and security (which are not always true and/or necessary). Vetiver can also be planted with bamboo, a plant traditionally used to protect riverbanks. Experience shows that using only bamboo has several drawbacks that can be overcome by adding vetiver. As noted previously washed out bamboo can create serious problems on rivers where there are low level bridge crossing.

3.9 Computer modelling
Software developed by Prati Amati, Srl (2006) in collaboration with the University of Milan determines the percentage or amount of shear strength that vetiver roots add to various soils under vetiver hedgerows. The software helps to assess vetiver's contribution to stabilize steep batters, particularly earthen levees. Under average soil and slope conditions, the installation of vetiver will increase slope stability by about 40%.

Using the software requires the operator to enter the following geotechnical parameters related to a particular slope site:
- Soil type.
- Slope gradient.
- Maximum moisture content.
- Soil cohesion at a minimum.

The program provides the required number of plants per square meter and the distance between rows, considering the slope gradient. For example:
- a 30° slope requires six plants per square meter (i.e. 7-10 plants per lineal meter) and a distance between rows of about 1.7 m (5.7').
- a 45° slope requires 10 plants per square meter (i.e. 7-10 plants per lineal meter) and a distance between rows of about 1 m (3').

4. APPROPRIATE DESIGNS AND TECHNIQUES

4.1 Precautions

VS is a new technology. As a new technology, its principles must be studied and applied appropriately for best results. Failure to follow basic tenets will result in disappointment, or worse, adverse results. As a soil conservation technique and, more recently, a bioengineering tool, the effective application of VS requires an understanding of biology, soil science, hydraulics, hydrology, and geotechnical principles. Therefore, for medium to large-scale projects that involve significant engineering design and construction, VS is best implemented by experienced specialists rather than by local people themselves. However, knowledge of participatory approaches and community-based management are also very important. Thus, the technology should be designed and implemented by experts in vetiver application, associated with an agronomist and a geotechnical engineer, with assistance from local farmers.

Additionally, although it is a grass, vetiver acts more like a tree, given its extensive and deep root system. To add to the confusion, VS can exploit vetiver's different characteristics for different applications. For example, its deep roots stabilize land, its thick leaves spread water and trap sediment, and its extraordinary tolerance to hostile conditions allows it to rehabilitate soil and water contamination.

Failures of VS can, in most cases, be attributed to bad applications rather than the grass itself or the recommended technology. For example, in one case, vetiver was used in the Philippines to stabilize batters on a new highway. The results were very disappointing and failures resulted. It later surfaced that the engineers who specified the VS, the nursery that supplied the planting material, and the field supervisors and labourers who planted the vetiver, lacked previous experience or training in the use of VS for steep slopes stabilisation.

Experience in Vietnam shows that vetiver has been very successful employed when it is applied correctly. Not surprisingly, improper applications may fail. Applications in the Central Highlands of Vietnam show that vetiver has effectively protected road embankments. However, among mass applications on very high and steep slopes without benches along the Ho Chi Minh Highway, failures have resulted. In short, to ensure success, decision makers, designers and engineers who plan to use the Vetiver System for infrastructure protection should take the following precautions:

Technical precautions:

- To ensure success, the design should be created or checked by trained people.
- At least for the first few months while the plant is becoming established, the site should be internally stable against possible failure. Vetiver manifests its full abilities when mature, and slopes may fail during the intervening period.
- VS is applicable only to earthen slopes with gradients that should never exceed 45-50°
- Vetiver grows poorly in the shade, so planting it directly under a bridge or other shelter should be avoided.

Precautions for decision-making, planning and organization:

- Timing: planning should consider the seasons and the time it takes to grow planting materials.
- Maintenance and repair: at an early stage, there is a period during which vetiver is not yet effective. Planning and budgeting should anticipate replacement of some.
- Procurement: All inputs can and should be procured locally (labour, manure, planting materials, maintenance contracts). Employment opportunity provides an incentive for the local community to protect the plants during their infancy and adolescence, and to maintain the quality and sustainability of the

works.

- Community involvement: As much as possible, local communities should be included in the design, materials procurement, and maintenance stages. Contracts with local people should be drafted, governing nurseries, quality/quantity specifications, and maintenance/protection.
- Timing: Decision makers should be ready to innovate and to consider VS in their planning and budgeting. For that, they need incentives to include such cost-effective methods in their plans, just as they have incentives - justified or not - to adopt more expensive conventional methods.
- Integration: Policy makers should recommend Vetiver System as part of a comprehensive approach to infrastructure protection, applied on a scale large enough to ensure a tangible increase in expertise and a gradual, spreading effect. VS should not be regarded merely as a fix for compromised local sites, despite its ability to provide a concise and immediate effect.

4.2 Planting time

The installation of vetiver plants is critical to the success and the cost of the project. Planting in dry season will require extensive and expensive watering. Experience in Central Vietnam shows that daily or twice daily watering is required to establish vetiver in the extremely harsh conditions in sand dunes. Growth is stunted in the absence of watering. Since it is difficult to select the best time to plant masses of plant material on cut slopes along the Ho Chi Minh Highway, for example, mechanical watering is required daily for the first few months.

Vetiver generally needs 3-4 months to become established, sometimes up to 5-6 months under adverse conditions. Since vetiver is fully effective at the age of 9-10 months, mass plantings should occur at the beginning of the rainy season (i.e. nursery development and production of plant material should be planned to meet that mass planting schedule).

Particularly in North Vietnam, it is possible to plant during the winter-spring period. When temperatures descend lower than 10ºC (50ºF) in North Vietnam, the grass does not grow. However, it can survive the cold weather and resumes growing immediately when the winter rain starts and the weather warms.

In central Vietnam, where air temperature usually stays above 15ºC (59ºF), mass planting occurs at the beginning of spring. Nurseries will require more care to ensure good growth and multiplication of the slips.

4.3 Nursery

The success of any project depends on good quality and sufficient numbers of vetiver slips. Details on nurseries and propagating the grass are discussed in Part 2. Large nurseries generally are not required to provide sufficient plant material. Instead, individual farmer households can set up and supervise small nurseries (a few hundred square meters each). They will be contracted and paid by the project according to the number of slips they can provide upon request.

4.4 Preparation for vetiver planting

In cases where mass planting of vetiver involves the participation of local people, an effective planting campaign should include the following steps:

Step 1: Experts visit the sites, and conduct a survey to identify problems and design the application of the technology;
Step 2: Discuss the problems and alternative solutions with local people;
Step 3: Use workshops and training courses to introduce the new technology;
Step 4: Organize the trial implementation, by establishing nurseries, contracting to purchase plant ma-

terial, maintenance, etc.;

Step 5: Monitor the implementation;

Step 6: Discuss results of the pilot, following workshop, field exchange visit, etc.;

Step 7: Organize mass planting.

In cases where specialized companies undertake the mass planting, steps 1, 4, 5 are recommended. However, local participation is still advisable to raise awareness, avoid vandalism, and ensure that the slips are protected from animals.

4.5 Layout specifications

4.5.1 'Upland' natural slope, cut slope, road batter, etc.

To stabilize upland natural slopes, cut slopes, and road batters, the following specifications may apply:

- Bank slope should not exceed 1(H) [horizontal]:1(V) [vertical] or 45º, gradient of 1.5:1 is recommended. Shallower gradients are recommended wherever possible, especially on erodible soils and/or in high rainfall areas.
- Vetiver should be planted across the slope on approximate contour lines with a Vertical Interval (VI) between 1.0-2.0m (3-6') apart, measured down the slope. Spacing of 1.0m (3') should be used on highly erodible soil, which can increase up to 1.5-2.0m (4.5-6') on more stable soil.
- The first row should be planted on the top edge of the batter. This row shall be planted on all batters that are taller than 1.5m (4.5').
- The bottom row should be planted at the bottom of the batter at the toe of the slope and on cut batter along the edge of table drain.
- Between these rows, vetiver should be planted as specified above.
- Benching or terracing 1-3 m (3-9') in width for every 5-8 m (15-24') VI is recommended for slopes that are taller than 10 m (30').

4.5.2 ***Riverbanks, coastal erosion, and unstable water retaining structures***

For flood mitigation and coastal, riverbank and dike/embankment protection, the following layout specifications are recommended:

- Maximum bank slope should not exceed 1.5(H):1(V). Recommended bank slope is 2.5:1. Note: the sea dike system in Hai Hau (Nam Dinh) is built with bank slope of 3:1 to 4:1.
- Vetiver should be planted in two directions:
  - For bank stabilisation, vetiver should be planted in rows parallel to flow direction (horizontal), on approximate contour lines 0.8-1.0m (2.5-3') apart (measured down slope). A recent layout specification to protect the sea dike system in Hai Hau (Nam Dinh) included spacing between rows lowered to 0.25 m. (.8').
  - To reduce flow velocity, vetiver should be planted in rows normal (right angle) to the flow at spacing between rows of 2.0m (6') for erodible soil and 4.0m (12') for stable soil. As added protection, normal rows are planted 1.0m (3') apart on the river dike in Quang Ngai.
- The first horizontal row should be planted at the crest of the bank and the last row should be planted at the low water mark of the bank. Note: since the water level at some locations changes seasonally, vetiver can be planted much further down the bank when the time is right.
- Vetiver should be planted on the contour along the length of the bank between the top and bottom rows at the spacing specified above.
- Due to high water levels, bottom rows may establish more slowly than upper rows. In such cases, the lower rows should be planted when the soil is driest. Some VS applications protect anti-salinity dikes; in those cases, the water may become more saline at certain times of the year, which may affect the

growth of vetiver. Experiences in Quang Ngai show that vetiver can be replaced by some local salt-tolerant varieties, including the mangrove fern.

- For all applications, VS can be used in combination with other traditional, structural measures such as rock or concrete riprap, and retaining walls. For example, the lower part of the dike/embankment can be covered by the combination of rock riprap and geo-textile while the upper half is protected with vetiver hedgerows.

4.6 Planting specifications

- Dig trenches that are about 15-20cm (6-8”) deep and wide.
- Place well-rooted plants (with 2-3 tillers apiece) in the centre of each row at 100-120mm (4-5”) intervals for erodible soils, and at 150mm (6”) for normal soils.
- Since soil on slopes, road batters and filled dike/embankment is not fertile, it is recommended that potted or tube stock be used for large scale mass planting and rapid establishment. Adding a bit of good soil-manure mixture (slurry) is even better. To protect natural river banks where the soil is usually fertile and initial watering can be ensured without extra effort, bare root planting is sufficient.
- Cover roots with 20-40mm (1-2”) of soil and compact firmly.
- Fertilize with Nitrogen and Phosphorus such as DAP (Di-Ammonium Phosphate) or NPK (note from experience vetiver does not respond significantly from potash applications) at 100g (3.5oz) per linear meter (row). The same amount of lime may be necessary when planting in acid and sulfate soil.
- Water within the day of planting.
- To reduce weed growth during the establishment phase, a pre-emergent herbicide such as Atrazine may be used.

4.7 Maintenance

Watering

- In dry weather, water every day during the first two weeks after planting and then every second day.
- Water twice weekly until the plants are well established.
- Mature plants require no further watering.

Replanting

- During the first month after planting, replace all plants that fail to establish or wash away.
- Continue inspections until the plants are suitably established.

Weed control

- Control weeds, especially vines, during the first year.
- DO NOT USE RoundUp (glyphosate) herbicide. Vetiver is very sensitive to glyphosate, so it should not be used to control weeds between rows.

Fertilizing

On infertile soil, DAP or NPK fertilizer should be applied at the beginning of the second wet season.

Cutting

After five months, regular cutting (trimming) is also very important. Hedgerows should be cut down to 15-20 cm (6-8”) above the ground. This simple technique promotes the growth of new tillers from the base and reduces the volume of dry leaves that otherwise can overshadow young slips. Trimming also improves the appearance of dry hedgerows and may minimize the danger of fire.

Fresh cut leaves can also be used as cattle fodder, for handicraft, and even roof thatch. Please note that vetiver planted for the purpose of reducing natural disasters should not be overused for secondary purposes.

Subsequent cuttings can be done two or three times a year. Care should be taken to ensure the grass has long leaves during the typhoon season. Vetiver can be cut immediately after the typhoon season ends. Another suitable cutting time could be around 3 months before the typhoon season begins.

Fencing and caring

During the several-month establishment period, fencing and care may be required to protect vetiver from vandalism and cattle. The old stems of mature vetiver are tough enough to discourage cattle. Where necessary, it is advisable to fence the area to protect the grass during the first few months after planting.

5. VS APPLICATIONS FOR NATURAL DISASTER REDUCTION AND INFRASTRUCTURE PROTECTION IN VIETNAM

5.1 VS application for sand dune protection in Central Vietnam

A vast area, more than 70,000 ha (175,000 acres), along the coastline of Central Vietnam is covered by sand dunes where the climatic and soil conditions are very severe. Sand blast often occurs as sand dunes migrate under the action of wind. Sand flow also takes place frequently due to the action of numerous permanent and temporary streams. Blown sand and sand flow transport huge amounts of sand from dunes landward onto the narrow coastal plain. Along the Central Vietnam coastline, giant sand "tongues" bite into the plain day after day. The Government has long implemented a forestation program using such varieties as Casuarinas, wild pineapple, eucalyptus, and acacia. However, when fully and well established, they may help reduce only blown sand. Until now, here has been no way to reduce sand flow (trees can not stabilize sand dunes, especially on their 'slip-face', this was tried in North Africa by FAO at great expense and failed).

