Vetiver System Applications

Technical Reference Manual

Paul Truong, Tran Tan Van and Elise Pinners

VETIVER SYSTEM:

Proven and Green Environmental Solutions

PREFACE

Dick Grimshaw, Founder and Chairman of The Vetiver Network International

THE VETIVER SYSTEM
PROVEN & 'GREEN' ENVIRONMENTAL SOLUTIONS

The Vetiver System (VS) is dependent on the use of a very unique tropical plant, Vetiver grass – *Vetiveria zizanioides*, 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 *Vetiveria 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 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.

All these applications can directly or indirectly impact on the rural poor through either protection or rehabilitation of farm land and provision of direct farm income, or indirectly by protecting rural infrastructure.

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 can 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.

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. I believe it will be used widely by people using and promoting the Vetiver System, and will be translated into many languages. We have to thank the authors for a job well done!

Tran Tan Van, Coordinator, Vetiver Network Vietnam (VNVN), Deputy Director, Vietnam Institute of Geosciences & Mineral Resources

Few existing plants have the unique attributes of multiple uses, environmentally friendly, effective and simple to use as Vetiver grass. Few existing plants have been known and used quietly over centuries and suddenly being promoted, widely used and widespread all over the world in the last 20 years as Vetiver grass. Fewer still plants have been idolized as Miracle Grass, Wonder Grass with capacity to create a living wall, a living filter strip and a live nail reinforcement.

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.), not to mention many other uses.

Nevertheless, the potential for Vetiver usage remains huge, and the awareness about its application needs to be made widely available to the public. In addition, here and there in Vietnam, as well as in other countries, there remain some reluctance, concern, even doubt about the values and effectiveness of Vetiver grass. Both TVNI and VNVN notice that in most cases, failure in the use of Vetiver grass is due to the improper understanding or incorrect applications rather than VS itself.

Based on the review of the huge volume of research and application results of Vetiver grass, the authors noticed that it is time to compile a newer version to replace the first World Bank Manual, the Green Book, which would cover a wider ranges of Vetiver grass applications. The authors have exchanged this idea and received an enthusiastic support of TVNI. Hence, the manual was first compiled in English but opportunity for the printing of its Vietnamese version came first so it was translated by the same authors into Vietnamese.

The manual is directed towards a wide range of readers such as engineers, managers and policy makers in the fields of construction, transportation, water resources engineering, agriculture, natural disaster mitigation, environmental protection etc., as well as local communities.

The authors welcome any comments from readers so that future additions may be improved.

Paul Truong, Director, The Vetiver Network International (TVNI) Asia and Pacific Region, Brisbane, Australia

Applications of the Vetiver System in the last 20 years have evolved through the following phases:

- Soil and water conservation in agricultural land
- Land stabilization and infrastructure protection
- Rehabilitation and phytoremediation of contaminated lands
- Treatment and disposal of waste and polluted water
- Poverty alleviation
- Crop protection
- Future applications: green house gas sequestration, fuel and phyto-mining etc.

This Manual is the second "How to" booklet sponsored by TVNI. The first Manual, Vetiver Grass - A Hedge Against Erosion (commonly called the **Green Book)** by John Greenfield, the Father of VS, published in 1987 by the World Bank, set out to show the principles of soil and water conservation in farm land and practical methods of how VS should be used to obtain maximum benefit. It also demonstrated the superiority of the flow through VS over the old conventional practice of contour bank or terrace system developed in the USA in the 1930s.

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.

AUTHORS

This manual was compiled by the following authors:

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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 and mine rehabilitation, wastewater treatment, 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 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 dykes, anti-salinity dykes and river dykes, 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.

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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, fundraising 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. She now works 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.

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CONTENT OF THE ENTIRE MANUAL

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**.

Part 1: The Vetiver Plant
Part 2: Propagation methods of Vetiver
Part 3: Vetiver System for disaster mitigation and infrastructure protection
Part 4: Vetiver System for prevention and treatment of contaminated water and land
Part 5: Vetiver System for on-farm erosion control and other uses.

APPENDIX: SUMMARY OF AVAILABLE RESOURCES

LINKS TO POWER POINT TYPE PRESENTATIONS

Vetiver System:

- An Overview - http://picasaweb.google.com/VetiverClients/VetiverSystemsOverview
- The Plant - http://picasaweb.google.com/VetiverClients/VetiverSystemsThePlant
- Propagation & Planting - http://picasaweb.google.com/VetiverClients/VetiverSystemPropagationAndPlanting
- Poverty Alleviation - http://picasaweb.google.com/VetiverClients/VetiverSystemsAndPovertyAlleviation

Agricultural applications:

- Soil & Water Conservation - http://picasaweb.google.com/VetiverClients/VetiverSystemSoilAndWaterConservation
- On Farm Use and Products - http://picasaweb.google.com/VetiverClients/VetiverSystemAndAgriculturalCropProduction

Water and Water Quality applications:

- Flood Control - http://picasaweb.google.com/VetiverClients/VetiverSystemsForFloodControl
- River Banks - http://picasaweb.google.com/VetiverClients/VetiverSystemForRiverAndStreamBankErosionControl
- Dams, Ponds and Lakes - http://picasaweb.google.com/VetiverClients/VetiverSystemForDamsReservoirsAndPonds
- Mine and Quarry Rehabilitation - http://picasaweb.google.com/VetiverClients/VetiverSystemForMineAndQuarryRehabilitation
- Pollution Control - http://picasaweb.google.com/VetiverClients/VetiverSystemForEffluentDisposal
- Landfill - http://picasaweb.google.com/VetiverClients/VetiverSystemForLandfillLeachateDisposal

Slope Stabilization applications:

- Rural Roads - http://picasaweb.google.com/VetiverClients/VetiverSystemAndRuralRoads
- Highways - batter/ fill and drainage - http://picasaweb.google.com/VetiverClients/VetiverSystemsForHighwayStabilization
- Railroads - http://picasaweb.google.com/VetiverClients/VetiverSystemAndRairoadProtectionAndStabilization
- Land Rehabilitation - http://picasaweb.google.com/VetiverClients/VetiverSystemsForLandRehabilitation
- Pipeline and electricity utilities - http://picasaweb.google.com/VetiverClients/VetiverSystemPipelinePowerlineStabilization

Other Uses:

- Urban Landscaping - http://picasaweb.google.com/VetiverClients/VetiverSytstemForUrbanLandscaping
- Other uses - handicrafts, aromatic oils, medicinal etc. - http://picasaweb.google.com/VetiverClients/VetiverSystemHandicraftsAndOtherUses

LINKS TO TEXTS SUPPORTING VARIOUS APPLICATIONS

GENERAL

- THE VETIVER SYSTEM - http://www.Vetiver.org/TVN_archive.htm" \l "Anchor-THE-49575
- THE VETIVER PLANT - http://www.Vetiver.org/TVN_archive.htm" \l "Anchor-5185
- PROPAGATION AND PLANTING OF VETIVER http://www.Vetiver.org/TVN_archive.htm" \l "Anchor-PROPAGATION-11481
- DISASTER MITIGATION - http://www.Vetiver.org/TVN_archive.htm" \l "Anchor-DISASTER-44867
- DISSEMINATION. TRAINING, ECONOMICS AND SOCIAL ISSUES - http://www.Vetiver.org/TVN_archive.htm" \l "Anchor-DISSEMINATION-33869
- FRENCH TRANSLATIONS OF SELECTED PAPERS - http://www.Vetiver.org/TVN_archive.htm" \l "Anchor-FRENCH-21683
- SPANISH TRANSLATIONS OF SELECTED PAPERS -

http://www.Vetiver.org/TVN_archive.htm" \l "Anchor-SPANISH-49425

- VETIVER SUPPLIERS AND CONSULTANTS http://www.Vetiver.org/TVN_archive.htm" \l "Anchor-VETIVER-17304

AGRICULTURAL CROP PRODUCTION AND RURAL INDUSTRIES

- AGRICULTURAL AND CROP PRODUCTION - http://www.Vetiver.org/TVN_archive.htm" \l "Anchor-AGRICULTURAL-44591
- HANDICRAFTS - http://www.Vetiver.org/TVN_archive.htm" \l "Anchor-HANDICRAFTS-43793
- MEDICINAL AND INSECTICIDAL USES OF VETIVER - http://www.Vetiver.org/TVN_archive.htm" \l "Anchor-MEDICINAL-5677
- THE VETIVER PLANT - http://www.Vetiver.org/TVN_archive.htm" \l "Anchor-THE-36680
- PROPAGATION AND PLANTING OF VETIVER – http://www.Vetiver.org/TVN_archive.htm" \l "Anchor-PROPAGATION-53555

INFRASTRUCTURE PROTECTION AND STABILIZATION

- SLOPE STABILIZATION (BUILDING SITES, HIGHWAYS, ROAD and RAILWAY CUT and FILL) - http://www.Vetiver.org/TVN_archive.htm" \l "Anchor-SLOPE-58521
- RIVERS, PONDS, RESERVOIRS and FLOOD PROTECTION - http://www.Vetiver.org/TVN_archive.htm" \l "Anchor-RIVERS-7431
- PUBLIC UTILITIES (pipelines, power lines, water carriers and other right of ways) - http://www.Vetiver.org/TVN_archive.htm" \l "Anchor-PUBLIC-63368

LAND REHABILITATION AND MINING

- LAND REHABILITATION - http://www.Vetiver.org/TVN_archive.htm" \l "Anchor-LAND-2821
- MINE AND QUARRY REHABILITATION – http://www.Vetiver.org/TVN_archive.htm" \l "Anchor-MINE-363

LANDSCAPING

- LANDSCAPING - http://www.Vetiver.org/TVN_archive.htm" \l "Anchor-LANDSCAPING-59125

POLLUTION AND WATER QUALITY

- LANDFILL STABILIZATION AND LEACHGATE CONTROL - http://www.Vetiver.org/TVN_archive.htm" \l "Anchor-LANDFILL-45656
- POLLUTION - EFFLUENT CONTROL (WATER QUALITY IMPROVEMENT) -

http://www.Vetiver.org/TVN_archive.htm" \l "Anchor-POLLUTION-7638

RIVERS, PONDS, RESERVOIRS and FLOOD PROTECTION

- RIVERS, PONDS, RESERVOIRS and FLOOD PROTECTION - http://www.Vetiver.org/TVN_archive.htm" \l "Anchor-RIVERS-13458

LINKS TO WELL ILLUSTRATED WEBSITES

- http://picasaweb.google.com/VetiverClients/VetiverSystemsOverview

http://picasaweb.google.com/VetiverClients/VetiverSystemsThePlant

PART 1

The Vetiver Plant

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1. INTRODUCTION

The Vetiver System (VS) is based on different applications of Vetiver grass (*Vetiveria zizanioides* L, now reclassified as *Chrysopogon zizanioides* L), and was first introduced 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's extraordinary characteristics, VS can now be 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 stabilisation and rehabilitation, and phyto-remediation. Being vegetative it is also environmental friendly.

When planted in rows Vetiver plants will form a hedge that 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 hedge can do this, Vetiver grass, due to its extraordinary and unique morphological and physiological characteristics mentioned below, can do it better than all other systems tested and over a very wide range of climatic and ecological conditions.

Additionally, 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 stabilisation.

2. SPECIAL CHARACTERISTICS OF VETIVER GRASS

2.1 Morphological characteristics

- Vetiver grass doe not have an above ground or underground stem, but it does have a 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.
- Highly resistance to pests, diseases and fire.
- The ability to form a dense hedge 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 upward with the deposited silt eventually forming terraces, if trapped sediment is not removed.


Picture 1: Erect and stiff stems, forming 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 -14^{o}C to +55^{o}C .

- 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 of tropical grasses, 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, stabilises the erodible ground (particularly steep slopes), then improves its microenvironment so other volunteer or sown plants can establish later. Because of these characteristics Vetiver can be considered as a nurse plant on disturbed lands.

Picture 2: Vetiver grass surviving forest fire; right: two months after the fire

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

Picture 4: On extreme acid sulfate soil in Tân An (left) and alkaline and sodic soil in Ninh Thuận (right)

2.4 Cold weather tolerance of Vetiver grass

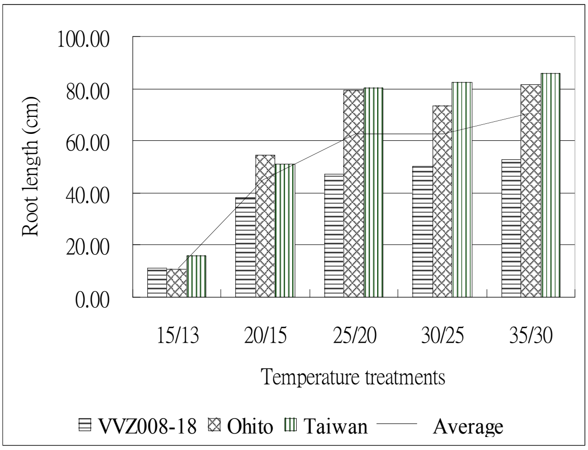
Although Vetiver is a tropical grass, it can survive and thrive under extremely cold conditions. Under frosty weather its top growth dies back but its underground growing points survive. In Australia, Vetiver growth was not affected by severe frost at –14^{o}C and it survived for a short period at –22^{o}C in northern China. In Georgia (USA), Vetiver survived in soil temperature of -10^{o}C but not at -15^{o}C. Recent research showed that 25^{o}C was optimal soil temperature for root growth, but Vetiver roots continued to grow at 13^{o}C. Although very little shoot growth occurred at the soil temperature range of 15^{o}C (day) and 13^{o}C 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 5^{o}C (Fig.1).

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) Salinity (50% yield reduction) Salinity (survived) Aluminum level (Al Sat. %) Manganese level Sodicity Magnesicity	 3.3-9.5 17.5 $mScm^{-1}$ 47.5 $mScm^{-1}$ Between 68% - 87% > 578 $mgkg^{-1}$ 48% (exchange Na) 2400 $mgkg^{-1}$ (Mg)	 4.2-12.5 (high level soluble Al)
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
Heavy Metals Arsenic (As) Cadmium (Cd) Copper (Cu) Chromium (Cr) Nickel (Ni) Mercury (Hg) Lead (Pb) Selenium (Se) Zinc (Zn)	 100 - 250 $mgkg^{-1}$ 20 $mgkg^{-1}$ 35 - 50 $mgkg^{-1}$ 200 - 600 $mgkg^{-1}$ 50 - 100 $mgkg^{-1}$ > 6 $mgkg^{-1}$ > 1500 $mgkg^{-1}$ > 74 $mgkg^{-1}$ >750 $mgkg^{-1}$	
Location	15^0S to 37^0S	41^0N - 38^0S
Climate Annual Rainfall (mm) Frost (ground temp.) Heat wave Drought (no effective rain)	 450 - 4000 -11^0C 45^0C 15 months	 250 - 5000 -22^0C 55^0C
Palatability	Dairy cows, cattle, horse, rabbits, sheep, kangaroo	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 fiber 7.1%



Genotypes: VVZ008-18, Ohito, and Taiwan, the later 2 are basically the same as Sunshine. _Temperature treatments:_ day 15 °C /night 13 °C. (PC: YW Wang)

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

2.6 Genetic characteristics

There are three Vetiver species that are being used for environmental protection purposes.

2.6.1 Vetiveria zizanioides L reclassified as Chrysopogon zizanioides L

There are two *V. zizanioides* genotypes found in the Indian sub continent:

- the wild and seeded north Indian genotype.
- the sterile or very low fertility south Indian genotype.