Photo 2: Sand flow in Le Thuy (Quang Binh) in 1999: the foundation of a pumping station (left) and the foundation of this woman's three-room house is being undercut by moving sand (right).

5.1.1 Trial application and promotion of VS for sand dune protection in coastal province of Quang Binh

In February 2002, with financial support from the Dutch Embassy Small Program and technical support from Elise Pinners and Pham Hong Duc Phuoc, Tran Tan Van from RIGMR initiated an experiment to stabilize sand dunes along the Central Vietnam coastline. A sand dune was badly eroded by a stream that served as a natural boundary between farmers and a forestry enterprise. The erosion occurred over several years, resulting in a mounting conflict between the two groups. Vetiver was planted in rows along the contour lines of the sand dune. After four months it formed closed hedgerows and stabilized the sand dune. The forestry enterprise was so impressed that it decided to mass plant the grass in other sand dunes and even to protect a bridge abutment. Vetiver further surprised local people by surviving the coldest winter in 10 years, when the temperature descended below 10ºC (50ºF), forcing the farmers to twice replant their paddy rice and Casuarinas. After two years, the local species (primarily Casuarinas and wild pineapple) became re-established. The grass itself faded away under the shade of these trees, having accomplished its mission. The project proved again that, with proper care, vetiver could survive very hostile soil and climatic conditions - photo 2.

According to Henk Jan Verhagen from Delft University of Technology (pers. comm.), vetiver may be equally effective in reducing blown sand (sand drift). For this purpose, the grass could be planted across the wind direction, especially at low places between sand dunes, where the wind velocity typically increases. On China's Pintang Island, off the coast of Fujian Province, vetiver hedges effectively reduced wind velocity and blow sand.

Following the success of this pilot project, a workshop was organized in early 2003. More than 40 representatives from local government departments, different NGOs, the University of Central Vietnam, and coastal provinces participated. The workshop helped the authors of this book and other participants to compile and synthesize local practices, particularly regarding planting times, watering, and fertilizing. Following the event, World Vision Vietnam decided in 2003 to fund another project in the Vinh Linh and Trieu Phong districts in Quang Tri province to employ vetiver for sand dune stabilisation - photos 3-7.

The following photos summarize a trial for the stabilization of sand dunes.

Photo 3: site overview (left) and early April 2002, one month after planting (right).

Photo 4: Left: early July 2002, four months after planting; right: November 2002, dense rows of grass have been established.

Photo 5: Left: Vetiver nursery; right: November 2002, mass planting.

Photo 6: Left: Vetiver protects bridge abutment along National Highway nr.1; right: December 2004, local species have replaced vetiver.

Photo 7: Left: mid-February 2003, post-workshop field trip; Note: Vetiver survives even the coldest winter in 10 years; right: June 2003, farmers from Quang Tri province visit a local nursery during a World Vision Vietnam-sponsored field trip.

Photo 8: Left: March 2002: VS trial at the edge of a shrimp pond, where a canal drains flood water to Vinh Dien River; right: November 2002: mass planting combined with rock riprap to protect bank along Vinh Dien river.

5.2 VS application to control river bank erosion

5.2.1 VS application for river bank erosion control in Central Vietnam

Within the framework of the same Dutch Embassy project mentioned above, vetiver was planted to halt erosion on a riverbank, on the bank of a shrimp pond, and on a road embankment in Da Nang City. In October 2002, the local Dike Department also mass planted the grass on bank sections of several rivers. Thereafter, the city authority decided to fund a project on cut slope stabilisation by installing vetiver along the mountainous road leading to the Banana project in Da Nang, illustrating the pace of adoption - photos 8-10

5.2.2 VS trial and promotion for river bank protection in Quang Ngai

As another result of this pilot project, vetiver was recommended for use in another natural disaster reduction project in Quang Ngai province, funded by AusAid. With technical support by Tran Tan Van in July 2003, Vo Thanh Thuy and his co-workers from the provincial Agricultural Extension Centre planted the grass at four locations, irrigation canals in several districts and a seawater intrusion protection dikes. Vetiver thrived in all locations and, despite its young age, survived a flood in the same year - photos 11-14.

Photo 9: Left: December 2004: Vetiver, combined with rock riprap, flourishes after two flood seasons (Da Nang); right: planted by local farmers, vetiver protects their shrimp ponds.

Photo 10: Left: Vetiver and rock riprap (upper) and concrete frame (lower) protect an embankment; right: a bend on Perfume Riverbank in Hue.

Photo 11: Left: Vetiver planted on river dike along Tra Bong River; right: lining the sides of an anti-salinity estuary dike along the same river.

Following these successful trials, the project decided to mass plant vetiver on other dike sections in three other districts, in combination with rock riprap. Design modifications introduced to better adapt vetiver to local conditions include planting mangrove fern and other salt-tolerant grasses on the lowest row to better withstand high salinity and to effectively protect the embankment toe. Encouragingly, local communities are more readily using vetiver to protect their own lands.

Photo 12: Upstream anti-salinity dike section with traditional concrete riprap facing the river (left) and along a section of the irrigation canal, surface erosion mars the opposite bank (right).

Photo 13: Left: severely eroded bank of the Tra Khuc River, at Binh Thoi Commune; right: primitive sand bag protection.

Photo 14: Left: Community members plant vetiver; right: November 2005: bank remains intact following the flood season.

5.2.3 VS application to control river bank erosion in the Mekong Delta

With William Donner Foundation financial support and Paul Truong's technical help, Le Viet Dung and his colleagues at Can Tho University initiated riverbank erosion control projects in the Mekong Delta. The area experiences long periods of inundation (up to five months) during the flood season, with significant difference in water levels, up to 5 m (15'), between dry and flood seasons, and powerful water flow during flood season. Further, the riverbanks consist of soils ranging from alluvial silt to loam, which are highly erodible when wet. Due to the improved economy of recent years, most boats travelling on rivers and canals are motorized, many with powerful engines that aggravate riverbank erosion by generating strong waves. Nevertheless, vetiver stands its ground, protecting large areas of valuable farm land from erosion - photos 15 and 16.

A comprehensive vetiver program has been established in An Giang Province, where annual floods reach depths of 6 m (18'). The province's long, 4932 km (3065 miles), canal system requires annual maintenance and repair. A network of dikes, 4600 km long, protects 209,957 ha (525,000 acres) of prime farmland from flood. Erosion on these dikes is about 3.75 Mm3/year and required US $1.3 M to repair.

The area also includes 181 resettlement clusters, communities built on dredged materials that also require erosion control and protection from flooding. Depending on the locations and flood depth, vetiver has been used successfully alone, and together with other vegetation to stabilize these areas. As a result, vetiver now lines rigorous sea and river dike systems as well as riverbanks and canals in the Mekong Delta. Nearly two million polybags of vetiver, a total of 61 lineal km (38 miles), were installed to protect the dikes between 2002 and 2005 - photos 15-16.

Between 2006 and 2010, the 11 districts of An Giang province are expected to plant 2025 km (1258 miles) of vetiver hedges on 3100 ha (7660 acres) of dike surface. Left unprotected, 3750 Mm3 of soil likely will be eroded and 5 Mm3 will have to be dredged from the canals. Based on 2006 current costs, total maintenance costs over this period would exceed US $15.5 M in this province alone. Applying the Vetiver System in this rural area will provide extra income to the local people: men to plant, and women and children to prepare polybags.

Photo 15: In An Giang vetiver stabilizes a river dike (left), and a natural river bank (right).

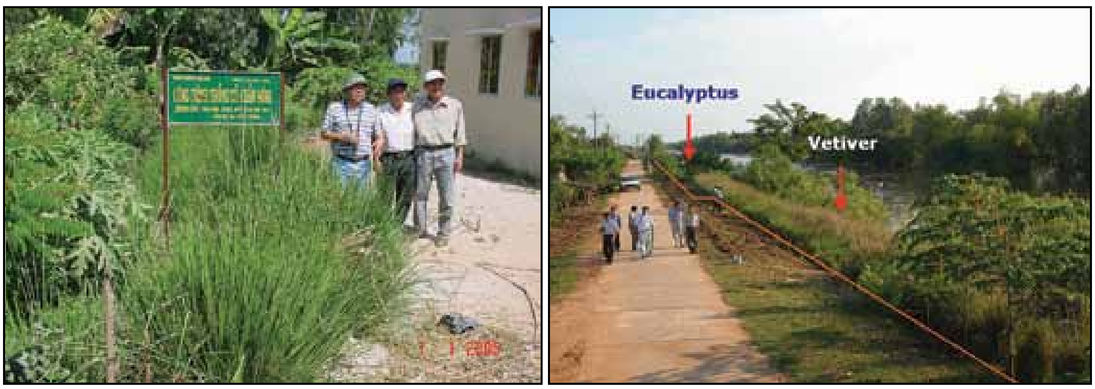


Photo 16: Left: Vetiver borders the edge of flood resettlement centres; right: the red markers delineate about 5 m (15') of dry land saved by vetiver.

5.3 VS application for coastal erosion control

Under the auspices of the William Donner Foundation and with technical support by Paul Truong, Le Van Du from Ho Chi Minh City Agro-Forestry University in 2001 initiated work on acid sulfate soil to stabilize canal and irrigation channels and the sea dike system in Go Cong province. Vetiver grew vigorously on the embankments in just a few months, despite poor soil. It is now protecting the sea dike, preventing surface erosion, and facilitating the establishment of endemic species - photos 17 and 18.

Photo 17: Planted behind natural mangrove on an acid sulphate soil sea dike in Go Cong province, vetiver reduces surface erosion and fosters the re-establishment of local grasses.

Upon the recommendation of Tran Tan Van, the Danish Red Cross in 2004 funded a pilot project using vetiver to protect sea dikes in Hai Hau district, Nam Dinh province - photo 18. Project planners were greatly surprised and delighted to discover that vetiver had already been installed; planted a couple of years earlier, vetiver was protecting several kilometers on the inner side of the sea dike system. Although the design was unconventional, the planting was working, and, more importantly, had convinced the local community that vetiver was effective. After typhoon No. 7 in September 2005 shattered the sections that rock riprap had protected, vetiver's effectiveness was unquestioned. Local farmers asked for a mass planting.

Photo 18: In North Vietnam; left: Vetiver planted on outer side of a newly built sea dike in Nam Dinh province; right: on the inner side of the dike, planted by the local Dike Department.

5.4 VS application to stabilize road batter

Following successful trials by Pham Hong Duc Phuoc (Ho Chi Minh City Agro-Forestry University) and Thien Sinh Co. in using vetiver to stabilize cut slopes in Central Vietnam, in 2003 the Ministry of Transport authorized the wide use of vetiver to stabilize slopes along hundreds of kilometers of the newly constructed Ho Chi Minh

Photo 19: Left: Vetiver stabilizes cut slopes along the Ho Chi Minh Highway; right: both alone and in combination with traditional measures.

Highway and other national, provincial roads in Quang Ninh, Da Nang, and Khanh Hoa provinces - photo 19.

This project is certainly one of the largest VS applications in infrastructure protection in the world. The entire Ho Chi Minh Highway is more than 3000 km (1864 miles) long. It is being and will be protected by vetiver planted on a variety of soils and climate: from skeletal mountainous soils and cold winter in the North to extremely acidic acid sulfate soil and hot, humid climate in the South. The extensive use of vetiver to stabilize cut slopes works, for example:

- Applied primarily as a slope surface protection measure, it greatly reduces run-off induced erosion, which would otherwise wreak havoc downstream - photos 20 and 21.
- By preventing shallow failures, it greatly stabilizes cut slopes which greatly reduces the number of deep slope failures.
- In some cases where deep slope failures do occur, vetiver still does a very good job in slowing down the failures and reducing the failed mass.
- It maintains the rural aesthetic and eco-friendliness of the road.

Photo 20: Left; If not properly protected rock/soil from this waste dump will wash far downstream. Right: impacting a downstream village in A Luoi district, Thua Tien Hue province.

On a road leading to the Ho Chi Minh Highway Pham Hong Duc Phuoc demonstrated clearly how VS should be applied, as well as its effectiveness and sustainability - photo 22.


Photo 21: Da Deo Pass, Quang Binh: Left: Vegetation cover is destroyed, revealing ugly and continuous failures of cut slopes; right: Vetiver rows on top of the slope very slowly squeeze down, considerably reducing the failed mass.

Table 6: Vetiver root depth on Hon Ba road batters.

	Position on the batter	Root depth (cm/inch)			
		6 months	12 months	1.5 year	2 years
	Cut Batter				
1	Bottom	70/28	120/47	120/47	120/47
2	Middle	72/28	110/43	100/39	145/57
3	Top	72/28	105/41	105/41	187/74
	Fill Batter				
4	Bottom	82/32	95/37	95/37	180/71
5	Middle	85/33	115/45	115/45	180/71
6	Top	68/27	70/28	75/30	130/51

He carefully monitored the development of vetiver at its: establishment (65-100%), growth to six months (95-160 cm (37-63”) after six months, tillering rate (18-30 tillers per plant), and root depth on the batter - table 6 above.