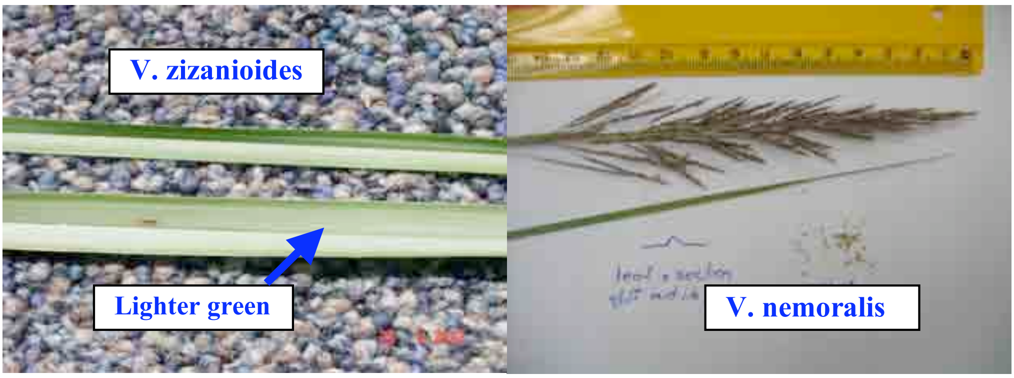
The north Indian genotype grows wild in the swampy, wetlands of northern India's Gangetic basin and it is used mainly for essential oil production in the region, not for soil conservation purposes. The south Indian genotype is the main cultivar used for essential oil production and this is the genotype that being used around the world for soil and water conservation purposes because of its unique and desirable characteristics already mentioned.

Recent results of the Vetiver Identification Program, by DNA typing have shown that of the 60 samples submitted from 29 countries outside South Asia, 53 (88%) were a single clone of *V. zizanioides*. The 53 samples tested came from North and South America, Asia, Oceania and Africa. Most interestingly among these cultivars are: Monto (Australia), Sunshine (USA), Vallonia (South Africa) and Guiyang (China). The implications are that, once the genotype is identified, all our R, D and A (Application) can be shared around the world. For example, as all Vetiver research conducted in Australia have been based on Monto Vetiver, all the Australian results presented in this paper can be applied with confidence in Vietnam when the correct Vetiver cultivar is used.

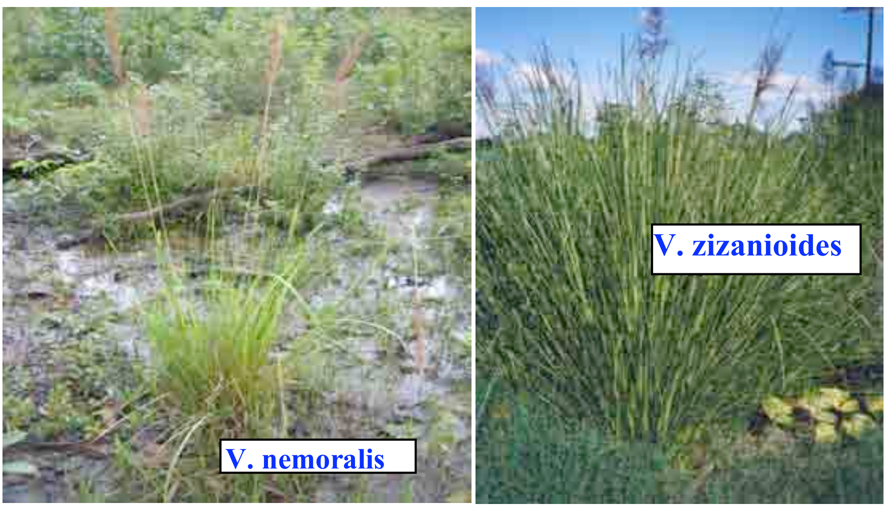
As the Vetiver available and being widely used in Vietnam came either from the Philippines or Thailand, it belongs to the sterile south Indian genotype. V. zizanioides is generally known in Vietnam as 'Vetiver' or 'Vectiver'.

2.6.2 Vetiveria 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 *V. nemoralis* and *V. zizanioides,* are that the latter is much taller and has thicker and stiff stems, *V. 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.



Picture 5: Vetiver leaves, left: V. zizanioides, right: V. nemoralis



Picture 6: Vetiver Shoots, left: V. nemoralis, right: V. zizanioides

Picture 7: Difference between V. zizanioides and V. nemoralis roots

Picture 8: V. zizanioides roots grown in soil (left and center) and in water (right)

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

Picture 9: V. nemoralis in Quang Ngai (left) and on Central Highlands (right)

Picture 8: Vetiveria nigritana in Mali, West Africa

2.6.3 Vetiveria 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 is a non-aggressive plant; it produces neither stolons nor rhizomes and has to be established vegetatively by root (crown) subdivisions or slips. It is imperative that any plants used for bioengineering purposes will not become a weed in the local environment. A sterile plant such as Vetiver is ideal for this application. In Fiji where Vetiver grass was introduced to the country for more than 100 years and it has been widely used for soil and water conservation purposes for more than 50 years, Vetiver grass has not become a weed in the new environment. Vetiver grass can be killed easily either by spraying with glyphosate (Roundup) or uprooting and drying out.

3. CONCLUSION

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

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http://picasaweb.google.com/VetiverClients/VetiverSystemsOverview
http://picasaweb.google.com/VetiverClients/VetiverSystemsThePlant

PART 2

Propagation methods of Vetiver

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1. INTRODUCTION

In most major applications, a large number of plants are required and the quality of the planting material is one of the most important criteria for successful application of the Vetiver System (VS). Therefore the establishment of nurseries capable of producing large quantity, high quality and low cost of planting materials are essential. TVNI recommends the use of the sterile Vetiver cultivar to avoid it becoming a weed in the new environment. DNA tests showed that the sterile Vetiver cultivar used around the world is genetically similar to the Sunshine cultivar in the US and Monto in Australia, both of which originated from southern India. Because of its sterility, the grass has to be propagated vegetatively.

2. VETIVER NURSERY

A nursery is needed to provide stock materials for vegetative and tissue culture propagation of Vetiver grass. The following are criteria needed to plan and establish a productive and easily managed Vetiver nursery:

- ***Soil type**:* For the ease of harvesting and minimizing root and crown damages, sandy loam to loam is the best. Clay loam is acceptable but heavy clay is not recommended.
- ***Topography**:* Slightly sloping land is recommended to avoid water logging in case of over watering. Flat sites are acceptable but watering must be monitored to avoid water logging, which will affect young plantlet growth. Vetiver will grow well under water logging conditions when mature, but young plantlets growth will be affected by water logging after planting.
- ***Shading:*** Shading will affect Vetiver growth, hence open space is recommended, but partially shaded areas are acceptable.
- ***Planting layout**:* Planting should be done in long and neat rows across the slope for easy mechanical harvesting.
- ***Harvesting method**:* Harvesting the mature plants can be done either mechanically or manually. For machine harvesting, the mature stock should be uprooted at 20-25cm below ground. Care must be taken to avoid damaging the crown of the plants; this can be best done by a single blade mouldboard plough or a disc plough with special adjustment.
- ***Irrigation method**:* Overhead irrigation is recommended to evenly distributing water in the first few months after planting. Flood irrigation can be used later on more mature plants.
- ***Training of operational staff**:* Availability of well trained staff is essential to the success of the nursery
- ***Mechanical planter**:* For large scale planting at the nursery, a modified

seedling planter can be used for Vetiver planting.
- ***Availability of farm machinery**:* Some basic farm machinery is needed for seedbed preparation, weed control, cutting, harvesting etc.

Picture 1: Machine planting on the left and manual planting on the right

3. METHODS OF PROPAGATION

The four commonly used methods for propagation of Vetiver are:
- Splitting mature tillers from a mother Vetiver plant or clump to produce bare root slips for immediate planting or polybags growing.
- 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 for large scale propagation.

3.1 Splitting mature tillers to produce bare root slips

The splitting from the mother clumps has to be done carefully so that each slip has at least 2 to 3 tillers (shoots) and a part of the crown, the shoots are then cut back to 20 cm length. After splitting the bare root slips can be dipped in various treatments such as rooting hormones, manure slurry (cow or horse tea), clay mud or just keeping in shallow water pools until new roots start growing. The slips should be kept in good sun light for faster growth and should be kept wet until planting out.

Figure 1: How to split Vetiver slips

3.2 Plant parts propagation

There are 3 parts of the Vetiver plant that can be used for propagation as shown below:

- Vetiver tillers or shoots.
- Vetiver crown or corms are the hard part of the plant between the shoots and the roots.
- Vetiver culms.

Picture 2: Bare root slips ready for planting out (left); dipping in clay mud or manure slurry (cow tea) (right)

A culm is defined as a stem an/or stalk of various grasses. The culm of the Vetiver grass is solid (not hollow), stiff, hard, having prominent nodes with lateral buds that can form roots and shoots upon exposure to moist condition. Laying or standing the cut pieces of culms on moist sand, or better under mist spray, results in the rapid formation of roots and shoots at each node. The following method of propagation was developed by Mr Le Van Du, Agro-Forestry University, Ho Chi Minh City.

The four steps are:

- preparation of Vetiver cuttings
- spray with water hyacinth solution (10%)
- cover the cutting completely with plastic bags and leave it for 24 hours
- plant out with manure, in a good seed bed.

3.2.1 Preparation of Vetiver cuttings

Picture 3: Old tillers (left) and young tillers (right)

Picture 4: Vetiver crown or corms (left) and Vetiver culms (right)

Vetiver culms:
Select old culms as they have more mature buds and more nodes than young culms. Cut culms to 30-50mm lengths, with 10-20mm below the nodes, strip off old leaf cover. In most cases, new shoots emerged one week after planting.

Vetiver tillers:
- Select mature tillers with at least 3 or 4 well developed leaves
- Separate tillers carefully to include the bases and some roots.

Vetiver crown or corms:
This is the base of a mature Vetiver plant where new shoots will start. Use only the top part of the crown. Using the mature crown is better.

3.2.2 Preparation of water hyacinth solution

Water Hyacinth solution contains a lot of hormones and growth regulators such as gibberellic acid, many Indol-Acetic compounds (IAA):

- Remove Water Hyacinth from lakes or canals.
- Put into 20 litre-plastic bag, tie the bag .
- Leave it for about 1 month until Water Hyacinth decomposes completely.
- Discard the solid parts and keep the solution only.
- Strain the solution and keep it in a cool place until use.

Picture 5: Spraying with water hyacinth solution (10%)

3.2.3 Treatment and planting

Picture 6: Cover cuttings completely with plastic bags, leave it for 24 hours

Picture 7: Planting out with manure, in a good seed bed

3.2.4 Advantages and disadvantages of bare root slips and culm slips

Advantages:

- Very efficient, low cost and fast to prepare the planting material.
- Small volume for transport, i.e. lower delivery cost.
- Very easy to plant out by hand.
- Can be mechanically planted out for large areas.

Disadvantages:

- Vulnerable to dryness and extreme temperature .
- Limited storage time on site .
- Need to be planted to moist soil.
- Need more frequent irrigation in the first few weeks.
- Recommended for good seedbed 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 of bud multiplication.
With this method there are four micro propagation stages, all in liquid medium:

- Inducement of lateral bud development.
- Multiplication of new shoots.
- Promoting root development on new shoots.
- Promoting growth in shade house or glasshouse.

The full details of this method are described in Lê Vãn Bé *et al*, 2006.

3.4 Tissue culture

Tissue culture is another method of large scale propagation of Vetiver planting materials. Instead of using a large part of the mother clumps, tillers and culms, tissue culture uses only some special tissues of the Vetiver plant, such as shoot tips, young flower inflorescences or nodal bud tissue. The procedure is fairly routine in the horticultural industry around the world. The tissue culture methods varies with the individual laboratories, but basically it involves the use of a very small bit of tissue, growing it in a special medium under aseptic conditions, plant the very small plantlets out to appropriate medium until fully developed into a small plant. For more details, refer to Truong (2006).

4. PLANTING MATERIAL PREPARATION

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 put in small pots or small plastic bags containing half soil and half potting mix. They are kept in these polybags for 3-6 weeks, depending on the temperature conditions. They are ready for planting out when at least 3 new tillers or shoots appear.

Picture 8: Bare root slips and tube (left), putting in polybags (middle) and polybags ready for planting (right)

4.2 Planting strip

Planting strips are a modified form of polybags, instead of individual bags, bare root slips or culm slips are planted at close spacing in specially prepared long furrow medium, which would facilitate transportation and planting. It is a labour saving practice at planting on difficult sites such as steep slopes, with high survival rate since the roots are not disturbed as in the case of using polybags.

Picture 9: Strips in containers (left), removed from containers (middle) and ready for planting (right)

Advantages and disadvantages of polybags and planting strips
Advantages:

- Very hardy and is not affected to exposure to high temperature and moisture stress
- Lower irrigation frequency after planted out
- Faster establishment and growth after planted out
- Longer period of storage time on site
- Recommended for harsh and hostile environments.

Disadvantages:

- More costly to produce
- Longer period to prepare, 4 -5 weeks or more
- Large volume and heavy load for transport, i.e. higher delivery cost
- More maintenance cost at site after delivery, if not planted out within a week.

5. NURSERIES IN VIETNAM

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

Picture 10: In the south, left: Can Tho University; right: An Giang province

Picture 11: In the centre south, in Quang Ngai (left) and Binh Phuoc (right)
Picture 12: Left: in the centre north, Quang Binh; right: along HCM highway
Picture 13: In the north, in Bac Ninh (left) and Bac Giang (right)

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PART 3

Vetiver System for natural disaster reduction and infrastructure protection

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

Besides soil erosion, many other types of natural disasters can be reduced or even eliminated by using Vetiver System (VS), e.g. landslides, road batter instability, erosion of river banks, canals or coastline, erosion of dikes, dam etc.

Heavy rains saturate rocks and soils, causing a lot of landslides and debris flows in many mountainous areas of Vietnam. Typical examples are the catastrophic landslides, debris flows and flashflood in Muong Lay district, Dien Bien province in 1996, the landslide on the Hai Van Pass in 1999, causing disruption of North-South traffic for more than half a month and costing more than 1 million USD for remedy. Vietnam's largest landslides, sized more than 1 million cubic meters, in Thiet Dinh Lake, Hoai Nhon district, Binh Dinh province, in An Nghiêp and An Linh communes, Tuy An district, Phu Yen province etc caused not only property damage but also losses of life.

River bank and coastal erosion, and dike failure are frequent events throughout Vietnam. Typical examples include: river bank erosion in Phu Tho, Hanoi; coastal erosion in Hai Hau district, Nam Dinh province; river bank erosion in several Central Vietnam provinces e.g. Thua Thien Hue, Quang Nam, Quang Ngai, Binh Dinh; and river bank and coastal erosion in the Mekong Delta etc. These events usually occur in the rainy season, along with floods/storms disasters, but in some cases, as observed in Hau Vien village, Cam Lo district in Quang Tri province river bank erosions also take place during the dry season, when the water level reached its lowest level.

These landslides become more common in areas where human activities play the decisive role. Nearly 200 km of more than 1000 km of the Ha Tinh - Kon Tum section of the Ho Chi Minh Highway are highly susceptible to landslide or slope instability, due mainly to the failure to understand the unfavorable geological conditions and the poor road construction practice. Many landslides take place recently in Yen Bai, Lao Cai, Bac Kan towns because local people cut at increased slope gradients for more housing space.

Landslides in Vietnam can also take place during major earthquakes such as those occuring in 1983 in Tuan Giao district, or in 2001 along the route from Dien Bien town to Lai Chau district.

From the economic point of view, the remediation of these measures is very expensive and the State budget for such works is never sufficient. For example, river bank revetment costs usually 200,000-300,000 USD/km, sometimes up to 0.7-1.0 million USD/km. An extreme case is the Tan Chau embankment in the Mekong Delta that costs nearly 7 million USD/km. It has been estimated that river bank protection in Quang Binh province alone would require more than 20 million USD, whereas the annual budget is only 300,000 USD. Construction of sea dike costs usually 0.7-1.0 million USD/km but more expensive sections costing up to 2.0-2.5 million USD/km are not rare. After the recent storm No. 7 in September 2005 that washed away many dike sections, some dike managers believe that even such improved dike systems are not strong enough (capable to withstand storms of up to 9th level only) and they begin to talk about constructing stronger sea dikes (capable to withstand storms of up to 12th level) that would cost about 7-10 million USD /km. Budget constraints always exist and as a result, structural, rigid protection measures can only be localized, for the most acute sections, and can never be extended to the full length of the river bank/coastline. The problems are thus compounded and seriously challenges the present concept of river bank and/or coastal protection using only localized, structural, rigid measures).

Each of these events represents some type of slope failure or mass wasting, reflecting the down slope movement of rock debris and soil in response to gravitational stresses. Such movement can be very slow, barely perceptible over years, or devastatingly rapid and apparent within minutes. Whether or not these types of natural disasters occur depends on many causes and therefore, to reduce their impact, especially by using bioengineering methods - the VS - we should understand these causes as well as some basic principles of slope stabilization.

2. GENERAL PRINCIPLES ON SLOPE STABILITY AND SLOPE STABILIZATION

2.1 Slope profile

Some slopes are gradually curved, while others are extremely steep. Profiles of naturally-eroded slopes are primarily dependent on climate and rock/soil type.
For resistant rock/soil, especially in arid regions, the chemical weathering is slow while physical weathering prevails. The crest of the slope is slightly convex to angular, the cliff face is nearly vertical, and a debris slope is present

at an angle of repose of 30-35°, i.e. the maximum angle at which loose material 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, while its base is concave.

2.2 Slope stability

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

For such slopes, their stability is based on the interplay between two types of forces, driving forces and resisting forces. Driving forces promote down slope movement of material, whereas 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 erosion of bank and instability of water retaining structures should be treated separately from other types of slope failure as the load on them is different. In our opinion, however, they are subject to one and the same interaction between the “driving forces” and the “resisting forces”, and failure will occur when the first overcome the later.

In fact, erosion of bank and instability of water retaining structures is slightly more complicated, being the result of interactions between hydraulic forces acting at the bed and toe, and gravitational forces acting on 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, or dispersed as wash load, or deposited along the toe of the bank 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, increases in bank height due to near-bank bed degradation or increases 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 the bank material properties and the geometry of the bank profile, they may fail by 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, as well as piping - and sapping-type failures, associated with stratified banks and adverse groundwater conditions.

2.2.3 Driving forces

The main driving force is gravity which, however, it can not act alone. Slope angle, climate, slope material, and especially water contribute to its effect:

- Failure occurs much more frequently on steep slopes than on gentle slopes.
- Water plays a key role in producing slope failure:
  - In the form of rivers and wave action, water erodes the base of slopes, removing support, which increases driving forces.
  - Water can also increase the driving force by loading, i.e. filling previously empty pore spaces and fractures, adding to the total mass subjected to the force of gravity.
  - The presence of water results in the so-called pore water pressure which reduces the shear strength of the slope material. More importantly, abrupt changes (both increase and decrease) in pore water pressure are believed to play the decisive role in causing slope failure.
  - Interaction of water with surface rock and soil (chemical weathering) slowly weakens slope material, reducing its shear strength, therefore reducing resisting forces.

2.2.4 Resisting forces

The main resisting force is the material's shear strength, a function of cohesion (ability of particles to attract and hold each other together) and internal friction (friction between grains within a material), which acts oppositely of 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 type of movement and material involved different types of slope failure may result as show in the Table 1.

Table 1: Different types of slope failure

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

Usually in rock fall and translational slide (involving one or more planes of weakness) will occur. On the other hand, as soil is more homogenous, without any visible plane of weakness, rotational slide or flow often occur. In general, most mass wasting involves more than one type of movement, e.g. upper slump and lower flow, or upper soil slide and lower rock slide etc.

2.4 Human impact on slope failure

Landslides are natural occurring phenomena. Landslides, or slope failure, occur whether people are there or not! However, human land-use does have a major impact on slope processes. The combination of uncontrollable natural conditions (earthquakes, heavy rainstorms, etc.) and artificially altered landforms (e.g. excavation into a slope, forest destruction, urbanization etc.) can result in disastrous slope failures.

2.5 Mitigation of slope failure

Minimizing slope failure requires three steps: 1. identification of potentially unstable areas, 2. prevention of slope failure, and 3. corrective measures when a slope failure occurs. Proper understandings of geological conditions are of utmost importance for the best mitigation practice.

2.5.1 Identification

Identification is usually accomplished by scientists by: 1. studying aerial photographs to determine sites of previous landslides or slope failures, and 2. 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 surface) covered by younger trees, water seeps, and areas where landslides have previously occurred. The information is then used to generate a hazard map depicting the various landslide-prone areas.

2.5.2 Prevention

Prevention of landslides and slope instability is much more cost effective than correction. Many methods are available for such purpose e.g. controlling drainage, reducing slope angle and slope height, providing vegetative cover, retaining wall, rock bolt, shotcrete (concrete but with finer grains/aggregate, so that you can use a powerful pump to apply; it contains admixture for fast solidifying). It is important to ensure that these methods are correctly and appropriately applied; applying them just as supporting and additional measures, ensuring first (at least temporary) that the slope is internally and structurally stable. All these again require a good understanding of the local geological conditions.

2.5.3 Correction

Correction of some landslides is possible by installing a drainage system, which reduces water pressure in the slope, thereby preventing further movement. On the other hand, slope instability problems along roads and other important places must be treated and this is usually very costly. If properly done, surface and subsurface drainage would be very effective but usually this is often neglected and instead, much more rigorous and expensive methods are used.

At present in Vietnam, the use of structural, rigid protection measures e.g. concrete or rock riprap bank revetment, groins, retaining walls etc. for slope stabilization, river bank and coastal erosion control is the most popular. These have been continuously used for several decades, but slopes continue to fail, and erosion becomes more severe. So what are the main weaknesses of these measures?

From an economic point of view, these measures are very expensive, as mentioned in the introduction, and the State budget for such works can never be sufficient. From technical and environmental perspectives, one may notice the following concerns:

- Rock/concrete is mined/produced elsewhere, where it can cause environmental problems;
- Localized structural, rigid measures do not absorb flow/wave energy. More correctly, their main problem is that they cannot follow the local settlement, and thus causing strong gradients. Strong gradients cause additional turbulence, and consequently additional erosion. Moreover, being localized, these measures more than often end up abruptly, i.e. they do not transit gradually and smoothly to the natural bank. Thus, they tend to displace erosion to another place, to the opposite side or downstream. In so doing, they even aggravate the disaster, rather than reducing it for the river as a whole. Typical examples of these can be found in several provinces in Central Vietnam;

- Structural, rigid measures bring in considerable amounts of stone, sand, cement into the river system, disposing and displacing large volumes of bank soil into the river; all eventually causing the river to become full, changing river bed dynamics, raising the river floor, and thus worsening flood and bank erosion problems. It is especially the case in Vietnam where workers throw the waste soil directly into the river while re-shaping the bank. Often they dump stone pieces directly into the river, at the toe of unstable bank to stabilize it. Sometimes, workers try to lay rock pieces on the river bed, considerably reducing the flow depth. And finally, after such embankments fail, a lot of remnants of rock baskets, groins etc. are scattered in the water;
- Rigid structures are not compatible with the soft ground particularly on erodible soils. As the latter is consolidated and/or eroded and washed away, it undercuts the upper rigid layer. This occurred in many places such as the right bank immediately downstream of the Thach Nham Weir (Quang Ngai province), where it cracked and collapsed. Engineers try to replace concrete plates with rock rip-rap with or without concrete frames which, however, leaves the problem of subsurface erosion unsolved. A very typical example can be seen along the Hai Hau sea dike, where the whole section of rock rip-rap collapsed as the foundation soil underneath was washed away;
- Rigid structures can only temporarily reduce erosion but they can not help stabilize the bank in case of big landslides with deep failure surface;
- Concrete or rock retaining walls are probably the most common engineering method applied for road batter stabilization in Vietnam. Most

of these walls are, however, passive, waiting for the slopes to fail. When they do fail, they also cause the walls to fail as seen in many cases along the Ho Chi Minh Highway;
- Rigid structures like rock embankments are unsuitable for certain applications such as sand dune stabilization. They are, however, in some cases, still being built, as can be observed along the new road in central Vietnam.

2.6 Vegetative slope stabilization

The use of vegetation as a bio-engineering tool for land reclamation, erosion control and slope stabilization has been implemented for centuries and its popularity has increased remarkably in the last decades. This is partly due to the fact that more knowledge and information on vegetation are now available for application in engineering designs, but also partly due to the cost-effectiveness and environment-friendliness of this "soft", bio-engineering approach.

Under the impact of several factors as presented above, a slope will become unstable due to: 1. surface erosion; and 2. internal structural weaknesses. Surface erosion often leads to rill and gully erosion, which with time will deteriorate the slope stability, while structural weakness will cause mass movement or land slip. Thus, in the long run, surface erosion can also cause slope failure and, therefore, slope surface protection should be considered as important as other structural reinforcements. In a way, slope surface protection is a kind of preventive measures whereas the latter are corrective ones. In many cases, it is sufficient just to apply some preventive measures to ensure the slope stability, which always cost much less than corrective ones.
Normally a good vegetative cover provided by grass seeding or hydro seeding/ hydro mulching is quite effective against surface 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 rill and gully erosion can still occur on even well vegetated slopes. Deep rooted trees are slow and often difficult to establish on such hostile environment. For these, engineers often blame the inefficiency of the vegetative cover and tend to apply structural re-enforcement soon after construction. In short, numerous experiences have shown that traditional slope surface protection by using local grass and trees, in many cases, can not ensure the needed stability.

2.6.1 Some 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 area ration, 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 stabilization in Vietnam

Along with rigid structural measures, softer solutions, using vegetation have also been tried in Vietnam, though to a much less extent. For river bank erosion control, the most popular bio-engineering method is probably the planting of bamboo, while for coastal erosion, mangrove, casuarinas, wild pineapple, nipa palm etc. are also being used. However, applications of these plants have shown some major weak points, for example:

- Growing in clumps, bamboo can not provide closed hedgerows. The flood water tends to concentrate at gaps in-between clumps, where the water destructive power increases, thus causing more erosion to occur;
- Bamboo has only a shallow (1-1.5 m deep) bunch root system, that are not in balance with the high, heavy canopy. Therefore clumps of bamboo put an additional heavy surcharge on a river bank, without contributing to the bank stability;
- With the bunch root system of bamboo, in many cases erosion undermines the soil below, creating conditions for larger landslides to take place. Examples of bank failure with extensive bamboo strips can be seen in several provinces in Central Vietnam;
- Mangrove trees, where they can grow, form a very good buffer zone to reduce wave power, thus reducing coastal erosion. However, establishment of mangrove is difficult and slow as its seedling is eaten by mice, and thus, of the hundreds of hectares planted, only a small part can develop 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. Similarly, wild pineapple is also planted along banks of rivers, streams and other channels as well as along the contour lines of dune slopes. But they are good mainly for reducing wind power and respectively, sand storm but not sand flow as they do not form closed hedgerows and do not have deep root systems. Examples of building sand

dikes along flow channels in Quang Binh province, with casuarinas and wild pineapple trees on top ended with obvious failure as the sand fingers continues to invade arable land. Moreover, experiences also show that casuarinas seedlings can hardly survive sporadic but extreme cold winter (less than $15^{o}C$) while wild pineapple dies from extremely hot summer in North Vietnam.

Fortunately, Vetiver grass is fast growing, can establish under very adverse conditions, and together with its very extensive and deep root system can provide the structural strength needed in a relatively short period of time. Thus, in many cases Vetiver grass can be a very good alternative, with only one thing to keep in mind - that although being very versatile, Vetiver is not an all-purpose recipe and the application technique should be learned and used with care.

3. SLOPE STABILIZATION USING VETIVER SYSTEM

3.1 Special characteristics of Vetiver grass suitable for slope stabilization

The following unique attributes of Vetiver grass have been researched, tested and developed into a very effective bioengineering tool for slope stabilization:

- Although classified as a grass, for land stabilization purposes, Vetiver plants behave more like fast growing trees or shrubs. Per unit area Vetiver roots are stronger than tree roots.
- Extremely deep and massive finely structured root system, capable of reaching down to 2 to 3m in the first year. Many experiments show Vetiver grass can reach 3.6m in the first 12 months on fill slope. This extensive and thick root system binds the soil and at the same time makes it very difficult to be dislodged and extremely tolerant to drought (Note that the grass certainly may not penetrate too far down into the groundwater table. Therefore at locations with high groundwater level, its root system may not be as long as in drier soil).
- Vetiver roots have very high tensile strength, which are as strong as, or even stronger than that of many hardwood species, which have been proven positive for root reinforcement in steep slopes.
- These roots have a mean design tensile strength of about 75 Mpa, which is equivalent to 1/6 of mild steel reinforcement and a shear strength increment of 39% at 0.5m depth.

- Vetiver roots can penetrate compacted soil profile such as hardpan and blocky clay pan common in tropical soils, providing a good anchor for fill and topsoil.
- It forms dense hedges when planted close together, reducing flow velocity, spreading and diverting runoff water and forming a very effective filter for erosion control. The hedges slow down the flow, allowing more time for water to infiltrate into the ground.
- Acting as a very effective filter, Vetiver hedges help reduce the turbidity of surface run-off. New roots are developed from nodes when buried by trapped sediment. Vetiver will continue to grow with the new ground level eventually forming terraces, if trapped sediment is not removed. In addition, this sediment can also contain seeds of local plants hence facilitating the latter's growth.
- Tolerance to extreme climatic variation such as prolonged drought, flood, submergence and extreme temperature from -14^{o}C to 55^{o}C (Truong *et al*, 1996).
- Ability to re-grow very quickly after being affected by drought, frost, salt and other adverse soil conditions when the adverse effects are removed.
- High level of tolerance to soil acidity, salinity, sodicity and acid sulfate conditions (Le van Du and Truong, 2003).

Vetiver grass is very effective when planted closely enough in rows. Natural slopes, cut slopes and filled embankments can all be stabilized by planting Vetiver grass in contour lines. The deep, rigorous root system helps stabilize the slopes structurally while its shoot helps spread out the surface run-off, reduce erosion and trap sediments to facilitate the growth of native species (Picture 1).

Picture 1: Forming a thick and effective bio-filter

Hengchaovanich (1998) also observed that Vetiver can grow vertically on slope steeper than 150% (~56^{o}). It can grow faster and impart more reinforcement, making it a better candidate for slope stabilization than other plants. Another less well known characteristic which sets it apart from other tree roots is it power of penetration. Its ‘innate’ strength and vigor enable it to penetrate through difficult soil, hard pan or rocky layer with weak spots. It even managed to punch through asphalt concrete pavement. According to the same author, indeed one can say that Vetiver roots basically behave like living soil nails or dowels of 2-3m depth, commonly used in ‘hard approach’ slope stabilization work. Together with its fast growing ability in difficult soil conditions, these characteristics make the grass a much better candidate for slope stabilization than other plants.