The successes and failures using vetiver to protect cut slopes along the Ho Chi Minh Highway are instructive:

- Slopes must first be internally stable. Since vetiver is most helpful at maturity, slopes may fail in the interim. Vetiver begins to stabilize a slope at three to four months, at earliest. Therefore, the timing of planting is also very important if slope failure during the rainy season is to be avoided.
- Appropriate slope angle should not exceed 45-50º.
- Regular trimming will ensure continued growth and tillering of the grass, and thus ensure dense, effective hedgerows.

Photo 22: Pham Hong Duc Phuoc, a road protection project in Khanh Hoa province, road to Hon Ba): left two photos: severe erosion on newly built batter occurs after only a few rains; right two photos: eight months after vetiver planting: Vetiver stabilized this slope, totally stopping and preventing further erosion during the next wet season.

6. CONCLUSIONS

Following considerable research and the successes of the many applications presented in this Part, we now have enough evidence that vetiver, with its many advantages and very few disadvantages, is a very effective, economical, community-based and environmentally-friendly sustainable bioengineering tool that protects infrastructure and mitigates natural disasters, and, once established, the vetiver plantings will last for decades with little, if any maintenance. VS has been used successfully in many countries in the world, including Australia, Brazil, Central America, China, Ethiopia, India, Italy, Malaysia, Nepal, Philippines, South Africa, Sri Lanka, Thailand, Venezuela, and Vietnam. However, it must be stressed that the most important keys to success are good quality planting material, proper design, correct planting techniques.

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PART 4 - VETIVER SYSTEM FOR PREVENTION AND TREATMENT OF CONTAMINATED WATER AND LAND

CONTENTS

1. INTRODUCTION

In the course of researching the application of its extraordinary attributes to soil and water conservation, vetiver was also found to possess unique physiological and morphological characteristics particularly well suited to environmental protection, particularly in the prevention and treatment of contaminated water and land. These remarkable characteristics include a high level of tolerance to elevated and even toxic levels of salinity, acidity, alkalinity, sodicity, and a whole range of heavy metals and agrochemicals, as well as exceptional ability to absorb and tolerate elevated levels of nutrients to consume large quantities of water in the process of producing a massive growth under wet conditions.

Applying the Vetiver System (VS) to wastewater treatment is an innovative phytoremediation technology that has tremendous potential. VS is a natural, green, simple, practicable and cost-effective solution. Most importantly, vetiver's leaf by-product offers a range of uses from handicrafts, animal feeds, thatches, mulch and fuel, to name just a few.

Its effectiveness, simplicity and low cost makes the Vetiver System a welcome partner in the many tropical and subtropical countries that provide domestic, municipal and industrial wastewater treatment and require mine phytoremediation and rehabilitation.

2. HOW THE VETIVER SYSTEM WORKS

VS prevents and treats contaminated water and soil in the following ways:

Preventing and treating contaminated water:

- Eliminating or reducing the volume of wastewater.
- Improving the quality of wastewater and polluted water..

Preventing and treating contaminated land:

- Controlling off site pollution.
- Phytoremediation contaminated land.

- Trapping eroded materials and trash in runoff water.
- Absorbing heavy metals and other pollutants.
- Treating nutrients and other pollutants in wastewater and leachate.

3. SPECIAL FEATURES SUITABLE FOR ENVIRONMENTAL PROTECTION PURPOSES

As addressed in Part 1, several of vetiver's special characteristics are directly applicable to wastewater treatment, among them the following morphological and physiological attributes:

3.1 Morphological attributes

- Vetiver grass has a massive, deep, fast-growing root system capable of reaching 3.6m deep in 12 months in good soil.
- Its deep roots ensure great tolerance to drought, allow excellent infiltration of soil moisture, penetrate compacted soil layers (hard pans), thus enhancing deep drainage.
- Most of the roots in vetiver's massive root system are very fine, with average diameter 0.5-1.0mm (Cheng et al, 2003). This provides an enormous volume of rhizosphere for bacterial and fungal growth and multiplication, thus enabling absorption of contaminants and breakdown processes such as nitrification.
- Vetiver's erect, stiff shoots can grow to three meters (nine feet). When planted close together they form a living porous barrier that retards water flow and acts as an effective bio-filter, trapping both fine and coarse sediment, and even rocks in runoff water - photo 1.

Photo 1: Morphological characteristics of vetiver.

3.2 Physiological attributes

- Highly tolerant to soil high in acidity, alkalinity, salinity, sodicity and magnesium.
- Highly tolerant to Al, Mn, and heavy metals such as As, Cd, Cr, Ni, Pb, Hg, Se and Zn in the soil and water (Truong and Baker, 1998).
- Highly efficient in absorbing dissolved N and P in polluted water - figure 1.

- Highly tolerant to high levels of N and P nutrients in the soil - figure 2.
- Highly tolerant to herbicides and pesticides.
- Breaks down organic compounds associated with herbicides and pesticides.
- Regenerates rapidly following drought, frost, fire, saline and other adverse conditions, once those adverse conditions are mitigated.

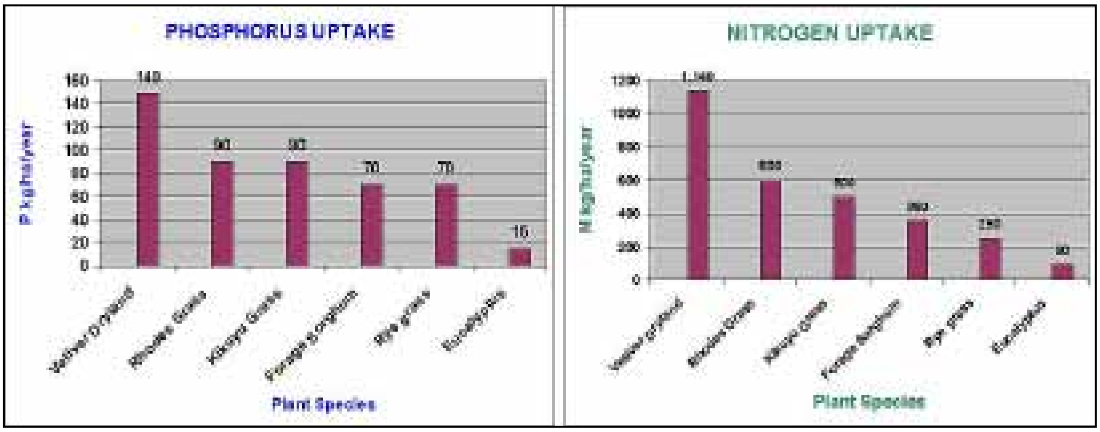

Figure 1: Higher capacity for the uptake of N and P than other plants.

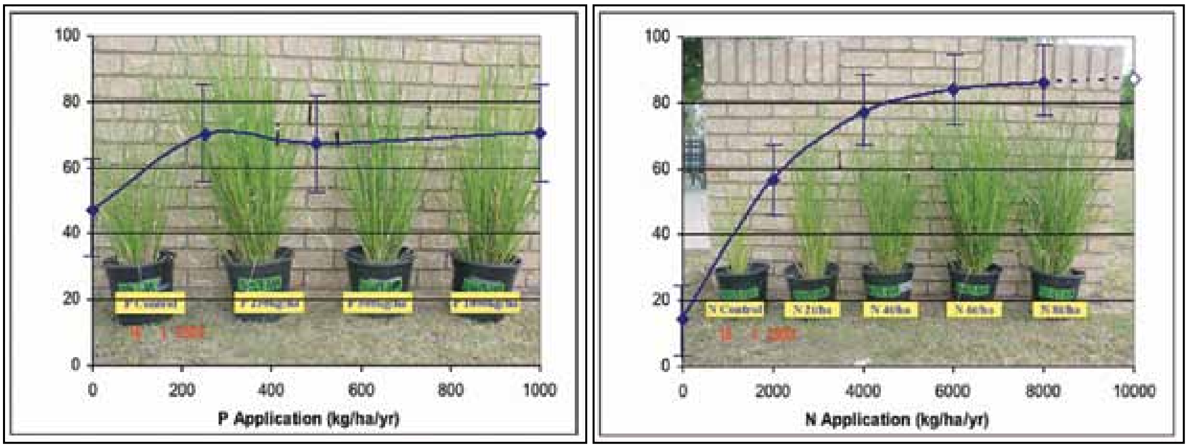

Figure 2: High level of tolerance to and capacity to absorb P and N.

4. PREVENTION AND TREATMENT OF CONTAMINATED WATER

Extensive R&D and Applications in Australia, China, Thailand and other countries have established that vetiver is highly effective in treating polluted wastewater from domestic and industrial discharges.

4.1 Reducing or eliminating the volume of wastewater

Vegetative methods currently are the only feasible and practicable way to totally eliminate or reduce wastewater on a large scale. In Australia, vetiver has largely displaced trees and pasture species as the most effective way to treat and dispose of landfill leachate, and domestic and industrial effluent.

To quantify the water use rate of vetiver, it is estimated that for 1kg of dry shoot biomass under ideal glasshouse conditions, vetiver will use 6.86L/day. Since the biomass of 12-week-old vetiver, at the peak of its growth cycle, is about 30.7 t/ha, a hectare of vetiver potentially would use 279KL/ha/day (Truong and Smeal, 2003).

4.1.1 Disposal of septic effluent
In 1996, VS was first applied in Australia to treat sewage effluent. Later trials demonstrated that planting about 100 vetiver plants in a park area less than 50m2 completely dried up the effluent discharge from a toilet block. Other plants, including fast-growing tropical grasses and trees, and crops such as sugar cane and banana, failed (Truong and Hart, 2001).

Photo 2: Vetiver cleaned up blue green algae in four days. Sewage effluent containing high Nitrate (100 mg/L) and Phosphate (10 mg/L) (left). Sewage effluent after four days (right). VS reduced N level to 6 mg/L (94%) and P to 1 mg/L (90%).

4.1.2 Disposal of landfill leachate
Disposal of landfill leachate is a large problem in major cities, since it is usually highly contaminated with heavy metals, as well as organic and inorganic pollutants. Australia and China have addressed this problem by using leachate collected at the bottom of the dumps to irrigate vetiver planted on the top of the landfill mound and retaining dam walls. Results to date have been excellent. In fact, vetiver's growth was so vigorous that, during the dry period, the landfills did not generate enough leachate to irrigate the plants. Planting 3.5ha of vetiver effectively disposed of 4 ML of leachate a month in summer and 2 ML a month in winter (Percy and Truong, 2005).

4.1.3 Disposal of industrial wastewater
In Queensland, Australia, a large volume of industrial wastewater generated by a food processing facility (1.4 million litres/day) and a beef abattoir (1.4 million litres/day) was successfully dispersed by land irrigation using vetiver (Smeal et al, 2003).

4.2 Improving wastewater quality
Off-site pollution is the greatest threat to the world environment. Although widespread in industrialized nations, it is particularly serious in developing countries, which often lack sufficient resources to mitigate the problem. Vegetative methods are generally the most accessible and efficient ways to improve water quality.

4.2.1 ***Trapping debris, sediment and agro-chemicals in agricultural lands***
In Australia research studies conducted on sugar cane and cotton farms show that vetiver hedges effectively trap particulate-bound nutrients such as P and Ca; herbicides such as diuron, trifluralin, prometryn, and fluometuron; and pesticides such as α, β and sulfate endosulfan and chlorpyrifos, parathion, and profenofos. If vetiver hedges were established across drainage lines, these nutrients and agro-chemicals could be retained on-site (Truong et

al. 2000) - figure 3.

An experiment conducted in Thailand at the Huai Sai Royal Development Study Centre, Phetchaburi Province, shows that vetiver contour hedgerows planted across the slope form a living dam while, at the same time, its root system forms an underground barrier that prevents water-borne pesticide residues and other toxic substances from flowing into the water body below. Thick culms just above the soil surface also collect debris and soil particles carried along the waterway (Chomchalow, 2006).

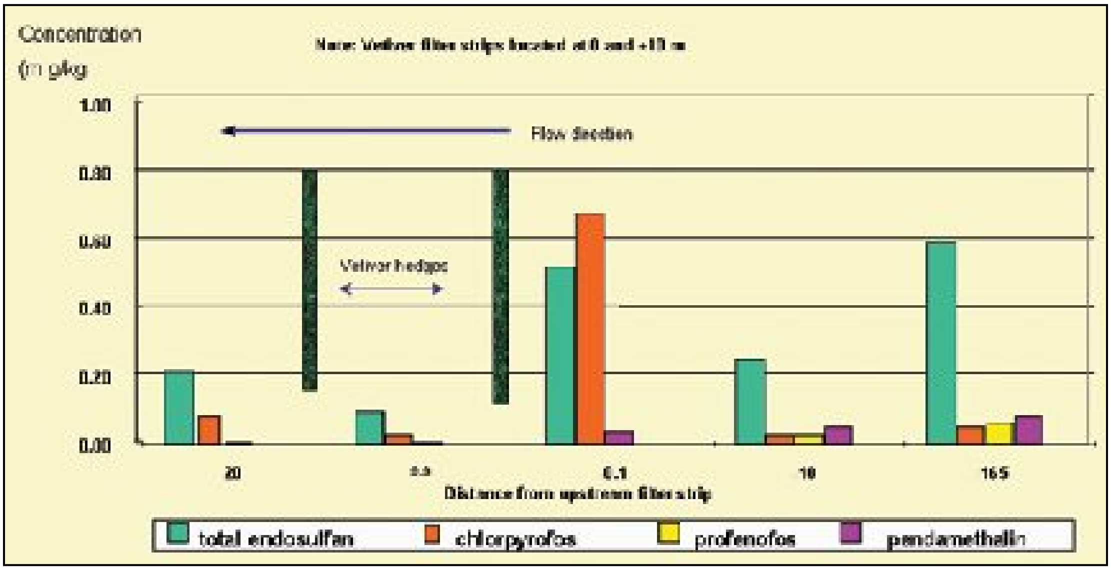

Figure 3: Herbicide concentration in soil deposited on up and down-stream vetiver filter strips.

4.2.2 Absorbing and tolerating pollutants and heavy metal

Vetiver's usefulness in treating polluted water lies in its capacity to quickly absorb nutrients and heavy metals, and its tolerance to elevated levels of these elements. Although the concentrations of these elements in vetiver plants are often not as high as those of hyper-accumulators, its very fast growth and high yield (dry matter production up to 100t/ha/year) allows vetiver to remove a much higher volume of nutrients and heavy metals from contaminated lands than most hyper-accumulators.

In Southern Vietnam, a demonstration trial was set up at a seafood processing factory to determine the length of time that effluent should remain in the vetiver field before its nitrate and phosphate concentrations were reduced to acceptable levels. Test results showed that total N content in wastewater was reduced by 88% and 91% after 48 and 72 hours of treatment, respectively, while the total P was reduced by 80% and 82% after 48 and 72 hours of treatment. The total amount of N and P removed in 48- and 72-hour treatments were not significantly different (Luu et al, 2006). Following these tests, a number of fish farms in the Mekong Delta adopted the VS to stabilize fishpond dikes, to purify fishpond water, and to treat other farm wastewater - photo 3.

In northern Vietnam, wastewater discharged from a small paper factory at Bac Ninh and a small nitrogen fertilizer factory at Bac Giang is as highly polluted with nutrients and chemicals as landfill leachate. The factories release their wastewater directly into a small river in the Red River Delta. Installed at both sites, vetiver became well established after two months. At this writing, the grass at the paper factory at Bac Ninh is generally in good shape, except for a few sections next to the polluted water, where it shows symptoms of toxicity. On the other hand, despite the highly polluted conditions, vetiver is established and growing well at the nitrogen fertilizer factory at Bac Giang. Excellent growth has been recorded for this site under semi-wetland conditions, where vetiver is expected to reduce pollutant levels significantly - photo 4.

Photo 3: Erosion control and wastewater treatment at a freshwater fish farm in the Mekong Delta.

Photo 4: Left: Vetiver at Bac Ninh; right: at Bac Giang.

In Australia, five rows of vetiver were sub-surface irrigated with effluent discharge from a septic tank. After five months, total N levels in the seepage collected after two rows were reduced by 83%, and after five rows by 99%. Similarly, total P levels were reduced by 82% and 85%, respectively (Truong and Hart, 2001) - figure 4.

In China, nutrients and heavy metals from pig farms are key sources of water pollution. Wastewater from pig farms contains very high levels of N and P and also Cu and Zn, which are added to feed as growth promoters. Results show that vetiver has a very strong purifying action. Its ratio of uptake and purification of Cu and Zn is >90%; As and N>75%; Pb is between 30% -71% and P is between 15-58%. Vetiver's ability to purify heavy metals and N and P from pig farms is ranked as: Zn>Cu>As>N>Pb>Hg>P (Liao et al, 2003).

4.2.3 Wetlands

Natural and constructed wetlands effectively reduce the amount of contaminants in runoff from both agricultural and industrial lands. Using wetlands to remove pollutants requires the use of a complex variety of biological processes, including microbiological transformations and physio-chemical processes such as adsorption, precipitation or sedimentation, plants such as *Iris pseudacorus*, *Typha spp, Schoenoplectus validus*, and *Phragmites australis*. At an average consumption rate of 600 ml/day/pot over 60 days, vetiver used 7.5 times more water than *Typha* (Cull et al. 2000). A wetland was constructed to treat sewage effluent generated by a small rural town. The project's goal was to reduce or eliminate the 500ML/day effluent produced by this small town before discharge into the waterways - photo 5. Astonishingly, the vetiver wetland has absorbed all the effluent produced by this small town (Ash and Truong, 2003). Table 1. Under wetland conditions in Australia, vetiver had the highest water use rate, when compared with wetland.

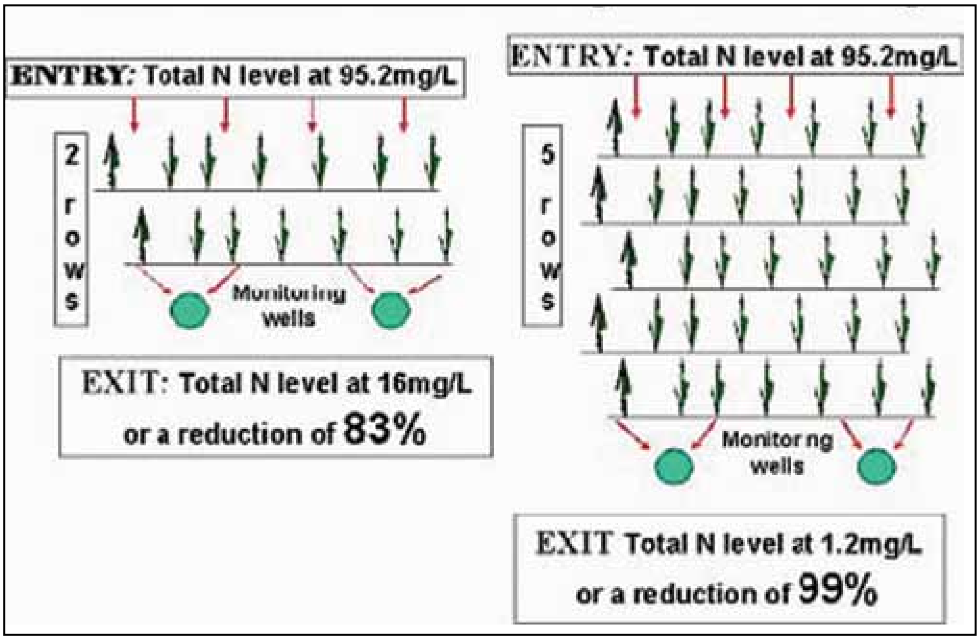

Figure 4: Effectiveness of N reduction in domestic sewage.

Table 1: Effluent quality levels before and after vetiver treatment.

Tests	Fresh influent (mg/l)	Results 2002/03 (mg/l)	Results 2004 (mg/l)
PH (6.5 to 8.5)*	pH 7.3-8.0	pH 9.0-10.0	pH 7.6-9.2
Dissolved Oxygen (2.0 mg/l min.)*	0-2	12.5-20	8.1-9.2
5 Day BOD (20 -40 mg/l max)*	130-300	29 to 70	1-7
Suspended solids (30-60 mg/l max)*	200-500	45 to 140	11-16
Total Nitrogen (6.0 mg/l max) *	30-80	13 to 20	4.1-5.7
Total Phosphorous (3.0 mg/l max) *	10-20	4.6 to 8.8	1.4-3.3

*License requirements

China raises the most pigs in the world. In 1998, Guangdong Province alone supported more than 1600 pig farms; 130+ farms produced more than 10,000 commercial pigs annually. Large piggeries produce 100-150 tons of wastewater per day, including pig manure collected from slatted floors, which contain high nutrient loads. Consequently, the disposal of wastewater from pig farms is a huge problem. Wetlands are considered to be the most efficient way to reduce both the volume and high nutrient loads of piggery effluent. To determine the plants best suited for the wetland system, vetiver was included in test of the most promising dozen species, which initially ranked the top three as vetiver, *Cyperus alternifolius*, and *Cyperus exaltatus*. However, further testing revealed that *Cyperus exaltatus* wilted and became dormant during autumn, rejuvenating in the next spring. Since effective wastewater treatment requires year-round growth, only vetiver and *Cyperus alternifolius* were determined to be suitable for wetland treatment of piggery effluent (Liao, 2000) - photo 6.


Photo 5: Left: Vetiver wetland; right: leachate disposal by overhead irrigation in Australia.


Photo 6: Left: Vetiver pontoon in pig farm ponds in Bien Hoa; right: in Guangzhou, China.

In Thailand very solid research has been conducted in the last few years on the application of VS to treat wastewater in constructed wetlands. One study used three ecotypes of vetiver (Monto, Surat Thani, and Songkhla 3) to treat wastewater from a tapioca flour mill, employing two treatment systems: (a) holding wastewater in a vetiver wetland for two weeks and then draining it, and (b) holding wastewater in a vetiver wetland for one week and then draining it off continuously for a total of three weeks. In both systems Monto displayed the most rapid growth of shoot, root, and biomass, and absorbed the highest levels of P, K, Mn and Cu in the shoot and root (Mg, Ca and Fe in the root, and Zn and N in the shoot). Surat Thani absorbed the highest levels of Mg in the shoot and Zn in the root, and Songkhla 3 absorbed the highest levels of Ca, Fe in the shoot, and N in the root maximally (Chomchalow, 2006, cit. Techapinyawat 2005).

4.2.4 Computer modelling for industrial wastewater

Computer models have become increasingly indispensable tools to manage environmental systems, including complex wastewater management plans such as industrial wastewater disposal. In Queensland, Australia, the Environmental Protection Authority has adopted MEDLI (Model for Effluent Disposal using Land Irrigation) as a basic model for industrial wastewater management. The most significant recent development in the use of VS for wastewater disposal is vetiver's MEDLI calibration for nutrient uptake and effluent irrigation (Vieritz, et al., 2003), (Truong, et al., 2003a), (Wagner, et al., 2003), (Smeal, et al., 2003).

4.2.5 Computer modelling for domestic wastewater

A computer model was developed recently in sub-tropical Australia to estimate the vetiver planting area needed to dispose of the total black and grey water output from each house. For example, a vetiver planting area of 77m2, at density of 5 plants/m2, is required to serve a household with six people, based on an output of 120L/person/day.

4.2.6 Future trend

As water shortages loom worldwide, wastewater should be considered as a renewable resource rather than as a problem that requires disposal. The current trend is to recycle wastewater for industrial and domestic use instead of disposing of it. Therefore, VS' potential as a simple, hygienic and low cost way to treat and recycle wastewater resulting from human activities is enormous - figure 5.

A most exciting development in wastewater treatment is vetiver's use in soil-based reed beds. In this new application, output water quality and quantity can be adjusted to satisfy a set standard. GELITA APA, Australia is developing and testing this system. Full details of this system are found in (Smeal et al. 2006) - figure 6.

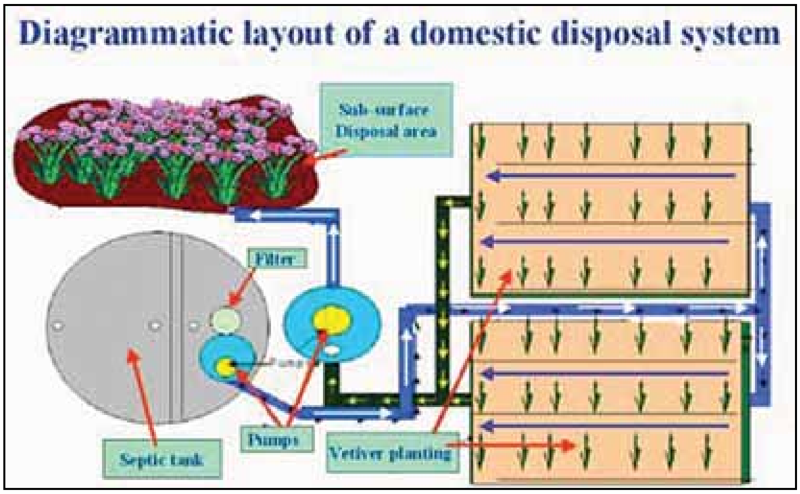

Figure 5: Layout of a domestic disposal system.