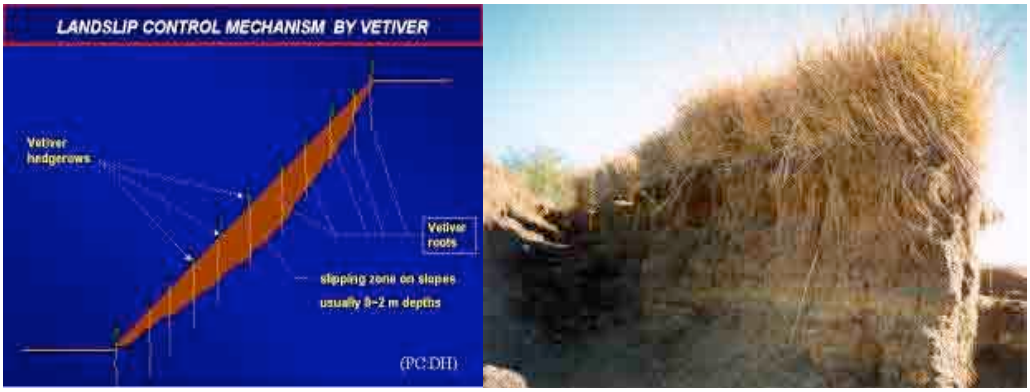


Figure 1: Principles of slope stabilization by Vetiver grass. Vetiver roots reinforce this dam wall from being washed away by flood

3.2 Additional special characteristics of Vetiver grass suitable for water disaster mitigation

To reduce water disasters such as flood, river bank and coastal erosion, dam and dike instability etc., Vetiver grass is planted in rows either parallel or across the water flow or wave direction. The following additional unique characteristics of the grass are also very useful:

- Due to its extraordinary root depth and strength, once fully established it is extremely resistant to high velocity flow. Experiences in north Queensland (Australia) show that Vetiver grass has withstood flow velocity higher than 3.5m/sec in river under flood conditions and up to 5m/sec in a drainage channel in southern Queensland.
- Under shallow or low velocity flow, the erect and stiff stems of Vetiver can act as a barrier to reduce flow velocity (i.e. increase hydraulic resistance)

and trap eroded sediment. In fact, it can stand erect in the flow as deep as 0.6-0.8m.

- Under deep and high velocity flow Vetiver tops will bend down, providing extra protection to surface soil and at the same time 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, over-topping and consequently the volume of water that may flow in the area protected by these structures. Vetiver hedgerows also help reduce the so-called retrogressive erosion that very often takes place when the water flow or wave retreats back after over-topping water retaining structures.
- Vetiver survives under prolonged submerged conditions as it is a wetland plant. Chinese research showed that Vetiver can survive more than 2 months under clear water.

3.3 Tensile and shear strength of Vetiver roots

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

Figure 2: Root diameter distribution

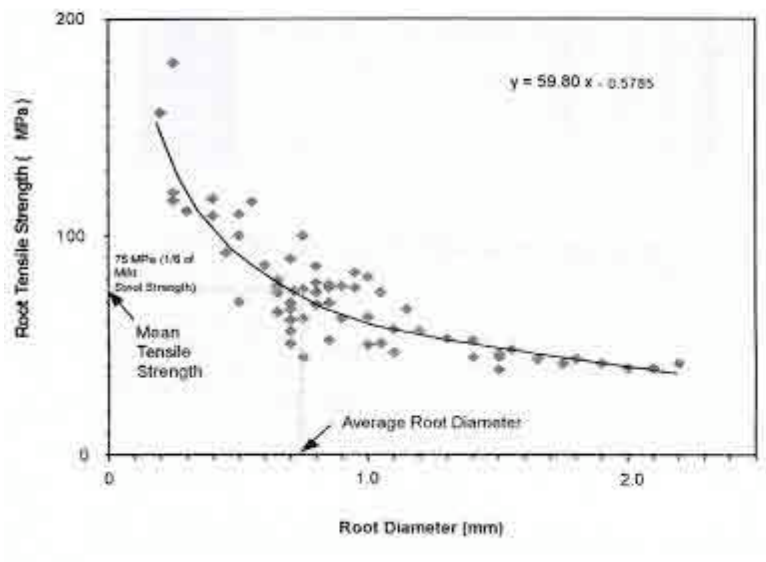


Table 4: Tensile Strength of Roots of Some Plants

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 Grass, Forbs Moss	15-31 2-20 2-7kPa
Vetiveria zizanioides	**Vetiver grass**	**40-120 (average 75)**

In a soil block shear test, Hengchaovanich and Nilaweera (1996) also found that root penetration of a two year old Vetiver hedge with 15cm plant spacing can increase the shear strength of soil in adjacent 50 cm wide strip by 90% at 0.25 m depth. The increase was 39% at 0.50 m depth and gradually reduced to 12.5% at 1.0 m depth. Moreover, because of its dense and massive root system it offers better shear strength increase per unit fiber 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.

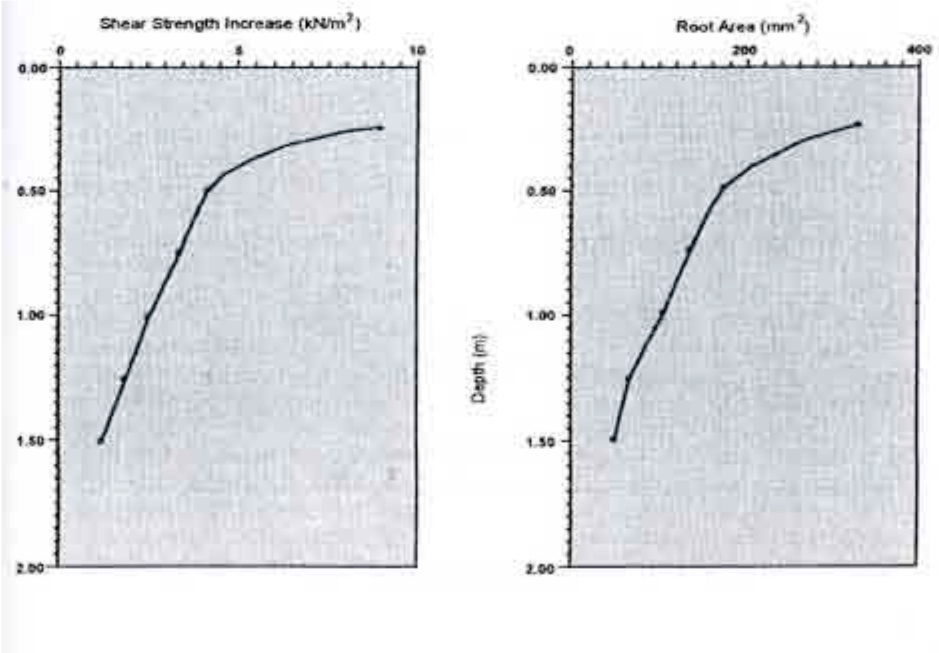


Figure 3: Vetiver root shear strength

Cheng *et al* (2003) supplemented the Diti Hengchaovanich's root strength research by conducting further tests on other grasses as shown in Table 5. Although Vetiver has the second finest roots, its tensile strength is almost 3 times higher than all the plants tested.

Table 5: Diameter and tensile strength of root 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

3.4 Hydraulic characteristics

When planted in rows Vetiver plants will form thick hedges and with their stiff stems these hedges can stand up to at least 0.6-0.8m, forming a living barrier which slows and spreads runoff water. If properly laid out, these hedges can act as very effective diversion structures spreading and diverting runoff water to stable areas or proper drains for safe disposal.

Hydraulic characteristics of Vetiver hedges under deep flows were determined by flume tests at the University of Southern Queensland for the design and incorporation of Vetiver hedges into strip cropping layout for flood mitigation (Fig.4). There Vetiver hedges were successful in reducing flood velocity and limiting soil movement, resulting in very little erosion in fallow strips and a young sorghum crop was completely protected from flood damage (Dalton *et al*, 1996).

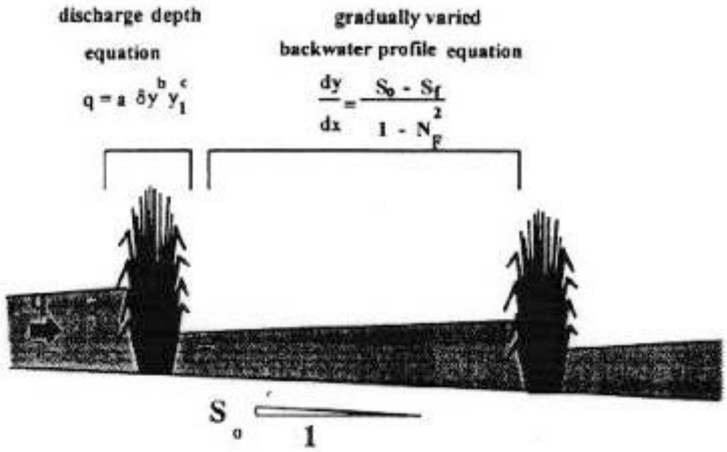


Figure 4: Hydraulic model of flooding through Vetiver hedges

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

Increase in water infiltration is one of the major effects of vegetation cover on sloping lands and there has been concern that the extra water will increase the pore water pressure in the soil which could lead to slope instability. However, field observations show much better counter-effects. First, planted on contour lines or modified patterns of lines which would trap and spread runoff water on the slope, the extensive root system of Vetiver grass helps prevent localized accumulation of surplus water and distribute it more evenly and gradually. Second, the possible increased infiltration is also balanced by a higher, and again, gradually rate of soil water depletion by the grass.

Research in soil moisture competition in crops in Australia (Dalton *et al*, 1996) indicated that under low rainfall condition this depletion would reduce soil moisture up to 1.5m from the hedges thus increasing water infiltration in that zone leading to the reduction of runoff water and erosion rate. From geotechnical perspective, these conditions will have beneficial effects on slope stability. On steep (30-60^{o}) slopes the space between rows at 1m VI (Vertical Interval) is very close, this moisture depletion would be greater and therefore further improves the slope stabilization process. However, in the very high rainfall areas, to reduce this potentially negative effect of Vetiver grass on steep slopes, as an extra protection, 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 Some applications of VS in natural disaster mitigation and infrastructure protection

Because of the above characteristics, in general Vetiver grass is very effective in erosion control of both cut and fill batters and other slopes associated with road construction. Vetiver is 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 stabilization for the following cases:

- Slope stabilization along highways, railways etc., especially effective for mountainous rural roads, where there is not enough funding for road slope stabilization and where the local community often takes part in road construction.
- Dike and dam stabilization, reduction of canal, river bank and coastal erosion etc., and protection of hard structures themselves e.g. rock rip-rap, concrete embankment, gabion etc.
- Slope above culvert inlets and outlets.
- Interface between cement and rock structures and erodible soil surface.
- As a filter strip to trap sediment at culvert inlets.
- As an energy reducer at culvert outlets
- Gully head erosion can be effectively stabilized by Vetiver hedges, when planted on contour lines above gully heads.
- Erosion by wave action can be eliminated by planting a few rows of Vetiver on the edge of the high water mark on big farm dam walls or river banks
- In forest plantation, Vetiver has been used successfully to stabilize shoulders of driving tracks on very slopes as well as gullies developed following harvests.

Also because of the above-mentioned characteristics, Vetiver grass is very effective in controlling water disasters such as flood, coastal and river bank erosion, dam and dike erosion and instability in general and for protection of bridge, culvert abutments and the interface between concrete/rock structures and soil in particular. Vetiver is particularly effective in cases where the embankment fill is highly erodible and dispersible, such as sodic, alkaline, 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. For slope stabilization in China for example, the saving is in the order of 85-90% (Xie, 1997 and Xia et al, 1999). In Australia the cost advantage of VS versus conventional engineering methods ranges from 64% to 72%, depending on the method used (Braken and Truong 2001). In short, the maximum cost is only 30% that of traditional measures.
- As with other bio-engineering technologies, VS provides a natural and environment friendly method of erosion control and land stabilization which 'softens' the harsh look often associated with conventional engineering measures such as concrete and rock structures. This is particularly important in urban and semi rural areas where the visual degradation of the environment caused by infrastructure development is often a major concern of local population.
- VS's maintenance costs are low in the long term. In contrast with conventional engineering structures, the efficiency of bio-engineering technology improves with time as the vegetative cover matures. VS requires a good maintenance program in the first 1-2 years but once established it is virtually maintenance free in the long term. Therefore, the measure is particularly suitable for remote areas where maintenance is costly and difficult.
- Particularly effective in poor and highly erodible and dispersible soils.
- Provides a natural soft bio-engineering technique instead of hard rock/concrete structures.
- Particularly suitable for regions or countries with low cost labor forces.

Disadvantages:

- The main disadvantage of the VS applications is the intolerance to shading by the Vetiver plants particularly in the establishment phase. Partial shading will reduce growth and severe shading can eliminate it in the long term by reducing its ability to compete with more shade tolerant species. However this weakness could be consider as a desirable characteristics in situations where a pioneer plant is needed to provide the initial stabilization, improve the micro environment for the introduction, either voluntarily or by planting of native endemic species.

- Vetiver contour system is only effective when the plants are well established. Therefore an initial establishment period of about 2-3 months in warm weather and 4-6 months in cooler time should be allowed for. This time lag can be overcome by planting early, in the dry season.
- Vetiver grass can be fully effective only when it forms closed hedgerows. Hence, the gaps in between clumps should be timely re-planted.
- It is difficult to plant and water on very high slopes.
- It requires protection from livestock during establishment phase.

Based on the above, it is clear that the advantages of using the VS as a bio-engineering tool outweigh its disadvantages particularly when the Vetiver plant is used as a pioneer species.

There is worldwide evidence to support the use of VS for embankment stabilization. Vetiver has been used successfully in Australia Brazil, Central America, China, Ethiopia, India, Italy, Malaysia, Philippines, South Africa, Sri Lanka, Venezuela, Vietnam, and the West Indies for stabilization of roadsides. Vetiver has been used in conjunction with geotechnical applications for embankment stabilization in Nepal and South Africa.

Combination with other types of remedy

Vetiver grass can be effective by itself or in combination with other traditional methods. For example, for a given section of river bank/dike, the lower, underwater part can be reinforced with rock/concrete riprap and the upper part with Vetiver. This gives an extra feeling of safety (although not always true and necessary).

In addition Vetiver grass can be planted in combination with bamboo, a traditional plant for river bank protection. Experience shows that bamboo alone is not effective because of its several drawbacks, which can be supplemented by Vetiver grass.

3.8 Computer modeling

More recently software developed by Prati Amati, Srl (2006) in collaboration with the University of Milan determines the additional shear strength provided to soil by Vetiver roots in various soils under Vetiver hedges treatments. This software is particularly suitable to assess the contribution of Vetiver roots needed for the application of VS on steep batter stabilization, particularly earthen levees, where Vetiver hedgerows will protect and consolidate the slopes and therefore the levees themselves. In general, under average soil and slope conditions, Vetiver planting will increase slope stability by about 40%. This software gives an estimate of additional shear strength provided to soil by Vetiver roots. To use the software, geotechnical parameters related to that particular slope site are needed, such as:

- type of soil
- slope gradient
- maximum water content
- soil cohesion at minimum cohesion

The software will provide the number of plants per square meter, the distance between the rows depending on the slope gradient. For example:

- on a 30° slope, 6 plants per square meter (i.e. 7-10 plants per meter of row; distance between rows of around 1,7 m) are required
- on a 45° slope, 10 plants per square meter (i.e. 7-10 plants per meter of row; distance between rows of around 1 m) are required.

4. APPROPRIATE DESIGNS AND TECHNIQUES

4.1 Some pre-cautions

It should be stressed that VS is a new technology as any new technology it has to be learnt and applied appropriately for best results. Failure to do so will bring disappointing outcomes and some times adverse results. As a soil conservation technique and recently a bio-engineering tool, the application of VS requires the understanding of biology, soil science, hydraulic and hydrological as well as geotechnical principles. Therefore for medium to large scale operation, this technology is best implemented by experts, who have gained experiences in previous works rather than by local people themselves. However knowledge of participatory approach and community-based management are also very important. Thus, it is best for the technology to be designed and implemented by experienced specialists in Vetiver application, in association with an agronomist and a geotechnical engineer, and with assistance from local farmers.

In addition it should be understood that Vetiver is a grass by botanical classification but it acts more like a tree than a typical grass with its extensive and deep root system. To add to the confusion, VS is able to exploit its different characteristics for different applications, for example deep roots for

land stabilization, thick growth for water spreading and sediment trapping and extraordinary tolerance to various chemicals for land rehabilitation etc.
Failures of VS in most cases can be attributed to bad applications rather than the grass itself or the technology recommended. For example in one instance when Vetiver was used to stabilize batters on a new highway in the Philippines, the results were very disappointing and failures to establish or to stabilize the slopes were common. It later materialized that the engineers who specified the VS, the nursery which supplied the planting materials and the field supervisors and laborers, who planted the Vetiver, had no previous experience or training in the use of VS for steep slopes stabilization.