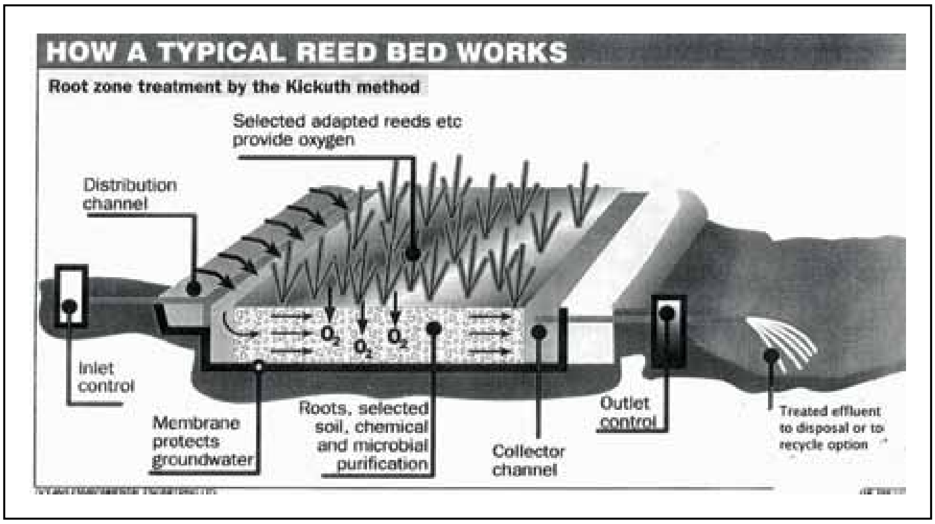

Figure 6: Workings of a typical reed bed.

5. TREATMENT OF CONTAMINATED LANDS

Among the most significant developments in environmental protection within the last 15 years are vetiver's documented tolerances to adverse soil conditions and to heavy metal toxicities. These benchmarks have opened up a new field for VS application: the rehabilitation of toxic and contaminated lands.

5.1 Tolerance to adverse conditions

5.1.1 Tolerance to high acidity, aluminium and manganese toxicity

Research shows that vetiver growth was not affected when adequately supplied with N and P fertilizers, even under extremely acidic conditions (pH = 3.8) and at a very high level of soil Aluminium Saturation Percentage (68%). Field tests confirm that vetiver grows satisfactorily at soil pH=3.0 and Aluminium level between 83-87%. However, since vetiver cannot survive an Aluminium saturation level of 90% at soil pH = 2.0, its threshold tolerance is between 68% and 90%. This tolerance is exceptional, since most plants are adversely affected at levels less than 30%.

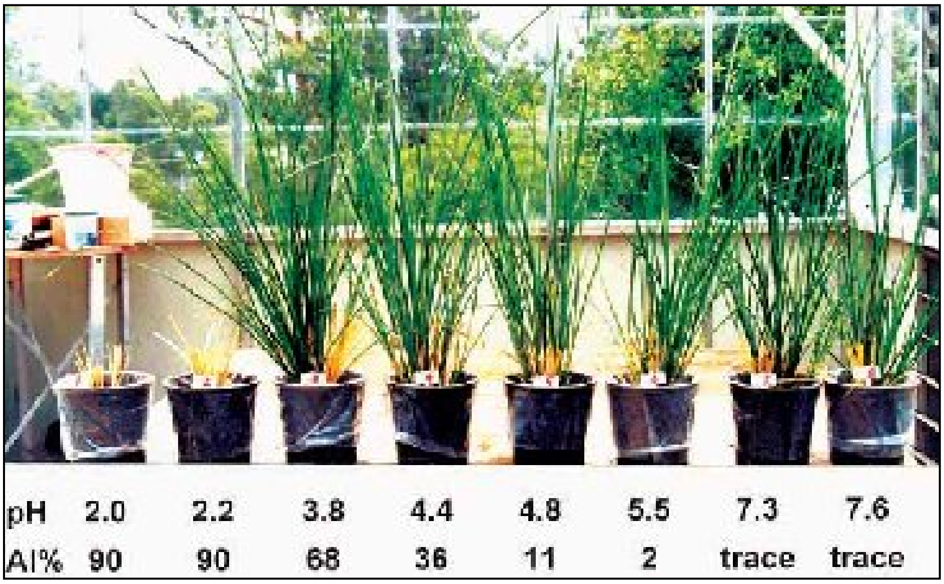

Photo 7: Under field conditions, vetiver thrives at soil pH=3.8 and Al saturation of 68% and 87%.

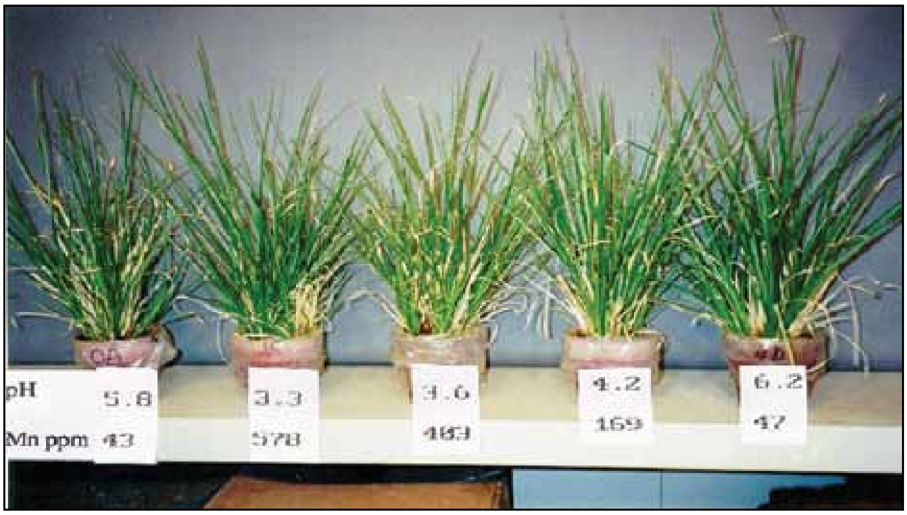

Photo 8: Vetiver growth was unaffected at pH=3.3 and at extremely high Mn level of 578 mg/kg.

Further, vetiver growth remained unaffected when the extractable manganese in the soil reached 578 mg/Kg, the soil pH was as low as 3.3, and plant manganese content was as high as 890 mg/Kg. Given its high tolerance to Al and Mn toxicity, vetiver has been used successfully to control erosion in acid sulfate soils with actual soil pH around 3.5 and oxidized pH as low as 2.8 (Truong and Baker, 1998) - photos 7 and 8.

Photo 9: Vetiver tolerates high soil salinity. Note 3rd pot from left represents half the salinity of sea water.

5.1.2 Tolerance to high soil salinity and sodicity

Given its salinity threshold level of ECse = 8 dS/m, vetiver compares favourably with some of the most salt-tolerant crop and pasture species grown in Australia, including Bermuda Grass (*Cynodon dactylon*) with a salinity threshold of 6.9 dS/m; Rhodes Grass (*Chloris gayana*) (7.0 dS/m); Wheat Grass (*Thynopyron elongatum*) (7.5 dS/m) and barley (*Hordeum vulgare*) (7.7 dS/m). With an adequate supply of N and P, vetiver grew satisfactorily on Na bentonite tailings with Exchangeable Sodium Percentage of 48% and a coalmine overburden with an exchangeable sodium level of 33%. The sodicity of this overburden was further exacerbated by the very high level of magnesium (2400 mg/Kg) compared to calcium (1200 mg/Kg) (Truong, 2004).

5.1.3 Distribution of heavy metals in vetiver plant

Table 2: Threshold levels of heavy metals: Vetiver and other plants

Heavy Metals	Threshold levels in soil (mg/Kg) (available)		Threshold levels in plant (mg/Kg)	
	Vetiver	Other plants	Vetiver	Other plants
Arsenic	100-250	2	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

The distribution of heavy metals in vetiver can be divided into three groups:

- Zn was almost evenly distributed between shoot and root (40%).
- Small amounts of As, Cd, Cr and Hg absorbed were translocated to shoots (1%-5%).
- Moderate amounts of Cu, Pb, Ni and Se were translocated to the top (16%-33%) (Truong, 2004).

5.1.4 Tolerance to heavy metals
Vetiver is highly tolerant to As, Cd, Cr, Cu, Hg, Ni, Pb, Se and Zn - Table 2 above.

5.2 Mine rehabilitation and phytoremediation
Given its extraordinary morphological and physiological characteristics, vetiver has been used successfully to rehabilitate mine waste rock and phyto-remediate mine tailings in: Australia: coal, gold, betonite and bauxite; Chile: copper. China: lead, zinc and bauxite (Wensheng Shu, 2003); South Africa: gold, diamond and platinum; Thailand: lead; Venezuela: bauxite (Lisena et al. 2006 and Luque et al.2006); Philippines: nickel.


Photo 10: Left, Bauxite mine at Los Pijiguaos, Venezuela protected with vetiver (note the planting of the steep slope by using ropes).

Photo 11: Nickel mine in southern Philippines protected by vetiver and coir matting (Biosolutions Inc).

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PART 5 - ON-FARM EROSION CONTROL AND OTHER USES FOR VETIVER

CONTENTS

1. INTRODUCTION

Years of experience in many countries have confirmed that, even if farmers have adopted vetiver to conserve soil, that application was not necessarily the main reason that they initially adopted it. In Venezuela, for example, vetiver was first grown to supply handicraft material. After crafts people embraced the dried leaves because they were beautiful and easy to weave, vetiver's soil conservation application was easier to introduce. Vetiver hedges were first appreciated in Cameroon as a barrier to keep snakes out of yards, and, in other places, vetiver was employed to delineate boundary lines (tree-marked boundaries were susceptible to challenge). In still other places the first reason vetiver was accepted was because it controlled pests in stored beans, and stem borers in maize (South Africa). This Part addresses several vetiver applications that are most commonly practiced by farmers.

2. SOIL AND WATER CONSERVATION FOR SUSTAINABLE CROP PRODUCTION

2.1 Soil and water conservation principles

The purpose of soil conservation practice is to control or reduce soil erosion caused by water and wind. In the case of water erosion, soil particles are first dislodged by excessive volume and/or high velocity of an overland flow of water. Wind erosion results from high wind velocity at ground level on bare surface.

Therefore the main goals of water erosion control practice are to protect the soil surface from being dislodged by the impact of the raindrops, to reduce the volume of runoff water using vegetative covers, and to control or lower the overland flow velocity. Contour/diversion banks (terraces) by design, divert runoff to a safe outlet, or waterway, or the drainage network. Vegetative barriers such as vetiver hedges planted across the slope or on the contour control the runoff, spreading it out and slowing it down as it slowly filters through the hedge. Since the erosive power of both water and wind erosion is proportional to the flow velocity (the speed of the downhill water and the force of the wind), the main principle of soil conservation is to reduce the speed of water and air. Correctly installed, vetiver hedges effectively control both water and wind erosion.

The objective of water conservation practice is to increase water infiltration to the soil body. This goal can be achieved most readily using vegetative cover, particularly vegetative hedges. When planted across the slope or on contour lines, dense vetiver hedges form a slowly permeable barrier that spreads runoff water and reduces its velocity. This allows more time for soil to absorb the water and the hedge to trap sediment.

2.2 Characteristics of vetiver suitable for soil and water conservation practices.

Unique characteristics of vetiver that are particularly important for soil and water conservation are:

- The soil-binding root system: deep, penetrating, massive, fibrous roots.
- Erect, stiff stems form a dense hedge, effectively retarding and spr.ading water flow, reducing its erosive power.
- Tolerance to all kinds of adverse soil conditions and poor soils, including acid sulfate, alkaline, saline and sodic environments.
- Ability to withstand prolonged submergence;
- Adaptability to a wide range of climatic conditions; growing both in the colder mountainous areas of the north and in extremely dry conditions in dunes of central coastal areas.
- Easy vegetative multiplication.
- Sterility; it flowers, but produces no seed. Since vetiver (*C. zizanioides*) has no spreading stolons or rhyzomes, it remains where it is planted and does not become a weed. Unlike *C. nemoralis*, which is indigenous to Vietnam and produces fertile seeds, *C zizanioides* is sterile and has a massive root system. Part 1 of this manual fully describes the significant differences between the two species.
- Its vertical root system, with very little lateral root growth. This ensures that the plant, when intercropped, does not generally compete with cash crops for nutrients and water.

Part 1 of this manual addresses the characteristics of vetiver in more detail. This part focuses on the important role in farming played by the first two characteristics: Vetiver's soil-binding root system and its ability to form dense hedgerows. Vetiver's strong root system is unmatched by any other plant used for on-farm erosion control. On flat lands and on gully floors, where the velocity of raging floodwater can be devastating, vetiver's deep, strong roots prevent the plant from dislodging. This grass can withstand extremely strong currents. In addition to reducing surface erosion on sloping land, vetiver's massive root system also contributes to slope stability. As described in Part 1, the deep, fibrous roots reduce the risk of landslide or collapse.

Photo 1: Strong current on this waterway in Australia flattened native grasses, leaving the vetiver hedge unaffected; its stiff stems reduced water velocity and its erosive power.

Vetiver's stiff stems form a dense hedge that reduces water velocity, allows more time for water to infiltrate the soil, and, where necessary, diverts surplus runoff water. This is the principle of 'flow-through' erosion control for farms on the flood plains as well as on steep slopes in high rainfall areas.

2.3 Contour banks or terrace systems versus the vetiver flow-through system

A review conducted for the World Bank compared the effectiveness and practicality of different soil and water conservation systems. It found that constructed measures must be site-specific and require detailed and accurate engineering and design. Furthermore, all hard systems require regular maintenance. Most evidence also suggests that constructed works reduce soil losses, but do not reduce runoff significantly. In some cases, they have a negative impact on soil moisture (Grimshaw 1988). On the other hand, when planted across the slope or on the contour, the vegetative conservation system forms a protective barrier across the slope that slows the runoff water and hoards sediment deposits. Since the barriers only filter the runoff and often do not divert 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 the flow-through system (Greenfield 1989), a sharp contrast to the contour terrace/waterway system in which runoff water collects by the terraces and is diverted quickly from the field to reduce its erosive potential. Since all runoff water is collected and concentrated in the waterways where most erosion occurs on agricultural lands, particularly sloping lands, this water is forever lost from the field. The flow-through system, on the other hand, conserves that water and protects the soil from loss on the waterways - figure 1.

This water conservation practice is very important in low rainfall regions such as the Central Highlands and Central Coastal Vietnam. 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 that offers high resistance to overland water flow, and have extensive and deep roots that bind the soil and prevent rilling and scouring near the barrier.
- Survive moisture and nutrient stress and re-establish top growth quickly after rain.
- Result in minimum loss of crop yield (the barrier should not proliferate as a weed, not compete for moisture, nutrients and light, and not host pests and diseases).
- Require only a narrow width to be effective.
- Supply materials that have economic value to farmers.

Vetiver exhibits all of these characteristics. Uniquely, it thrives in arid and humid conditions, grows under some extreme soil conditions, and survives wide variation in temperature (Grimshaw 1988).

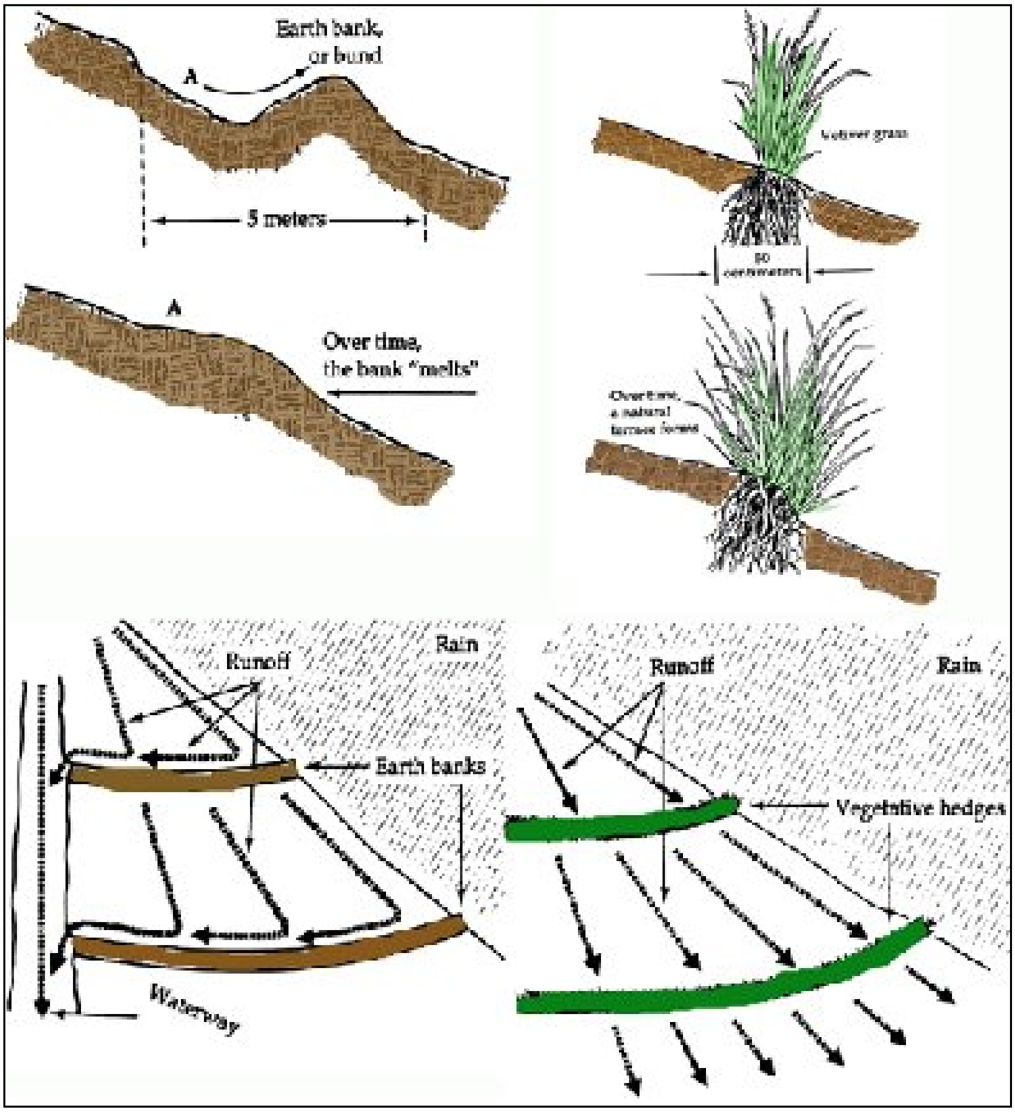

Figure 1: Above left: contour bank; below left: banks divert the water; above right: Vetiver hedges create banks or terraces over time; below right: Vetiver hedges slow the runoff to increase infiltration, and the water remains in the field (Greenfield 1989).

2.4 Application on flood plains

VS is an important tool to control flood erosion in all the flood plains of major rivers in Vietnam. Its use is not restricted to the Red River Delta in the north and Mekong delta in the south. Its application is particularly important to central coastal provinces, where flash flooding regularly occurs with devastating effects, such as the case of the Lam River flood plain in Nghe An province.

Vetiver hedges on flood plains:

- Reduce flow velocity that can lodge crops, and the run off's erosive power.

- Trap fertile alluvial soil on site, which maintains the fertility of the plain.
- Increase water infiltration in low rainfall regions such as Ninh Thuan province.

Strip cropping that involves wide buffer strips (that can take up a much as 30% of the land) between crops uses a "flow-through" system uses a "flow-through" system similar to that provided by vetiver hedges, but does not prevent crop lodging, as it does not reduce the speed of the runoff. Unlike vetiver hedges, this method requires a strict sequence of crop rotation, so it cannot be implemented during drought because crops cannot be planted. Strip cropping has been used effectively on the flood plains of the Darling Downs region in Australia to mitigate floodwater damage to crops and to control soil erosion on low gradient lands subject to deep overland flooding.

Photo 2: Left: fertile sediment remains as floodwater passes the vetiver hedge; right: a healthy crop of sorghum, protected by a vetiver hedgerow, survives flooding on the flood plain of the Darling Downs, Australia.

In a large field trial at Jondaryan (Darling Downs, Queensland, Australia), six rows of vetiver totalling more than 3000m (900 linear feet) were planted on the contour at 90m (180 feet) spacing. These rows provided permanent protection against floodwaters. Data collected from a small flow over the site shows that the hedges reduce significantly the depth and resulting energy of water flowing through the hedges. At a low depression, a single hedge trapped 7.25 tons of sediment. Results over the last several years, including several major flood events, confirm that VS successfully reduces flood velocity and limits soil movement, with very little erosion in fallow strips (Truong et al. 1996, Dalton et al. 1996a and Dalton et al. 1996b). This trial demonstrates that VS is a viable alternative to strip cropping practices on Australia's flood plains.

2.5 Application on sloping land

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% and soil loss from 14.4 t/ha to 3.9 t/ha, and increased sorghum yield from 2.52 t/ha to 2.88 t/ha over a four-year period. The yield increase was attributed mainly to in situ soil and moisture conservation over the entire toposequence protected by the vetiver hedge system (Truong 1993). Under small plot conditions at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), vetiver hedges were more effective in controlling runoff and soil loss than either 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. Average reductions of 69% in runoff and 76% in soil loss were recorded from vetiver plots, compared to control plots (Rao et al. 1992).

In Nigeria, vetiver strips were established on 6% slopes at the end of 20m (60') runoff plots for three growing seasons to assess their effects on soil and water loss, soil moisture retention and crop yields. Results showed that vetiver stabilized soil and chemical conditions within the entire 20m (60') distance behind the strip. Under vetiver management, cowpea yields were increased between 11 and 26%, and maize increased about 50%. In comparable 20m runoff plots without vetiver (control), soil loss and runoff water were 70% and 130% higher, respectively. Vetiver strips increased soil moisture storage between 1.9% and 50.1%, depending on depth. The nutritive content in eroded soils on the control plots was consistently poorer than on vetiver plots, which also enhanced Nitrogen use efficiency by about 40%. This research demonstrates the usefulness of vetiver hedges as a soil and water conservation measure in the Nigerian environment (Babola et al. 2003).

Photo 3: Vetiver planted on very steep slopes at about 1,700 m a.s.l. In the Munnar area of the Western Ghats of India in the state of Kerala. This major tea growing area suffers from serious erosion. All the estates in the area are now adopting the Vetiver System.

Similar results have been reported on a range of slopes, soil types, and crops in Venezuela and Indonesia In Natal, South Africa, vetiver hedges have increasingly replaced contour banks and waterways on steep sugarcane lands, where farmers have concluded that the vetiver system is the most effective and low-cost form of soil and water conservation in the long term (Grimshaw 1993). A cost-benefit analysis conducted on the Maheswaran watershed in India considered both engineered structures and vetiver vegetative barriers. The vetiver system was adjudged more profitable even during its initial stages due to its efficiency and low cost (Rao 1993).

In Australia, R&D over the last 20 years has confirmed overseas findings, particularly vetiver's effectiveness in soil and water conservation, gully stabilization, degraded land rehabilitation, and trapping sediment in waterways and depressions. In addition to these applications, vetiver has proven its versatility in:

- 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.

In Vietnam most of the on-farm experience with the Vetiver System was gained from 'the cassava project' (a Nippon Foundation project: 'Enhancing the Sustainability of Cassava-based Cropping Systems in Asia', in China, Thailand and Vietnam, 1994-2003), implemented in collaboration with Thai Nguyen University of Agriculture and Forestry (TUAF), National Institute for Soil Fertility (NISF), and Viet Nam Agricultural Science Institute (VASI, now VAAS). This project worked with farmers in northern mountainous areas in Yen Bai, Phu Tho, Tuyen Quang, and Thai Nguyen, in mountainous parts of Thua Thien Hue province, and the southwest.

Note: Cassava (*Manihot esculenta*) is one of the most important staple crops in humid tropical regions, but as a tuber crop typically planted in monoculture it is one of the most erosive crops in the developing world. Hence the importance of promoting more sustainable Cassava production systems. In this project farmers tested several combinations of measures including: (1) inter-cropping (e.g. contour farming with groundnut), (2) introduction of improved planting material (low-branching varieties to reduce impact of rain) combined with increased (organic and chemical) fertilization, and last but not least (3) anti-erosion hedgerows, and the application of VS proved to be among the most effective measures to reduce soil loss (see CIAT cassava project).

2.6 Effects on Soil Loss

While reducing soil loss has its own merit, keeping fertile soil on-farm, farmers ultimately judge its importance. When their farm soils are deep, farmers may not value soil conservation because it requires work and occupies valuable farmland. However, where slope farming is more intensive, and farmers apply manure and/or chemical fertilizer, then the positive effect of vetiver is not just about reducing soil loss, but also about retaining soil fertility and preventing surface runoff (Truong and Loch, 2004). In wetter areas, vetiver's deep, extensive root system has an additional advantage: it absorbs soluble nutrients that otherwise would be lost to deeper, unreachable layers of the soil. These nutrients return to the soil when vetiver grass is cut and used as mulch hence these nutrients can be recycled.

Photo 4: Difference in soil loss between vetiver (left) and *Flemingia congesta* (right), a legume.

Photo 5: This vetiver hedgerow on a 20% slope in Fiji trapped enough soil to create a natural terrace with a 2m high riser over a period of 30 years. At the same time it reduced rainfall runoff and the loss of nutrients resulting in increased sugar cane yields.

In the mountainous regions of northern Vietnam, *Tephrosia* and wild pineapple have traditionally been used as hedges (sometimes in combination with terracing) to reduce soil loss. However, wild pineapple's effectiveness is quite low. Its thick stems create mounds that can even increase erosion by concentrating and forcing water through tight spaces between the mounds. *Tephrosia* is effective only as long as the plant remains established; it dies after two to three years. On moderate slopes, vetiver hedges are a welcome alternative to traditional terracing, which is often labour intensive.

Dr. Pham Hong Duc Phuoc, Nong Lam University, led researchers in tests of vetiver's soil conservation properties on coffee plantations on sloping land in Dong Ngai province (southwest Vietnam).

Photo 6: Vetiver controls erosion on a coffee plantation in the Central Highlands of Vietnam.