Experience in Vietnam shows that the use of Vetiver is very successful when it is applied correctly, but improper applications may fail. Experiments in the Central Highlands of Vietnam show excellent protection of road embankment by using Vetiver grass. But mass applications along the Ho Chi Minh Highway, on very high and steep slopes without benches have witnessed some failures.
In brief, to ensure success, decision makers, designers and engineers who plan to use Vetiver System for infrastructure protection should keep in mind some following precautions:

Technical precautions:

- The design should be done or checked by trained people to ensure success.
- The site should be internally stable against the (possible) failure, at least in the first few months before the grass can exert its full effect. The impact of Vetiver grass does not come immediately and the slopes may fail during the intervening period.
- VS is applicable only for earthen slopes with gradients that should never exceed 45-50^o.
- Vetiver grows poorly in the shade so planting directly under a bridge should be avoided if possible.

Pre-cautions for decision making, planning and organization:

- Timing: planning has to take into account the seasons and the time it takes to grow planting materials.
- Maintenance and repair: there will be at an early stage a period in which Vetiver is not yet effective, and also replacement of some plants may be necessary, this needs to be included in the planning and budgeting.
- All inputs can be procured locally (labor, manure, planting materials, maintenance contracts), which is an added advantage for the local community employment and for the protection (at early stages), the quality and sustainability of the works.
- As much as possible, local communities need to be involved in the design, production of planting materials, establishment and protection at early

stages; for this, contracts have to be drawn up with local people (for nurseries, quality/quantity specifications, for maintenance/protection)

- There needs to be sufficient readiness to innovate among decision makers, and for them to take account of the application of VS in the planning and budgeting (and for that, they need incentives to include such cost-effective methods; just as they have incentives - justified or not - to decide on more expensive conventional methods)
- Policy makers should recommend Vetiver System, not be regarded as a fix for locally affected sites (where it can provide a concise and immediate effect), but rather as part and component of a comprehensive approach for infrastructure protection, to be applied on a scale large enough to allow for tangible build up of expertise and a gradual, spreading effect.

4.2 Planting time

Planting time is very crucial for the success and the cost of the project. Planting in dry season will require extensive and expensive watering. Experience in Central Vietnam shows that watering daily or even twice daily is required for extremely harsh conditions in sand dunes. Without watering, the grass does not die but its growth is affected. For mass planting on cut slopes along the Ho Chi Minh Highway, it is difficult to select the best planting time so mechanical watering is required daily for several first few months.
Given the fact that the grass needs 3-4 months to establish, sometimes 5-6 months in adverse conditions, and around 9-10 months to become fully effective, it is advisable to mass plant the grass at the beginning of the rainy season, i.e. nursery time starts during the spring.

Planting during the winter-spring period (especially in North Vietnam) is also possible. In many places in North Vietnam, the temperature can sometimes be lower than $10^{o}C$ and under such conditions although the grass does not grow, it can survive the cold weather and with the winter rain it starts growing immediately when the weather warms up.

In central Vietnam, where air temperature usually stays above $15^{o}C$, another possibility could be that mass planting starts at the beginning of spring, but in this case, nurseries will need more care to ensure good growth and multiplication of the seedlings.

4.3 Nursery

Good quality and sufficient planting materials are a decisive factor for the success of the project. Details on nursing and propagating the grass are discussed in Part 2. In general, large scale nurseries are not necessary in many cases. Several small nurseries (a few hundred square meters each) could be set up to be supervised by individual farmer households. They will be contracted and paid by the project according to the number of seedlings they can provide at request.

4.4 Preparation for Vetiver grass planting

In cases where mass planting of Vetiver grass involves participation of the local people, the following steps are usually taken for a planting campaign:

- Step 1: Site visit and survey by experts to identify problems and applicability of the technology;
- Step 2: Discussion with local people about the problems and alternative solutions;
- Step 3: Introduction of the new technology (workshop, training course);
- Step 4: Organizing the trial implementation (establishment of nursery, contracting etc.);
- Step 5: Monitoring the implementation;
- Step 6: Discussion of pilot results (workshop, field exchange visit etc.);
- Step 7: Organizing mass implementation etc.

In cases where the mass planting is implemented by specialized companies, steps 1, 4, 5 are recommended, but local participation is still very much advisable, at least for awareness raising, avoidance of vandalism and protection from animals.

4.5 Layout specifications

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

For the stabilization of such slopes, the following specifications may apply:

- Bank slope shall not exceed 1(H):1(V), gradient at 1.5:1. Shallower gradients are recommended wherever possible especially on erodible soils and/or in high rainfall areas

- Vetiver shall be planted on approximate contour lines between 1.0-2.0m apart (measured down slope). On highly erodible soil a spacing of 1.0m shall be used which can increase up to 1.5-2.0m on more stable soil.
- First row shall be planted right on the top edge of the batter. This row shall be planted on all batters which exceeds 1.5m in height.
- Bottom row shall be planted at the bottom of the batter and on cut batter along the edge of table drain.
- In between these rows Vetiver shall be planted as specified above.
- Benching or terracing 1-3 m in width for every 5-8 m (vertical interval) is recommended for slopes which are more than 10 m in height.

4.5.2 River banks, coastal erosion and instability of water retaining structures

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

- Maximum bank slope shall not exceed 1.5(H):1(V). Recommended bank slope of 2.5:1. The sea dike system in Hai Hau (Nam Dinh) is built with bank slope of 3:1 to 4:1.
- Vetiver shall be planted in two directions:
  - For bank stabilization, Vetiver shall be planted in rows parallel to flow direction (horizontal), on approximate contour lines 0.8-1.0m apart (measured down slope). In a recent layout specification for the protection of the sea dike system in Hai Hau (Nam Dinh), the spacing between rows is even lowered down to 0.25 m.
  - For reduction of flow velocity, Vetiver shall be planted in rows normal (right angle) to the flow at spacing between rows of 2.0m for erodible soil and 4.0m for stable soil. For the protection of the river dike in Quang Ngai, these normal rows are planted even 1.0m apart.
- First horizontal row shall be planted at the crest of the bank and the last row shall be planted at the low water mark of the bank (Note that at some locations the water level can change a lot seasonally and Vetiver grass can be planted (in the right time) much further down the bank).
- Vetiver shall be planted on the contour along the length of the bank between the top and bottom rows at spacing specified above.
- Due to the high water level, the bottom row may establish more slowly than other upper rows. So if possible, this row should be planted when the soil is driest. For some VS applications for the protection of anti-salinity dikes, the water may become more saline at certain time during the year and this may affect the growth of Vetiver grass. In such cases, experiences in Quang Ngai show that it could be replaced by some local salt-tolerant varieties such as mangrove fern, etc.

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

4.6 Planting specifications

- Dig trenches of about 15-20cm in depth and width.
- Well rooted plants (2-3 tillers each) are to be placed (centered) 100-120mm apart on each row for erodible soils and 150mm for normal soils.
- As the 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. Addition of a bit more of good soil-manure mixture is even better. For natural river bank protection, where the soil is usually good and fertile, and initial watering can be ensured without extra efforts, bare root planting are sufficient.
- Cover roots with 200-300mm of soil and compact firmly.
- Fertilize with Nitrogen and Phosphorus such as DAP (Di Ammonium Phosphate) or NPK at 100g per linear meter row. For acid and sulfate soil, the same amount of lime may be necessary during planting.
- Water within the day of planting.
- To reduce weed growth during establishment phase, pre-emergent herbicide such as Atrazine can be used.

4.7 Maintenance

4.7.1 Watering

- In dry weather water everyday in the first 2 weeks after planting and then every second day.
- Water twice weekly until the plants are well established.
- Mature plants require no further watering.

4.7.2 Replanting

- Replace all plants that fail to establish or wash away during the first month after planting.
- Continue inspections until vegetation is suitably established.

4.7.3 Weed control

- Control weeds, especially vines during the first year.

- Vetiver is very sensitive to glyphosate (RoundUp) herbicide, so this herbicide should not be used to control weed in between rows.

4.7.4 Fertilizing

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

4.7.5 Cutting

Regular cutting (trimming) is also very important when VS is applied. The hedgerows shall be cut down to 15-20 cm above the ground. This simple technique helps to reduce the volume of dry leaves that otherwise can overshadow young seedlings, and thus facilitates the latter's growth. This can also help get rid of the unpleasant appearance of the drying hedgerows, which may also result in undesirable fires.

The cut fresh leaves can also be used for other purposes such as for cattle fodder, for handicraft or even roof thatching etc., but when Vetiver grass is planted for the purpose of natural disaster reduction, it is not recommended to over-use it for other sideline purposes.

The first cutting can be done after 4-5 months, to promote the development of new shoots from the base. Subsequent cuttings can be done twice or 3 times a year. And again, care should be taken to ensure the grass has long leaves during the typhoon season. A good cutting time could be immediately after the typhoon season ends. Another suitable cutting time could be around 3 months before the typhoon season begins.

4.7.6 Fencing and caring

Fencing and caring may be necessary against vandalism and cattle during the first several months when the Vetiver grass is establishing. When the grass has fully established, old stems are hard enough to discourage cattle. Therefore, where necessary, it is advisable to protect the grass by fencing during the first few months after planting.

5. SOME VS APPLICATIONS FOR NATURAL DISASTER REDUCTION AND INFRA-STRUCTURE PROTECTION IN VIETNAM

5.1 VS application for sand dune protection in Central Vietnam

A vast area, more than 70,000 ha, along the coastline of Central Vietnam is covered by sand dunes where the climatic and soil conditions are very severe. Sand fly 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 amount of sand from dunes landward onto the narrow coastal plain. Traveling along the Central Vietnam, one can easily notice giant sand “tongues” that are eating into the plain day by day. The Government has long implemented a forestation program using such varieties as Casuarinas, wild pineapple, eucalyptus, acacia etc. But at most, when fully and well established they may help reduce only blown sand. There was no way yet to reduce sand flow.

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 tried to stabilize sand dunes along the coastline of Central Vietnam. A sand dune was badly eroded by a stream that served as a natural boundary between farmers and a forestry enterprise. The erosion took place for several years, resulting in a mounting conflict between the two groups. Vetiver grass was planted in rows along the contour lines of the sand dune. After 4 months it formed closed hedgerows and the sand dune was stabilized. The forestry enterprise was so happy that it decided to mass plant the grass in other sand dunes and even for the protection of a bridge abutment. The grass further surprised local people by surviving the coldest winter in ten year, when the temperature lowered down below $10^{o}C$, forcing the farmers to replant twice their paddy rice and Casuarinas. After 2 years, local species such as Casuarinas, wild pineapple etc. re-established. The grass itself faded away under the shade of these trees but it has accomplished its mission. The project again proved that with proper care Vetiver grass could survive very hostile soil and climatic conditions (Picture 2).

According to Henk Jan Verhagen from Delft University of Technology (pers. comm.), it may be equally effective using Vetiver grass to reducing blown sand. For this purpose, the grass could be planted across the wind direction, especially at low places in-between sand dunes, where the wind velocity is expected to increase. On China's Pintang Island, off the coast of Fujian Province, vetiver hedges were extremely effective in reducing wind velocity and blow sanmd.

Following the success of this pilot project, a workshop was organized in early 2003 for more than 40 participants from local government departments, different NGOs and Universities of Central Vietnam's coastal provinces. The workshop helped both the authors of this paper and other participants draw useful lessons, especially on planting time, watering, fertilizing etc. After the event, also in 2003 World Vision Vietnam decided to fund another project for introducing Vetiver grass for sand dune fixation in the two Vinh Linh and Trieu Phong districts in Quang Tri province.

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

Picture 2: Sand flow in Le Thuy (Quang Binh) in 1999, exposing the foundation of a pumping station (left) and a 3-room brick house of this woman (right)



Picture 3: Left: site overview; right: early April 2002, one month after planting


Picture 4: Left: early July 2002, four months after planting; right: November 2002: a dense rows of grass established

Picture 5: Left: the nursery; right: mass planting in November 2002

Picture 6: Left: Vetiver grass for protection of bridge abutment along Nat. Highway nr.1; Right, December 2004: Vetiver grass is replaced by local spp

Picture 7: Left: mid-February 2003 post-workshop field trip; the grass looks green even after the coldest in 10 years winter; Right: June 2003: nursery at home; a World Vision Vietnam-sponsored field trip for farmers from neighboring Quang Tri province

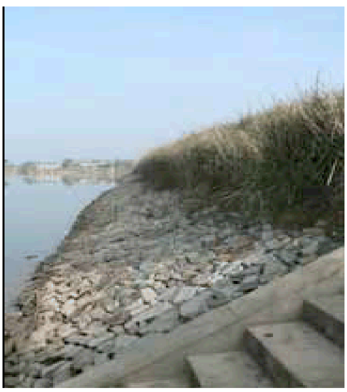
5.2 VS application for river bank erosion control

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 grass was planted to fix erosion of a river bank, bank of a shrimp pond and a road embankment in Da Nang City. Consequently, in October 2002 the local Dike Department also decided to mass plant the grass on more bank sections of several rivers. Furthermore, the city authority decided to fund a project on cut slope stabilization using Vetiver grass along the mountainous road leading to the Bana project in Da Nang, illustrating how fast adoption is spreading.

Picture 8: Left: VS trial at a shrimp edge, where a canal drains flood water to Vinh Dien River (March 2002); right: mass Vetiver planting combined with rock rip-rap for bank protection along Vinh Dien River (Nov. 2002)

Picture 9: Left: Vetiver together with rock rip-rap in good shape already after 2 flood seasons (Da Nang, Dec. 2004); right: local farmers planted Vetiver ***grass to protect their shrimp ponds***



Picture 10: Vetiver protecting an embankment with rock rip-rap and concrete frame at the lower part, and Vetiver on the upper part (left), and a bend on Perfume Riverbank in Hue (right)

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

Also as a result of this pilot project, Vetiver grass was recommended for use in another natural disaster reduction project in Quang Ngai province, which was funded by AusAid. With technical support from Tran Tan Van, in July 2003, Vo Thanh Thuy and his co-workers from the provincial Agricultural Extension Center planted the grass at 4 locations, for sea water intrusion protection dike and irrigation canal in several districts. The grass grew well in all locations, and although at its young age, survived the flood in the same year (Pictures 11-14).


Picture 11: Left: Vetiver grass planted on river dike along Tra Bong River; right: on both sides of an anti-salinity estuary dike along the same river


Picture 12: Anti-salinity dike section upstream, with the old-fashioned concrete rip-rap facing the river (left) and along a section of the irrigation canal; note the poor shape of the opposite bank due to surface erosion (right)

Picture 13: Another section of the poorly eroded bank at Binh Thoi Commune, Tra Khuc River (left) and the traditional, primitive protection by local farmers using sand bag (right)

Picture 14: Vetiver grass comes in with local participation (left) and the bank stays intact after the flood season in Nov. 2005

Following these successful trials, the project has decided to mass plant the grass on other dike sections at 3 more districts, in combination with rock rip-rap measure. Some design modifications have been introduced to better adapt Vetiver grass to the local conditions. For example, mangrove fern and more salt tolerant grasses are planted on the lowest row to better withstand the high level of saline water and effectively protect the embankment toe. The grass is further introduced to local communities so that they themselves can protect their own land.

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

With financial support from Donner Foundation and technical support from Paul Truong, Le Viet Dung and his colleagues at Can Tho University started works on river bank erosion control in the Mekong Delta. The area features long inundation (up to 3-5 months) during the flood season, with large (up to 4-5 m) difference in the water levels between dry and flood seasons, and strong water flow during the high water (flood) season. In addition, river banks are mostly made up of soils ranging from alluvial silt to loam, which are extremely erodible when wet. Due to the fast economic development in recent years, most boats traveling on rivers and canals now are motorized, in many cases with very powerful car engines. These boats aggravate the problem of river bank erosion further by generating strong waves. However, despite these negative factors, Vetiver grass withstands well, protecting large areas of invaluable farm land from erosion (Pictures 15 and 16).

A comprehensive Vetiver program has been carried out in An Giang Province, where annual flood can reach up to 6 m depth. The province 4932 km long canal system needs maintenance and repair every year. In addition, a network of dikes, 4600 km long, was built to protect 209,957 ha of prime farm land from flood. The erosion on these dikes is about 3.75 Mm^3/year and required USD 1.3 M to repair.

There are also 181 resettlement clusters built on dredged materials for people to live. These clusters also need erosion control measure from flood. Depending on the locations and flood depth Vetiver has been successfully used by itself or in combination with other vegetation. The total length of Vetiver planting for dike protection from 2002-05 is 61 km using 1.8 M polybags.

It is anticipated that for the next 5 years, 2006-2010, the 11 districts of An Giang province will plant 2025 km of Vetiver hedges on 3100 ha of dike surface. If unprotected by Vetiver, it is expected that 3750 Mm^3 of soil will be eroded and 5 Mm^3 will have to be dredged from the canals. Based on the current cost, the total maintenance cost over this period would exceed USD 15.5 M for this province alone. In addition, application of VS in this rural region will provide extra income to the local people: men to plant and women and children to prepare Vetiver polybags. As a result, extensive use of Vetiver grass is now seen along the rigorous sea and river dike systems as well as along river bank, canals etc. in the Mekong Delta.

Picture 15: Vetiver grass and river dike (left) and along a natural river bank (right) in An Giang

Picture 16: Left: Vetiver along the edge of flood resettlement centers; Right: see the red line, showing about 5 m of dry land being saved thanks to Vetiver grass

5.3 VS application and promotion for coastal erosion control

In 2001 with financial and technical supports from the Donner Foundation and Paul Truong respectively, Le Van Du from Ho Chi Minh City Agro-Forestry University initiated works on Acid Sulfate Soil to stabilize canal and irrigation channels and sea dike system in Go Cong province. Despite the poor embankment soil Vetiver grew rigorously in just a few months, helping to protect the sea dike, preventing surface erosion and facilitating endemic species to establish (Picture 17).

Picture 17: Planting Vetiver grass in Go Cong province, behind the natural mangrove on this Acid Sulfate Soil sea dike. Surface erosion is reduced and local grass re-established

In 2004, at the recommendation of Tran Tan Van, the Danish Red Cross funded a pilot project using Vetiver grass for sea dike protection in Hai Hau district, Nam Dinh province (Picture 17). The project implementers came in and to their great surprise, they found out that Vetiver grass had already been planted 1-2 years earlier to protect several km of the inner side of the local sea dike system. Although the planting design was not up to the standard recommended for such application, this planting has helped protect the dike system from erosion and the local people were already convinced of the effectiveness of the grass, asking for more mass planting. The effectiveness of Vetiver grass in reducing erosion of the sea dike was even more remarkable after typhoon No. 7 in September 2005, which even broke the sections rigorously protected by rock rip-rap.

Picture 18: VS application and promotion in North Vietnam; left: Nam Dinh province, Vetiver on outer side of the newly built sea dike; right: the local Dike Department planted Vetiver on the inner side of their sea dike

Concerned with the wellbeing of the people living on the path of these typhoons in the Ha Long area, where their livelihood depends on the stability of this protective sea dike system, HRH Princess Maha Chakri Sirindhorn of Thailand, Patron of The Vetiver Network, has just approved a project for Chaipattana Foundation, a private foundation set up by the HM The King of Thailand, to assist Vietnam both technically and financially to improve the stability of a sea dike at Hai Hau District, Nam Dinh Province, where the sea dike system was devastated by typhoons number 6 and 7 in September 2005. A group of Thai engineers and Vetiver experts has come to Hai Hau in July 2006 to finalize the project details with Vietnam's Ministry of Agriculture and Rural Development.

5.4 VS application and promotion for road batter stabilization

A particular bold move was made by the Ministry of Transport, following successful trials by Pham Hong Duc Phuoc (Ho Chi Minh City Agro-Forestry University) and Thien Sinh Co. in using Vetiver grass for cut slope stabilization in Central Vietnam. In 2003, the Ministry of Transport allowed the wide use of Vetiver grass for slope stabilization along hundreds of km of the newly constructed Ho Chi Minh Highway and other national, provincial roads in Quang Ninh, Da Nang, Khanh Hoa provinces etc. (Picture 19).

Picture 19: Vetiver grass for stabilizing cut slopes along the Ho Chi Minh Highway (left); either by itself or in combination with other traditional measures

This project is probably one of the largest VS applications in infrastructure protection in the world. The entire Ho Chi Minh Highway, over 3000 km long, 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 and humid climate in the South. The extensive use of Vetiver grass for cut slope stabilization brings in very good results e.g.:

- Applied primarily as a slope surface protection measure, it greatly reduces run-off induced erosion, which would otherwise have caused many other hazards downstream (Picture 20);
- By preventing shallow failures, it greatly stabilizes cut slopes and consequently greatly reducing the number of deep slope failures;
- In some cases where deep slope failures do occur, it still does a very good job in slowing down the failures and reducing the failed mass; and
- It helps increase the environmental friendliness of the road etc.

Picture 20: Improper rock/soil waste disposal (left) which moves very far downstream (right), in a village in A Luoi district, Thua Tien Hue province

Picture 21: Ugly and continuous failures of cut slopes as the vegetation cover is destroyed (Da Deo Pass, Quang Binh, left); but with Vetiver rows on top the slope very slowly squeezes down, considerably reducing the failed mass (right)

Pham Hong Duc Phuoc demonstrated clearly how VS should be used and its effectiveness and sustainability on a road leading to the Ho Chi Minh Highway. He carefully monitored the development of the VS in term of establishment (65-100%), top growth (95-160 cm after 6 months), tillering rate (18-30 tillers/plant) and root depth on the batter (Table 6).

Table 6: Vetiver root depth on Hon Ba road batters

	Position on the batter	**Root depth (cm)**			
		6 months	**12 months**	**1.5 year**	**2 years**
	Cut Batter				
1.	Bottom	70	120	120	120
2.	Middle	72	110	100	145
3.	Top	72	105	105	187
	Fill Batter				
4.	Bottom	82	95	95	180
5.	Middle	85	115	115	180
6.	Top	68	70	75	130

Failures and successes with Vetiver grass protecting cut slopes along the Ho Chi Minh Highway show some further lessons:

- The slopes should first be internally stable as the effect of Vetiver grass does not come immediately and the slopes may fail before it really takes place. Stabilization may take place only after 3-4 months at the earliest; hence timing is also very important if slope failure during the forthcoming rainy season is to be avoided;

- Appropriate slope angle should not exceed 45-50^{o}; and
- Regular trimming is also important to ensure further growth of the grass to achieve good, dense hedgerows etc.

Picture 22: Left two Pictures: Severe erosion on newly built batter occurred just after a few rains. Vetiver will be planted to protect this slope during the next wet season; right two Pictures: same location 8 months after Vetiver planting. Vetiver has stabilized and totally stopped and prevented further erosion in the wet season (Pham Hong Duc Phuoc, a road protection project in Khanh Hoa province, road to Hon Ba).

6. CONCLUSIONS

From the results of research and the successes of numerous applications presented above, it is clear that we now have enough evidence that VS, having many advantages and very few disadvantages, is a very effective, low cost, community-based and environment-friendly bio-engineering tool for natural disaster mitigation and infrastructure protection. It has been used successfully in many countries in the world, e.g. Australia, Brazil, Central America, China, Ethiopia, India, Italy, Malaysia, Nepal, Philippines, South Africa, Sri Lanka, Thailand, Venezuela, Vietnam etc. However it must be emphasized that to provide an effective support for engineering structures, the two most important points are good quality of the planting material and the all-important appropriate design and correct planting techniques.

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http://www.vetiver.org/ICV3-Proceedings/IND_vetoil.pdf
http://picasaweb.google.com/VetiverClients/VetiverSystemsForFloodControl
http://picasaweb.google.com/VetiverClients/VetiverSystemForRiverAndStreamBankErosionControl
http://picasaweb.google.com/VetiverClients/VetiverSystemForDamsReservoirsAndPonds
http://picasaweb.google.com/VetiverClients/VetiverSystemForEffluentDisposal
http://picasaweb.google.com/VetiverClients/VetiverSystemAndRuralRoads
http://picasaweb.google.com/VetiverClients/VetiverSystemsForHighwayStabilization
http://picasaweb.google.com/VetiverClients/VetiverSystemAndRairoadProtectionAndStabilization
http://picasaweb.google.com/VetiverClients/VetiverSystemsForLandRehabilitation
http://picasaweb.google.com/VetiverClients/VetiverSystemPipelinePowerlineStabilization

PART 4

Vetiver System for prevention and treatment of contaminated water and land

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1. INTRODUCTION

Whilst conducting research into the role of the extraordinary physiological and morphological attributes of Vetiver grass for soil and water conservation, it was discovered that Vetiver grass also possesses some unique characteristics suitable for environmental protection purposes, particularly in the prevention and treatment of contaminated water and land. This can be attributed to its high level of tolerance to elevated and sometimes toxic levels of salinity, acidity, alkalinity, sodicity as well as a whole range of heavy metals and agrochemicals. Latest research also shows its exceptional ability to absorb and to tolerate extreme levels of nutrients to consume large quantities of water in the process of producing a massive growth under wet conditions.

Application of the Vetiver System (VS) for wastewater treatment is a new and innovative phytoremediation technology, which has the potential to meet all the right criteria. It is a natural, green, simple, practicable and cost effective solution, and most importantly, its by-product offers a range of uses from handicrafts, animal feeds, thatches, mulch and fuel just to name a few.

Due to its effectiveness, simplicity and low cost, the Vetiver System has been used in many countries with tropical and subtropical climates for domestic, municipal and industrial wastewater treatment and mine phytoremediation and rehabilitation.

2. HOW THE VETIVER SYSTEM WORKS

VS can prevent and treat contaminated water by:

Preventing and treating contaminated water
- Reducing the volume or eliminating the wastewater
- Improving the quality of wastewater and polluted water.

Preventing and treating contaminated land
- Controlling offsite pollution
- Phytoremediation of contaminated land.

3. SPECIAL FEATURES SUITABLE FOR ENVIRONMENTAL PROTECTION PURPOSES

As presented in Part 1 several special characteristics of Vetiver grass are considered suitable for waste water treatment. However the following morphological and physiological attributes are most critical for its effectiveness for these applications.

3.1 Morphological attributes

- Vetiver grass has a massive, penetrating and very deep, fast growing root system capable of reaching 3.6m deep in 12 months on good soils.
- The depth of root structure provides the plant with great tolerance to drought, permits excellent infiltration of soil moisture and penetrates through compacted soil layers (hard pans) and reduces or prevents deep drainage.
- The majority of this massive root system is very fine, with average diameter 0.5-1.0mm (Cheng *et al*, 2003), providing an enormous volume of rhizosphere for bacterial and fungal growth and multiplication, which are essential for contaminant absorption and breakdown processes such as nitrification etc.
- The erect and stiff shoots can grow to three meters and when planted close together they form a living porous barrier that retards water flow and acts as a very effective bio-filter, trapping both fine and coarse sediment in runoff water (Picture 1).

Picture 1: Morphological characteristics of Vetiver grass

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 (Figure1).
- Highly tolerant to soil high in nutrients (Figure 2).
- High level of tolerance to herbicides and pesticides.
- Ability to break down some organic compounds associated with herbicides and pesticides.
- Ability to grow back rapidly after being affected by drought, frost, fire, saline and other adverse conditions when the adverse effects are removed.

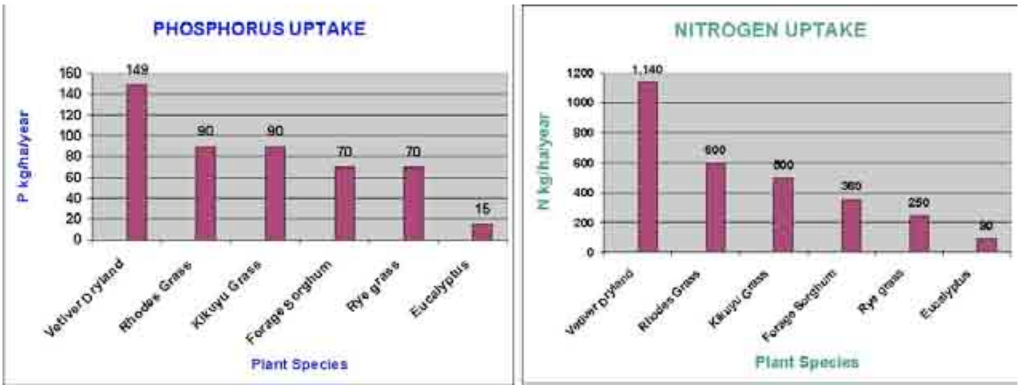


Figure 1: Higher capacity of uptake N and P than other plants

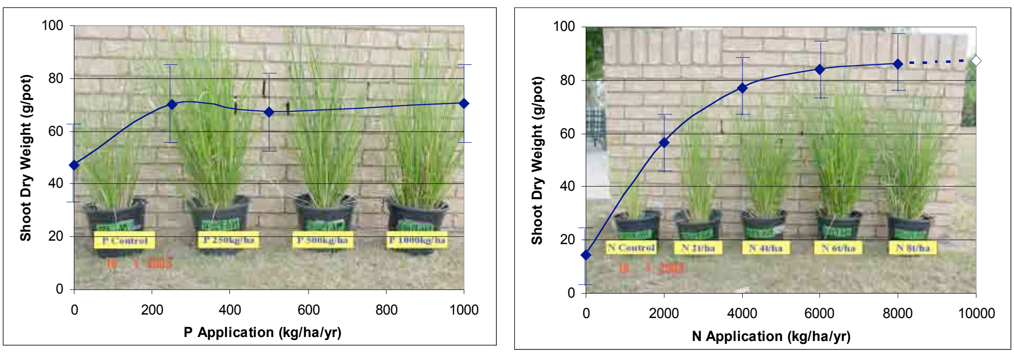


Figure 2: High capacity of absorbing P and N and high level of tolerate to these nutrients

4. PREVENTION AND TREATMENT OF CONTAMINATED WATER

Due to the above attributes, 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 discharges as well as from industries.

4.1 Reducing or eliminating the volume of wastewater

For large-scale reduction or total elimination of wastewater, vegetative methods are the only feasible and practicable method available to date. In the past, trees and pasture species have been used for the disposal of wastewater in Australia, but recently Vetiver grass has been found to be more effective than trees and pasture species in the disposal and treatment of landfill leachate, domestic and industrial effluent.

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

4.1.1 Disposal of septic effluent

Picture 2: In 4 days Vetiver cleaned up blue green algae.

Left: infested sewage effluent due to high Nitrate (100 mg/L) and Phosphate (10 mg/L). Right: same effluent after 4 days: the treatment reduced N level to 6 mg/L (94%) and P to 1 mg/L (90%).

The first application of the VS for effluent disposal was conducted in Australia in 1996, and subsequent trials demonstrated that planting about 100 Vetiver plants in an area less than 50m^2 have completely dried up the effluent discharge from a toilet block in a park, where other plants such as fast growing tropical grasses and trees, and crops such as sugar cane and banana have failed (Truong and Hart, 2001).

4.1.2 Disposal of landfill leachate

Disposal of landfill leachate is a major concern to all large cities, as the leachate is often highly contaminated with heavy metals, organic and inorganic pollutants. In Australia and China this problem can be solved by irrigating Vetiver planted on the top of the landfill mound and retaining dam wall with leachate collected at the bottom of the dumps. Results to date have been excellent, the growth was so vigorous that during the dry period, there was not enough leachate to irrigate the Vetiver. A planting of 3.5ha has effectively disposed of 4 ML a month in summer and 2 ML a month in winter (Percy and Truong, 2005).

4.1.3 Disposal of industrial wastewater

In Australia, the disposal of large volume of industrial wastewater by land irrigation was carried out successfully at a food processing factory with daily out put of 1.4 million liters and a beef abattoir with daily out put of 1.4 million liters (Smeal *et al*, 2003).