Table 1: Effects of VS on soil loss and runoff on agricultural lands

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	88.7	20.2	64.1	50	21.9
Venezuela (15% slope)	16.8	12	1.1	88	76	72
Venezuela (26% slope)	35.5	16.1	4.9	-	-	
Vietnam	27.1	5.7	0.8	-	-	
Bangladesh	-	42	6-11	-	-	
India	-	25	2	-	-	

(Truong and Loch, 2004)

Photo 7: Vetiver hedges protect organic school gardens on 50% slopes in the East Bali Poverty Project, Indonesia.

In Indonesia the introduction of VS on-farm has been very effective through a school organic gardening education program. In the Bali Poverty Project VS is planted by school children in gardens, as well as along local roads. Children then introduce their skills back home.

2.7 Design and extension: farmers' considerations

Using vetiver to control on-farm soil erosion has made one thing clear: farmers consider many factors before deciding whether and how to use vetiver (Agrifood Consulting International, March 2004). Research farmers (well-off farmers who were subsidized to conduct the trial) shed some light on farmers' reasoning. Among their concerns, adoption of improved plant varieties and chemical fertilizer was highest. Their priorities and willingness to adopt vetiver as the primary soil conservation method were different from other, non-subsidized farmers.

Once farmers understand vetiver principles, and have the opportunity to assess the short-term and long-term impact of VS, they are much more inclined to adopt it. Hence, it is important to place farmers at the centre of the approach, and anticipate that each will adjust the guidelines (e.g. recommended spacing) to fit his own circumstances. Knowing this, the field worker will be better able to advise the farmer to assure the success of the system. The use of subsidized inputs or other material incentives for farmers to collaborate in VS trial and adoption is discouraged, since it will undermine the repeatability of results.

Photo 8: Making soil loss visible (CIAT cassava project). Note difference in rainfall runoff. Less than half in the furthest trap with vetiver protection.

The following checklist for feasibility of large-scale adoption of Vetiver System for Soil and Water Conservation:

A. How important is the soil erosion problem?

- How deep is the soil profile?
- How visible is soil loss to farmers on-site or downstream?
- What is the extent or value of the soil loss? If fertilizer has been applied then farmers are more willing to make an effort to protect their investment, and resist loss through runoff or leaching to deeper layers (e.g. deep-rooted vetiver can recover soluble Nitrogen that quickly leached to unreachable lower layers)
- Given slope gradient and soil texture, how erosion-prone is the soil?
- How does VS compare with other available erosion control methods (e.g. contour ridging, stone contour lines, plastic mulch, and plant varieties that are low-branching, have a fast closing canopy)?

B. How important is the cropping system, compared to other parts of the farm?

Farmers are more interested to invest in conservation practices that produce a profitable crop:

- What is the relative value of the piece of land (willingness to invest labour, money)?
- What is the general position of the farmer? How much labour/money can he/she invest in this plot? What compete with her/his time and money (e.g. paddy land or off-farm labour)?
- Is the farmer sufficiently sure of land tenure to justify efforts improving it?
- Does the distance from homes to the fields justify labour investment?
- Can the farmer use vetiver in complementary applications?
- Is there enough nursery space to propagate vetiver, or otherwise obtain it?
- What policies militate against applying soil and water conservation measures?
- What ecological limitations affect the use of vetiver? (e.g. Vetiver does not tolerate shade; once established, however, shade is less of a problem).

Farmers are urged to test, compare and combine Vetiver System with other soil and water conserving practices.

3. OTHER MAJOR ON-FARM APPLICATIONS

3.1 Crop protection: stem borer control in maize and rice

Stem borers attack maize, sorghum, rice and millets in Africa and Asia. The moths lay their eggs on the leaves of the crop. Professor Johnnie van den Berg, entomologist, (School of Environmental Sciences and Development, Potchefstroom University, South Africa.) found that the moths prefer to lay eggs on the leaves of vetiver planted around the crop instead of on the maize or rice crop itself. Given the option, about 90% of the eggs are deposited on vetiver instead of on the crop. This is known as the “push pull” system - figure 2.

Because vetiver leaves are hairy, the larvae that hatch on them cannot move around easily. The larvae fall off the plant and die on the ground, resulting in very high mortality, about 90%. Vetiver also harbours many helpful insects that are predators of pests that attack crops. In cooperation with Dr. van den Berg, Can Tho University is currently studying the practical application of this effect on rice. Preliminary results are very promising. Van den Berg also reports that the sugar cane borer, *Eldana saccharina* prefers to lay its eggs on vetiver. In India *Chilo partellus* also is found in cane. Vetiver grass hedgerows provide very good habitat for beneficial insects such *Chrysopidae sp*. and other beneficial insects. Vetiver alone is not enough to control pests and must be part of an overall IPM package that manages crop health.

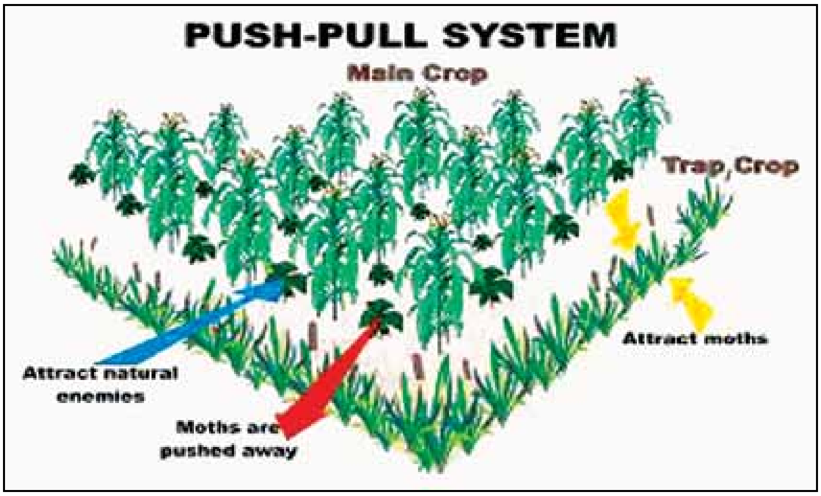

Figure 2: The Push-Pull system: Vetiver attracts the insect to lay eggs where they have little chance of survival.

Photo 9: Left, Stem borer (*Chilo partellus)* in maize; right (left) Vetiver's hairy leaves make it an inhospitable host; stem borer larvae drop off and die on the ground.

Photo 11: Maize stem borer control (Zululand, South Africa).

3.2 Animal feed

Vetiver leaves are tasty fodder readily eaten by cattle, goats and sheep. Table 2 compares vetiver's nutritional values to those of other subtropical grasses in Australia. Young vetiver grass is quite nutritious, actually comparable to mature Rhodes and Kikuyu grass. However, the nutritional value of mature vetiver grass is low, and it lacks crude protein.

A study in Vietnam (Nguyen Van Hon, 2004) shows that young vetiver grass can partially replace mature *Brachiaria mutica* grass as feed for growing goats.

Table 2: Nutritional values of vetiver, Rhodes and Kikuyu grass, Australia.

Analytes	Units	Vetiver grass			Rhodes	Kikuyu
		Young	Mature	Old	Mature	Mature
Energy (ruminant)	kCal/kg	522	706	969	563	391
Digestibility	%	51	50	-	44	47
Protein	%	13.1	7.93	6.66	9.89	17.9
Fat	%	3.05	1.30	1.40	1.11	2.56
Calcium	%	0.33	0.24	0.31	0.35	0.33
Magnesium	%	0.19	0.13	0.16	0.13	0.19
Sodium	%	0.12	0.16	0.14	0.16	0.11
Potassium	%	1.51	1.36	1.48	1.61	2.84
Phosphorus	%	0.12	0.06	0.10	0.11	0.43
Iron	mg/kg	186	99	81.40	110	109
Copper	mg/kg	16.5	4.0	10.90	7.23	4.51
Manganese	mg/kg	637	532	348	326	52.4
Zinc	mg/kg	26.5	17.5	27.80	40.3	34.1

Vetiver leaves are generally useful by-products of soil and water conservation measures. Vetiver leaves are nutritious when cut (pruned) at intervals between one and three months, depending on climatic conditions. Their nutrient content, like many tropical grasses, varies according to season, growth stage and soil fertility. In India when vetiver is chopped by a manual forage chopper domestic buffaloes find the grass totally palatable. When vetiver is used for other purposes, fodder may prove an added value. After an extremely harsh winter in Quang Binh province, vetiver was the only green fodder available; the cold had killed the other grasses. Further, vetiver grass growing on pig farm waste contains high contents of crude protein, carotene and lutein, relatively lower contents of Ca, Fe, Cu, Mn and Zn, and acceptable levels of heavy metal, Pb, As and Cd (Pingxiang Liu 2003).

Photo 11: Left: buffalo graze on vetiver bordering dike; right: cattle eat young vetiver.

Vetiver can grow under very high levels of nitrogen (as much as 10,000 kg of N per ha). Thus when vetiver is an an integral part of a constructed wetland for waste treatment (animal and human) it will yield over 100 tons of dry matter per ha. and is high in nutrients.

Vetiver will also grow well on salinized soils, if the area has a high ground water table as is the case of parts of India's Haryana and Punjab States, there is a potential of dry matter yields of 70 tons per ha of forage.

Vetiver's forage potential would benefit from further research both in the management of the grass as a forage and the identification of cultivars that are more suitable as a forage.

3.3 Mulch to control weeds and conserve soil water

Given a silica content higher than other tropical grasses, such as *Imperata cylindrica*, vetiver shoots take a longer time to break down. This makes vetiver ideal for use as mulch and roof thatching (as thatch it does not harbour insects).

Weed control: When spread evenly on the ground, whole or desiccated vetiver leaves form a thick matt that suppresses weeds. Vetiver mulch successfully controls weeds in coffee and cocoa plantations in the Central Highlands and tea plantations in India. At the same time the mulch when it breaks down quickly builds up soil organic matter and improves soil nutrients from deep down uptake of nutrients that are normally not available yo other plants.

Photo 12: Vetiver controls erosion and its mulch suppresses weeds in coffee plantation in the Central Highlands of Vietnam .

Photo 13: Vetiver mulch controls weeds in a tea plantation, southern India (P Haridas).

Water conservation: The thick cover of vetiver mulch increases water infiltration and reduces evaporation, particularly important under the hot, dry conditions of the coastal provinces like Ninh Thuan. It also protects the soil surface from the impact of raindrops, a major cause of soil erosion.

4. FARMLAND REHABILITATION AND PROTECTION OF FLOOD REFUGE COMMUNITIES

4.1 Sand dune stabilization

Sand dunes occupy more than 70,000 ha (172,974 acres) along the coast of Central Vietnam. These dunes are highly mobile due to strong wind and highly erodible during heavy rains. Without stabilization, the sand invades valuable farmland, destroying crops, and clogging rivers and streams. Local farmers suffer enormous losses as a consequence. Traditional methods of stopping dune movement, which include the planting *Casuarina* trees and wild pineapple, and constructing small dikes made of sand, are ineffective. Planting vetiver hedges offers the best solutions to date.

The following case study illustrates the problem: In Quang Binh Province the toe slope of a sand dune was badly eroded by a meandering stream that served as a natural boundary between the dunes and a Forest Enterprise nursery. The stream undercutting the dune foot slope moved the sand, depositing it on irrigated farms downstream. The farmers, who tried to divert the sand-stream with dikes made of dune sand, succeeded only in transferring the problem to other farms. The situation created conflicts among farmers, and, since the stream had been diverted from its nursery toward the dune, with the Forestry Enterprise.

Four rows of vetiver were planted in contour lines on the slope of the sand dune, starting from the edge of the stream. After only four months, the plantings had formed closed hedgerows and stabilized the sand dune toe. The Forestry Enterprise was so impressed with this result that it mass planted the grass on other sand dunes and even used it to protect a bridge abutment. The grass further surprised local people by surviving the coldest winter in ten years, when the temperature plummeted below 10^{o}C, a cold spell that forced farmers to twice replant their paddy rice and *Casuarina sp*. After two years, local species such as *Casuarina sp* and wild pineapple re-established themselves between the vetiver rows. Under the shade of the native trees, the grass itself faded away, having accomplished its mission. The project proves again that vetiver can withstand very hostile soil and climatic conditions.

Several issues should be considered when addressing dune slope protection:

1. Assessing and planning together with local communities is very important a community can:
   - Provide valuable ideas during planning.
   - Contribute financially.
   - Provide labour for implementation.
   - Protect and maintain the plantings.
   - Benefit from employment associated with the establishment and maintenance of the site.
2. Training local people: When teaching local people about vetiver multiplication, planting and maintenance, provide instruction about its other uses (fodder, handicraft).
3. Propagation: Local nurseries can be contracted to propagate vetiver and supply bare root slips for installation.
4. Maintenance and monitoring: The local community can monitor and maintain the plantings. Dry sands shift, sometimes burying or even washing away the young grass, so maintenance at early stages is important.

Photos 14 and 15 - Community vetiver hedges on dunes in Le Thuy district and Quang Binh province. Vetiver is equally effective in reducing blowing sand. For this use, the grass should be planted across the wind direction, especially in troughs between sand dunes, where wind velocity typically increases. This use has been tested on coastal dunes in Senegal - photo 16, as well on Pintang Island, off the East China coast.