4.2 Improving wastewater quality

Off-site pollution is the greatest threat to the world environment, this problem is widespread in industrialized nations but it is particularly serious in developing countries, which often do not have enough resources to deal with the problem. Vegetative method is generally the most efficient and commonly used for water quality improvement.

4.2.1 Trapping debris, sediment and agro-chemicals in agricultural lands

In Australia research studies in sugar cane and cotton farms have shown that Vetiver hedges were highly effective in trapping particulate-bound nutrients such as P, Ca and herbicides such as diuron, trifluralin, prometryn and fluometuron, and pesticides such as α, β and sulfate endosulfan and chlorpyrifos, parathion and profenofos. These nutrients and agrochemicals could be retained on site if Vetiver hedges were established across drainage lines (Truong *et al*. 2000) (Fig.3).

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

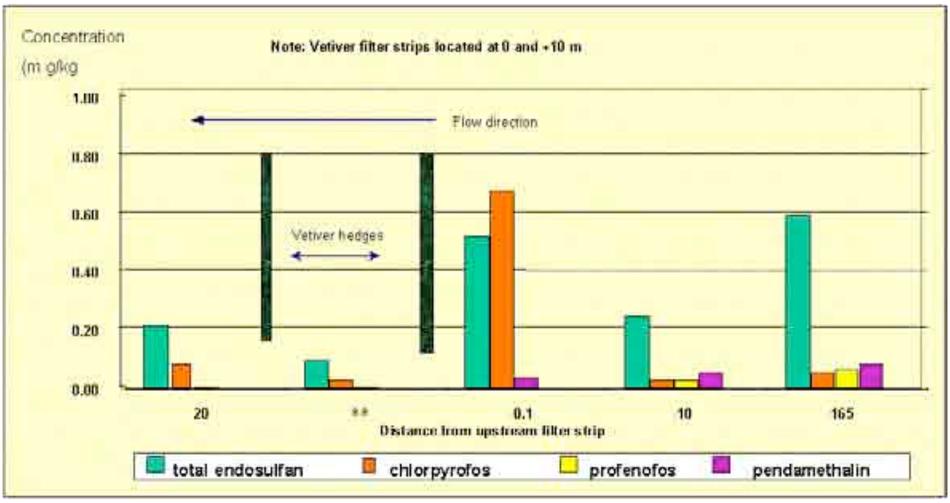


Figure 3: Herbicide concentration in soil deposited up- and downstream Vetiver filter strips

4.2.2 Absorbing and tolerating pollutants and heavy metal

The key feature of VS in treating polluted water lies in its capacity to quickly absorb nutrients and heavy metals, and its tolerance to very elevated levels of these elements. Although the concentrations of these elements in Vetiver plants is often not as high as those of hyper-accumulators, however due to its very fast growth and high yield (dry matter production up to 100t/ha/year), Vetiver can remove a much higher quantity of nutrients and heavy metals from contaminated lands than most hyper-accumulators.

In Vietnam, a demonstration trial was set up at a sea food processing factory to determine the treatment time required to retain effluent in the Vetiver field to reduce nitrate and phosphate concentrations in effluent to acceptable levels. Analytical 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 to 80% and 82% after 48 and 72 hours of treatment. The amount of total N and P removed in 48 and 72 hour treatments were not significantly different (Luu *et al*, 2006).

In Australia, five rows of Vetiver were sub-surface irrigated with effluent discharge from a septic tank. After five months growth total N levels in the seepage collected after 2 rows was reduced by 83% and after 5 rows by 99%. Similarly total P levels were reduced by respectively 82% and 85%, see Figure 4 (Truong and Hart, 2001).

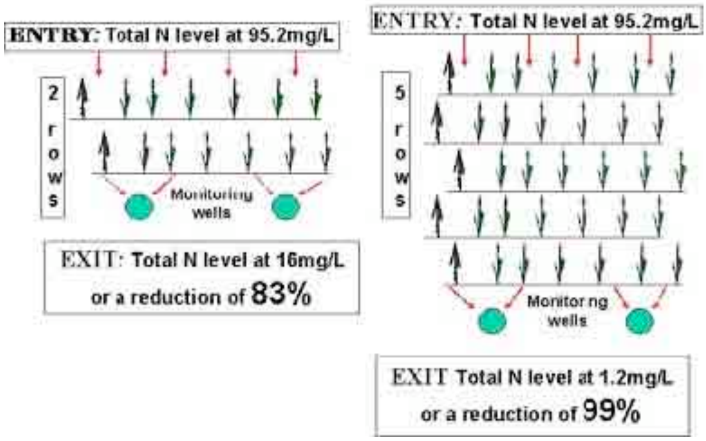


Figure 4: Effectiveness of N reduction in domestic sewage

In China, nutrients and heavy metals from pig farm are key sources of water pollution. Wastewater from pig farm contains very high N and P and also Cu and Zn, which are used as growth promoters in the feeds. The results showed that Vetiver had a very strong purifying ability.

Its ratio of uptake and purification of Cu and Zn was >90%; As and N>75%; Pb was between 30% -71% and P was between 15-58%. The purifying effects of Vetiver to heavy metals, and N and P from a pig farm were ranked as: Zn>Cu>As>N>Pb>Hg>P (Xuhui *et al*., 2003; Liao *et al*, 2003).

4.2.3 Wetlands

Natural and constructed wetlands have been shown effective in reducing the amount of contaminants in runoff from both agricultural and industrial lands. The use of wetlands for the removal of pollutants involves a complex variety of biological processes, such as microbiological transformations and physio-chemical processes, e.g. adsorption, precipitation or sedimentation.

In Australia**,** under wetland conditions, Vetiver had the highest water use rate compared with other wetland plants such as *Iris pseudacorus, Typha spp*, *Schoenoplectus validus*, *Phragmites australis*. At the average consumption rate of 600 ml/day/pot over a period of 60 days, Vetiver used 7.5 times more water than Typha (Cull *et al.* 2000).

A wetland was constructed to treat sewerage effluent output from a small rural town. The aim of this scheme was to reduce/eliminate the 500ML/day effluent produced by this small town before the effluent is discharged to the waterways (Picture 3). The results so far has been outstanding, Vetiver wetland has absorbed all the effluent produced by this small town, see Table 1 (Ash and Trương, 2003).

Picture 3: Vetiver wetland (left) and leachate disposal in Australia

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 min.)*	0-2	12.5-20	8.1-9.2
5 Day BOD (20 -40 mg/l max)*	130-300	29 to 70	7-1
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*

In China the disposal of wastewater from pig farms is one of the biggest problems in densely populated areas. China is the largest pig raising country in the world. In 1998 Guangdong Province had more than 1600 pig farms with more than 130 farms producing over 10,000 commercial pigs each year. These large piggeries produce 100-150 ton of wastewater each day, which included pig manure collected from slatted floors, containing high nutrient loads. Wetlands are considered to be the most efficient means of reducing both the volume and high nutrient loads of the piggery effluent. To determine the most suitable plants for the wetland system, Vetiver grass was selected along with another 11 species in this program. The best species are Vetiver, *Cyperus alternifolius*, and *Cyperus exaltatus*. However, further testing showed that *Cyperus exaltatus* wilted and became dormant during autumn and did not rejuvenate until next spring. Full year growth is needed for effective wastewater treatment. Therefore Vetiver and *Cyperus alternifolius* were the only two plants suitable for wetland treatment of piggery effluent, see Picture 4 (Liao, 2000).


Picture 4: Vetiver pontoon in pig farm ponds in Bien Hoa (left) and in China (right)

4.2.4 Computer modeling for industrial wastewater

In recent years, computer models have been increasingly considered as an essential tool for managing environmental systems. The complexity of wastewater management has made computer models instrumental in the planning and implementation of industrial wastewater disposal schemes. 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 development in VS use for wastewater disposal in recent years is that Vetiver has been calibrated for use in MEDLI, 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 modeling for domestic wastewater

Recently a computer model was developed in sub tropical Australia to estimate the Vetiver planting area need to dispose the total black and grey water output of each house. For example, based on the output of 120L/person/day, the Vetiver planting area of 77m^2, at density of 5 plants/m^2, needed for a house with 6 people.

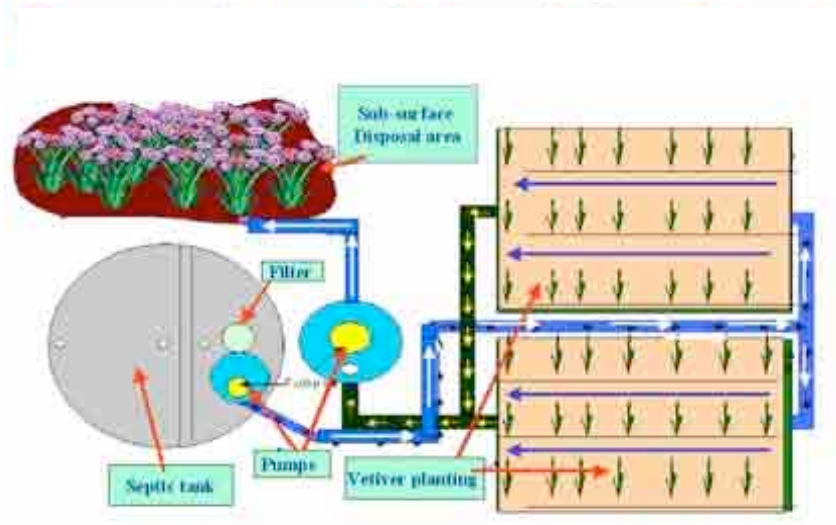


Figure 5: Layout of a domestic disposal system

4.2.6 Future trend

As water shortage is looming worldwide, wastewater should be considered as a resource rather than a problem. **The current trend is to recycle wastewater for industrial and domestic use** instead of disposal. Therefore the potential of VS is enormous as a simple, hygienic and low cost means of treating and recycling wastewater resulting from human activities (Figure 5).

The most recent and significant development of Vetiver used for wastewater treatment is its use in soil based reed beds. In this new application output water quality and quantity can be adjusted to provide a desired standard. This system is now under development and tested at GELITA APA, Australia. The full details of this system are described in (Smeal *et al.* 2006). See Figure 6.

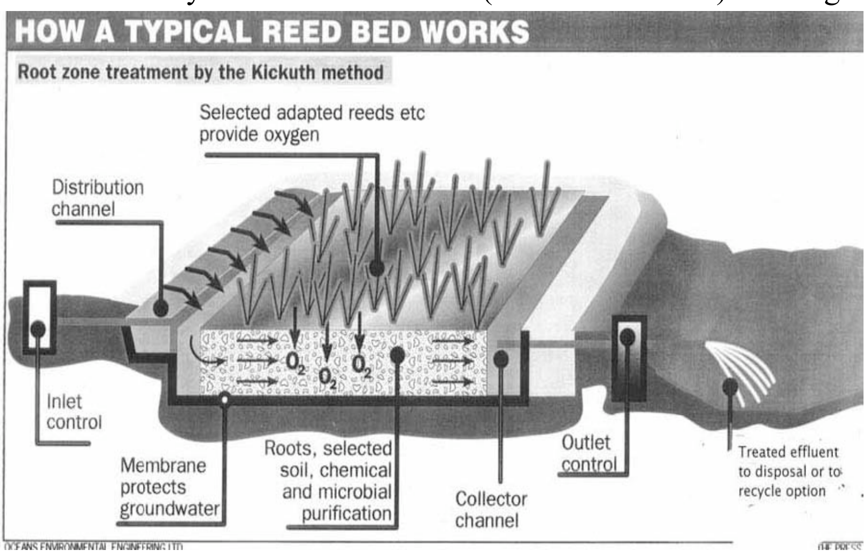


Figure 6: How a typical reed bed works

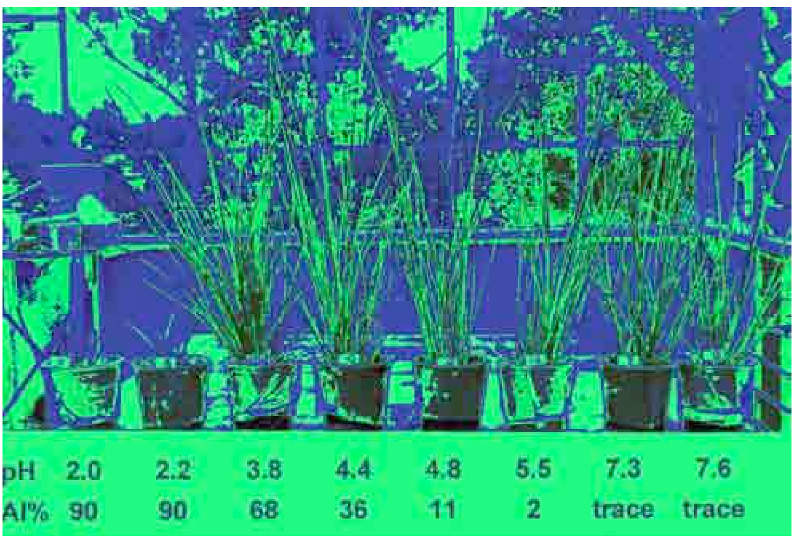
5. TREATMENT OF CONTAMINATED LANDS

In term of environmental protection, the most significant breakthroughs in the last 15 years are firstly research leading to the establishment of benchmark tolerance levels of Vetiver grass to adverse soil conditions and secondly its tolerance to heavy metal toxicities. These have opened up a new field of application for VS: the rehabilitation of toxic and contaminated lands.

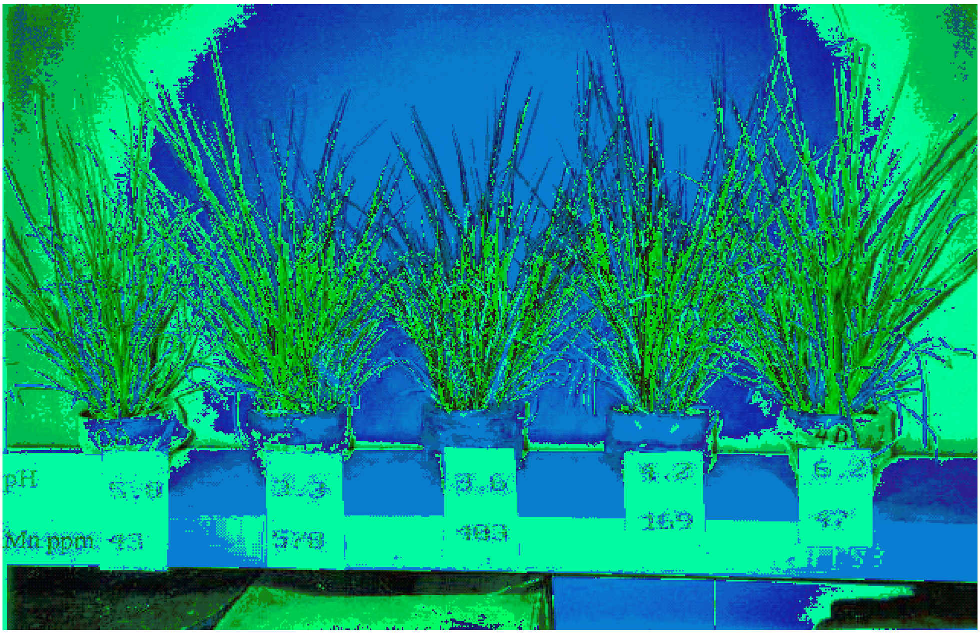
5.1 Tolerance to adverse conditions

5.1.1 Tolerance to high acidity, Aluminium and Manganese toxicity

Research results showed that with N and P fertilizers, Vetiver growth was not affected even under extremely acidic conditions (pH = 3.8) and at a very high level of soil Aluminium Saturation Percentage (68%)., but Vetiver did not survive an Aluminium saturation level of 90% at soil pH = 2.0. Therefore the threshold level must be between 68% and 90%. Field-testing confirmed later that Vetiver grew satisfactorily at soil pH=3.0 and Aluminium level between 83-87%, which is extremely high as growth of most plant is affected at level less than 30%. In addition Vetiver growth was not affected when the extractable manganese in the soil reached 578 mg/Kg, soil pH as low as 3.3 and plant manganese content was as high as 890 mg/Kg. As a result of its high tolerance level to Al and Mn toxicity, Vetiver has been used successfully for erosion control in Acid Sulfate Soils with actual soil pH around 3.5 and oxidized pH is as low as 2.8. See Pictures 5 & 6 (Truong and Baker, 1998).