Photo 14: Early April 2002 – vetiver one month after planting. Note: Mulch was put above the top row (left). Mid October 2002 (seven months): Casuarinas have become re-established between vetiver rows (right).

Photo 15 shows the way the local community extended the practice, with support from local foresters. February 2003: hedgerows established in October 2002 survived the coldest-ever winter in Quang Binh.

Photo 16: Vetiver protects dunes at a beach resort in Senegal (left) and Pingtang Island, China (right) from wind erosion. Also forms a windbreak to protect young plants.

4.2 Productivity enhancement on sandy and saline sodic soil under semi-arid conditions

In south-central Vietnam, Ninh Thuan and Binh Thuan are two coastal provinces that share a peculiar climatic condition. Although both are situated on the coast, they experience semi-arid conditions, with annual rainfall between 200-300mm (8-12”). This results in an extreme shortage of fresh water for cropping and animal husbandry.

The “soil” of the coastal dune is saline, alkaline, and sodic, with a thin compacted gypsum (sodic-petrocalcic) layer just under the topsoil. Agricultural production in the region is very limited, due in part to the poor soil conditions (the gypsum layer effectively prevents roots from penetrating into the more humid layer underneath) and in part to the lack of rainfall. The coastal dune is also prone to wind erosion and water erosion when it rains, so it yields very sparse vegetation and fodder for livestock. These factors contribute to extreme hardship and poverty in the local population.

From 2003 to 2005, Professor Le Van Du and his students from Ho Chi Minh City Agro-Forestry University planted vetiver on these saline sodic soils to determine whether VS could improve the productivity of farms in desert-like conditions. They learned that, once established under initial irrigation, vetiver grew exceptionally well. During the first two months, vetiver grew two to three times faster than any other crop, yielding a fresh biomass of 12 tons on non-saline sandy soils (96% sand) and 25 tons on alkali-sodic soils. In three months, its roots penetrated 70 cm (26.5”), through the compacted gypsum layer, reaching ground moisture that local maize, grapes, and other plants could not reach. The scientists noted a great improvement in soil fertility after only three months, specifically that soluble salt and pH had been greatly reduced. Although soil pH had hardly changed after three years of grape cultivation, following the vetiver installation soil pH declined up to 2 units from the surface layer to a depth of 1m (3’), and dissolved salt content. The reduction in sodium content by more than half dramatically improved the productivity of local crops such as corn and grapes.

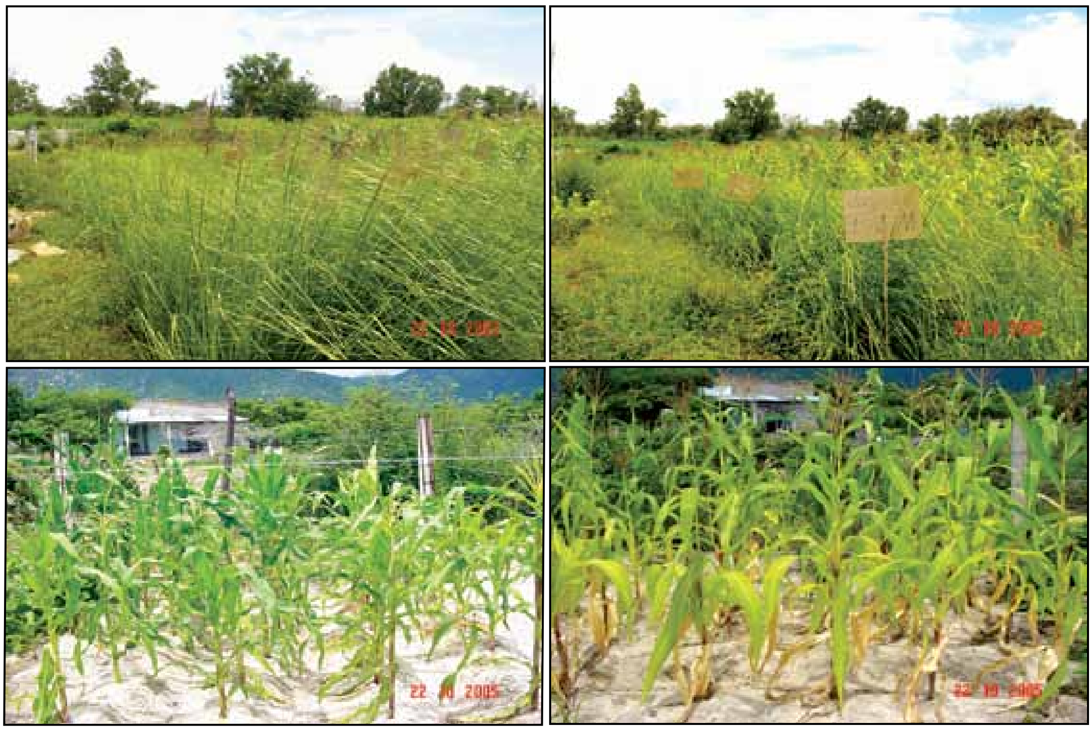

Photo 17: Vetiver roots penetrated compacted gypsum barrier to tap ground water.

Photo 18: left: Sandy soil in its original state; right: the same soil, now used for a vineyard, following rehabilitation using vetiver mulch.

4.3 Erosion control on extreme acid sulfate soils

Developing agriculture and aquaculture in an acid sulfate soil region requires an effective and stable irrigation and drainage system. Residents in these areas commonly use local soil (high clay, low pH, high toxicity) to build infrastructure, which is susceptible to soil erosion because it cannot support most vegetation. Since acid sulfate zones are low in topography and subject to annual flooding, local communities suffer extreme hardship.

Found in different regions, the soils share common characteristics: extreme acid sulfate, pH between 2.0 and 3.0 in the dry season, and high levels of Al, Fe, and SO_4^{2}. The high clay content of the soil causes it to crack as it dries, resulting in large holes that let in water, and cause erosion during the rainy and flood seasons. As a consequence, very few endemic plants can establish and survive during the dry season, including those considered to be locally tolerant species

Vetiver has stabilized embankments and controlled canal bank erosion at five sites located on extreme acid sulfate soils in Vietnam: one flood protection dike (protecting a people cluster or flood-refuge community) in Tien Giang province, three in Long An provinces, and one section of a flood protection dike near Ho Chi Minh City.

Photo 19: Before (left) and after (right) vetiver installation in extreme acid sulfate soil on an embankment in Tien Giang province, Vietnam.

When planted in polybags, vetiver readily established itself in the acid sulfate soils. Although no vetiver survived when planted as bare root slips directly into fresh acid sulfate soil, more than 80 percent of bare root slips survived and grew normally in the same soil when a small amount of lime, good topsoil, or manure was first added to the furrows.

The following results were recorded:

- Over four months, once it was established, vetiver markedly reduced soil loss by erosion. Bare canal banks lost soil at a rate of 400-750 tons/ha, compared with only 50-100 tons/ha on a channel embankment protected by vetiver.
- After 12 months, soil loss had become negligible.
- The banks were completely stabilized when vetiver was trimmed to 20-30cm (8”-12”) and the shoots were used as mulch covering the bare area of the bank (Le van Du and Truong, 2006).

4.4 Protection of flood-refuge communities or people clusters

Major flooding occurs annually in several provinces of the Mekong Delta in southern Vietnam. These floods are usually up to 6-8m (18-24’) deep and can last as long as three to four months. As a result, houses are flooded every year unless they are located on land protected by major dike systems. Subsistence farmers have to rebuild their homes every year, at great personal sacrifice.

To overcome this problem, local governments designate as Flood-refuge Communities or People Clusters areas of relatively high ground that have been augmented with soil from the surrounding land. Although these constructed areas are high enough to escape annual prolonged floods, their banks are highly erodible and require protection from the strong currents and waves generated during the flood season. Vetiver hedgerows have been highly effective in protecting these clusters against flood erosion, with the added benefit of treating community effluent and wastewater during the dry season.

4.5 Protection of farm infrastructure

VS is widely used to protect farm infrastructure by stabilizing farm dams, aquaculture dikes, and rural roads, among other applications. Photo 21 shows vetiver reducing the impact of a gully that drains water from the seasonally flooded farm area (background) towards the river. Since the gully also threatens the shrimp pond (right), vetiver also protects the banks of the pond, especially in the area where the farmer drains the water from the pond into the gully, the most vulnerable place.

Photo 20: Left: Flood-Refuge Community (or People Clusters) in Tan Chau District, An Giang Province; (right) the bank of the Cluster.

Photo 21: Vetiver protects a shrimp pond near a natural gully that drains water into a river (Da Nang province); this model was established as part of the first vetiver project financed by the Royal Netherlands Embassy in Vietnam.

Vetiver stabilizes slopes bordering dirt roads and rivers, preventing landslides in mountainous regions and riverbank erosion on the flood plain. In the Philippines and India, vetiver is also widely used to stabilize the narrow dikes that separate paddy fields on sloping land.

This planting reinforces the sides of these dikes and as a result reduces the width of the dikes, thus releasing more land available for cropping. An added bonus is that the planting will provide fodder for cattle and buffalo during the dry season. PART 3 addresses stream bank protection in more detail.

Photo 22: Vetiver, installed in a cross-hatched pattern, protects shrimp pond dikes in Quang Ngai.

Photo 23: The right section of this rural road in Quang Ngai is protected by vetiver; the left section is unprotected.

5. OTHER USES

5.1 Handicraft

Rural communities in Thailand, Indonesia, Philippines, Latin America, and Africa are using vetiver leaves to produce high-quality handicrafts, an important means of generating income. “Vetiver Handicrafts in Thailand,” published by the Pacific Rim Vetiver Network (1999), is a well illustrated practical guidebook to this use. References at the end of this Part provide details on how to obtain this guide.

Photo 24: Typical Thai handicrafts supported by the Royal Development Projects Board of Thailand.

Photo 25: Vetiver handicrafts from Mali made by weaving vetiver leaf into a " fabric" for pillows and throws.

Photo 26: Vetiver handicrafts made by a Venezuelan women's cooperative supported by the POLAR Foundation.

The Royal Development Projects Board of Thailand offers free training on vetiver handicraft-making to foreign participants.

5.2 Roof thatch

Vetiver leaves for thatch last longer than *Imperata cylindrica*, at least twice as long according to farmers in Thailand, Africa and the South Pacific Islands, making them particularly suitable for use in bricks and as thatching. Users report that the leaves repel termites.

Photo 27: Roof thatching in Venezuela.

Photo 28: Left to right: Thatched roofs in Fiji, Vietnam and Zimbabwe.

5.3 Mud brick making

Vetiver straw is widely used in Senegal, Africa, to make mud bricks that resist cracking Housing construction in Thailand uses bricks and columns made from clay composite to which vetiver leaves have been added. These building materials have rather low thermal conductivity, which makes the resulting construction comfortable and energy-efficient, as well as a labour-based appropriate technology.

5.4 Strings and ropes

Farmers who grow rice, the main crop of the Mekong Delta, have discovered another use for vetiver leaves

Photo 29: Left: Vetiver reinforces a wooden structure along a river; right: cut vetiver leaves make string for use as rice binding

as string to bind rice seedlings and rice straw. They prefer vetiver string because it is pliant and tough, even more pliant and stronger than the banana, rush and Nipa palm string commonly used.

5.5 Ornamentals

Mature vetiver has light purple and very pretty flower heads, which can be used as cut flowers, potted plants or landscaping in gardens and other public open spaces such as lakes and parks.

Photo 30: Vetiver borders a lake in an expensive suburb (Brisbane, Australia)

Photo 31: Different ornamental applications in Australia, China and Vietnam.

5.6 Oil extraction for medicinal purposes and cosmetics

In Africa, India and South America, vetiver roots are widely used for medicinal purposes, ranging from common cold to cancer treatment. American research confirms that oil extracted from vetiverroots has anti-oxidant characteristics with cancer reduction/prevention applications. In India and Thailand, healing-arts practitioners use vetiver oil extensively in aromatherapy applications because of its documented calming effects.

Table perfumery applications:

- Pure essential oil (perfume in its own right) - known as Ruh Khus, Majmua. Note, because of the oils low volatility it provides a base for other fragrances to adhere to.Vetiverol - weak aroma and high solubility in alcohols, renders best fixative and blending qualities.
- Diluted forms - flavouring, refreshing and refrigerating applications (colognes, toilet waters).

Medicinal aromatherapy:

- Skin care, Central Nervous System (CNS) benefits.
- Stops nosebleeds and treats bee stings.

Table 3: World production and use of vetiver root oil Chemical composition and applications of vetiver oil.

Vetiver root Oil : Vetiver Oil

U.C. Lavania

Central Institute of Medicinal & Aromatic Plants, Lucknow (India)

Annual World Production of Vetiver Oil	250 tons
Estimated oil price	US $ 80 / kg
Major Oil Producing countries	Haiti, Indonesia (Java), China, India, Brazil, Japan
Major Consumers	USA, Europe (France), India, Japan
Major Uses	Perfumery (Perfume, Blending, Fixative), Flavors, Cosmetics, Masticatories
Roots as such	Multifarious refrigerating applications

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