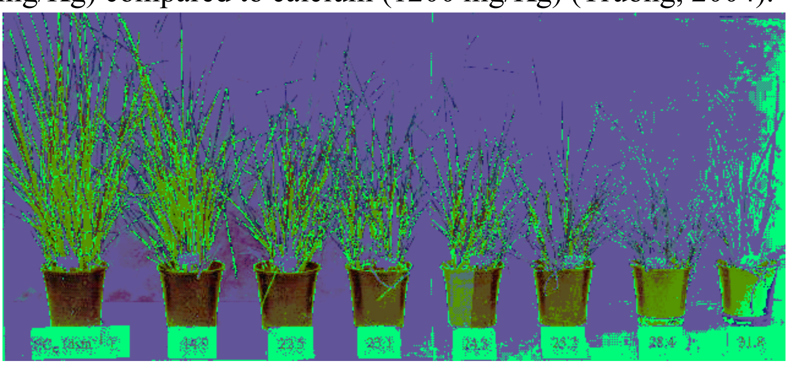
Picture 5: Vetiver thrives at soil pH=3.8 and Al saturation of 68% and 87% under field conditions



Picture 6: Growth was not affected at pH=3.3 and extremely high Mn level of 578 mg/kg

5.1.2 Tolerance to high soil salinity and sodicity

With the salinity threshold level at ECse = 8 dS/m Vetiver grass compares favorably with some of the most salt tolerant crop and pasture species grown in Australia such as Bermuda Grass (*Cynodon dactylon)* with threshold at 6.9 dS/m; Rhodes Grass (*Chloris guyana*) at 7.0 dS/m; Wheat Grass (*Thynopyron elongatum*) at 7.5 dS/m and barley (*Hordeum vulgare*) at 7.7 dS/m With 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%. Moreover 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).



Picture 7: Vetiver is very tolerant to high soil salinity

5.1.3 Distribution of heavy metals in Vetiver plant

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

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

5.1.4 Tolerance to heavy metals

This table shows that Vetiver is highly tolerant to As, Cd, Cr, Cu, Hg, Ni, Pb, Se and Zn.

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	2.0	21-72	1-10
Cadmium	20-60	1.5	45-48	5-20
Copper	50-100	Not available	13-15	15
Chromium	200-600	Not available	5-18	0.02-0.20
Lead	>1 500	Not available	>78	Not available
Mercury	>6	Not available	>0.12	Not available
Nickel	100	7-10	347	10-30
Selenium	>74	2-14	>11	Not available
Zinc	>750	Not available	880	Not available

5.2 Mine rehabilitation and phytoremediation

With the above extraordinary morphological and physiological characteristics, Vetiver grass has been used successfully for mine waste rock rehabilitation and phytoremediation of mine tailings in:

- Australia, coal, gold, betonite and bauxite
- China: lead, zinc and bauxite (Wensheng Shu, 2003)
- South Africa: gold, diamond and platinum
- Thailand: lead
- Chile: copper
- Venezuela: bauxite

Picture 8: Coal mine rehabilitation in Australia (left) and bauxite mine in Venezuela (right)

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Links to well illustrated websites:

- http://picasaweb.google.com/VetiverClients/VetiverSystemForMineAndQuarryRehabilitation
- http://www.Vetiver.org/TVN_archive.htm" \l "Anchor-LAND-2821
- http://www.Vetiver.org/TVN_archive.htm" \l "Anchor-MINE-363
- http://www.Vetiver.org/TVN_archive.htm" \l "Anchor-LANDFILL-45656
- http://www.Vetiver.org/TVN_archive.htm" \l "Anchor-POLLUTION-7638

PART 5

On-farm erosion control and other uses

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1. INTRODUCTION

Years of experience in many countries has shown that, even if Vetiver has been well adopted by farmers for soil conservation, its effectiveness in soil conservation is not necessarily the main reason that first convinces farmers to adopt VS. In Venezuela, for example, Vetiver was first grown for handicraft purpose, after which the soil conservation application was easier to introduce. In Cameroon Vetiver was first appreciated as a hedge to keep snakes out of the yards, and in other places the use of Vetiver was primarily for boundary marcation (where tree marked boundaries are controversial). In yet other places the first reason to accept Vetiver is its suitability to control storage pests in beans, or stem borers in maize (South Africa).

In this part we describe several applications of Vetiver most commonly practiced by farmers.

2. SOIL AND WATER CONSERVATION FOR SUSTAINABLE CROP PRODUCTION

2.1 Soil and water conservation principles

The objective of soil conservation practice is to control or reduce soil erosion by water or wind. In the case of water erosion, soil particles are first dislodged and removed from their original position by excessive volume and/or high velocity of overland flow of water. In the case of wind erosion by high wind velocity at ground level on bare surface.

Therefore the main aims of the water erosion control practice are to protect the soil surface from rain drop impact (from dislodging) and to reduce the volume of runoff water by vegetative covers, and to lower the overland flow velocity by contour banks (terraces) or vegetative barriers such as Vetiver hedges. As the erosive power of both water and wind erosion is proportional to the flow velocity (the speed of the water running down), the main principle of soil conservation is to **reduce the speed of water**.

When correctly implemented, Vetiver hedges are very effective in controlling both water and wind erosion.

The objective of water conservation practice is to increase water infiltration to the soil body. This can be achieved most effectively by a vegetation cover and particularly by vegetative hedges. When planted on contour lines, due to its dense nature, Vetiver hedges form a porous barrier, spreading and reducing the flow velocity of runoff water, thus allowing more time for infiltration and trapping sediment.

2.2 Unique characteristics of Vetiver grass suitable for soil and water conservation practices.

The characteristics that are particularly important for soil and water conservation are:

- the **soil-binding root system**: deep, penetrating, extensive root system;
- erect, stiff **stems forming a dense hedge**, effectively retarding and spreading water flow, reducing its erosive power;
- the tolerance to all kinds of adverse soil conditions or poor soils, such acid sulfate, alkaline, saline and sodic;
- tolerance to prolonged submergence;
- adaptable to a **wide range of climatic conditions**; doing well in the colder mountainous areas of the north and in extremely dry conditions in dunes of central coastal areas;
- **easy to multiply** (vegetative multiplication)
- Vetiver is sterile, it flowers, but produces no seed, and the plant has no above or underground stems, so it **does not become a weed** and remains where it is planted. There exist conflicting reports on this, claiming that in the central highlands Vetiver became a weed, being difficult to get rid of. However, this is not about *V. zizanioides* but about *V. nemoralis* (indigenous to Vietnam) which produces fertile seeds and does not have the extensive root system that is found in *V. zizanioides*. PART 1 of this manual fully describes the differences between the two species.
- the architecture of the roots is vertical, very little lateral root growth, which ensures that the plant, when intercropped, **does not compete for nutrients and water with crop plants**. Research in Vietnam also confirmed this.

In PART 1 of this manual the characteristics of Vetiver are discussed in more detail. In this PART the important role of the first two characteristics, the soil-binding root systems and the dense hedge forming of the stems are further demonstrated.

The **strong root system** of Vetiver grass is not equaled by any other plant used for on-farm erosion control.

In flatter lands and on gully floors, where the strength of flood water flow can be really destructive, these strong roots prevent dislodging of the plant. The plant can withstand extremely strong currents.

Picture 1: Strong current on this waterway in Australia flattened the native grass but the Vetiver hedge was not affected and its stiff stems reduced water velocity and its erosive power

On **sloping land** the well developed root system can, in addition to reducing surface erosion, also contributes to slope stability as described in PART 1: the deeply penetrating root system can reduce the risk of landslide or collapse of terraces.

The **stiff stems, forming a dense hedge**, reduce water velocity, allowing **more time for water to infiltrate the soil**, and where necessary divert surplus runoff water. This is the principle of 'flow-through' erosion control system for farms on the flood plains as well as on steep slopes in high rainfall areas.

2.3 Contour banks or terrace system versus Vetiver flow through system

A review conducted for the World Bank comparing the effectiveness and practicality of different soil and water conservation systems found that constructed measures must be site specific and require detailed and accurate engineering and design. Furthermore, all structured systems require regular maintenance. Most of the evidence also suggests that constructed works reduce soil losses, but do not reduce runoff significantly and in some cases have a negative impact on soil moisture (Grimshaw 1988). The vegetative conservation system, on the other hand, when planted on the contour, forms a protective barrier across the slope, which slows the runoff water causing sediment to be deposited. Since the barriers only filter the runoff and 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 known as the flow-through system (Greenfield 1989). This is in sharp contrast with the contour terrace/waterway system in which runoff water is collected by the terraces and diverted as quickly as possible from the field to reduce its erosive potential. All runoff water is therefore collected and concentrated in the waterways where most erosion occurs in agricultural lands, particularly on sloping lands, and this water is lost from the field. With the flow-through system, not only is this water conserved but also no land is wasted on the waterways (Figure 1).

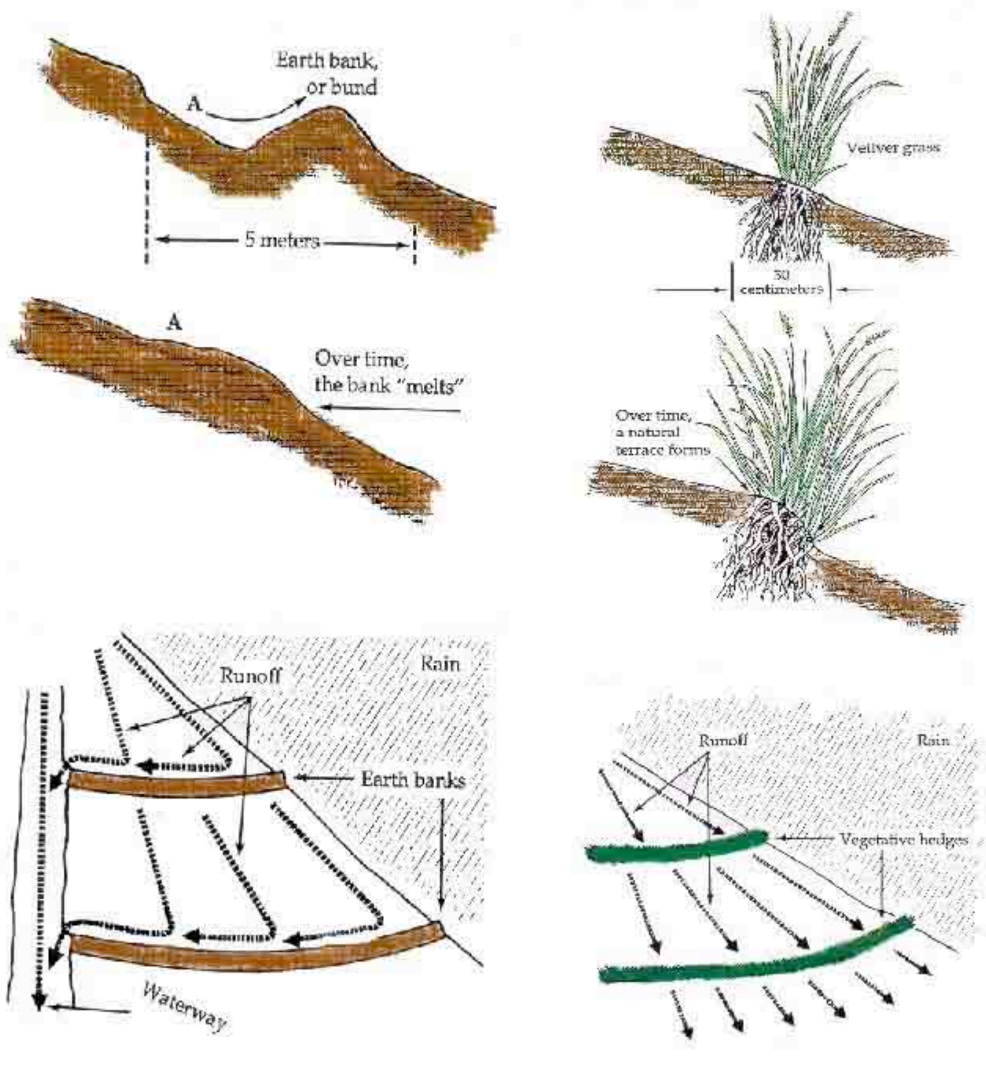


Figure 1: Above left: contour bank, and below left: the banks divert the water and above right: Vetiver hedges create banks or terraces over time, and

below right: the water remains in the field, the Vetiver hedges slow down the runoff to increase infiltration (Greenfield 1989)

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

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

2.4 Application on flood plains

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

The three major roles of Vetiver hedges on the flood plains are to:

- reduce flow velocity, that is erosive power;
- trap the fertile alluvial soil on site, retaining the fertility of the plain; and
- increase water infiltration in low rainfall regions such as Ninh Thuan province.

On the flood plains of the Darling Downs in Australia strip-cropping practice is used to mitigate floodwater damage to crops and to control soil erosion on low gradient lands subject to deep overland flooding. Strip cropping uses a similar "flow-through" system as that of Vetiver grass hedges. Strip cropping requires a strict sequence of crop rotation but it is not possible during drought as crops cannot be planted.

In a large field trial at Jondaryan (Darling Downs region, Queensland, Australia), six rows of Vetiver totaling over 3000m were planted on the contour at 90m spacing. These rows provided permanent protection against flood waters. Data collected from a small flow over the site show that the hedges reduce significantly the depth and therefore energy of flow through the hedges. At a low depression, 7.25 tons of sediment was trapped by one hedge. Results over the last several years, (including several major flood events) have shown that VS is very successful in reducing flood velocity and limiting soil movement, with very little erosion in fallow strips (Truong *et al.* 1996, Dalton *et al.* 1996a and Dalton *et al.* 1996b).The results of this trial demonstrated that VS can be considered as an alternative to strip cropping practice on the flood plains of Australia.

Picture 2: Left: fertile sediment is retained while flood water passes the Vetiver hedge; and right: an excellent crop of sorghum after the flood on the flood plain of the Darling Downs, Australia

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

Picture 3: Vetiver planted on very steep slope for soil and water conservation on a tea plantation in India

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

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

In Australia Vetiver grass R & D over the last 20 years have confirmed overseas findings, particularly its effectiveness in soil and water conservation, gully stabilization, degraded land rehabilitation and trapping sediment in waterways and depressions. In addition to these applications, three contributions of significant importance to the versatility of Vetiver applications are:

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

In Viet Nam most of the on-farm experience with 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; it was 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).

In Vietnam 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 in the south west.

Effect on soil loss

Reduction of soil loss has a merit in itself, keeping fertile soil on-farm, but the importance of this is judged by farmers, who may take into account soil depth: if the soils are deep, then they may not worry so much about soil loss in itself and find that soil conservation with Vetiver is not a priority, considering that it also requires some work, and it takes up farm land.

Picture 4: Vetiver hedgerows in Dong Rang commune of northern Viet Nam, showing the amount of soil trapped by the hedge. The hedge also provides in-situ mulch, stops runoff and erosion, and reduces the slope by natural terrace formation

However, where slope farming becomes more intensive and farmers invest in it for example by putting manure and/or applying chemical fertilizer, then the positive effect of Vetiver is not just about reducing of soil loss, but also about preventing surface runoff and retaining soil fertility (Truong and Loch, 2004). And in higher rainfall areas the extensive, deep root system has an additional positive effect: these deep roots take up soluble nutrients that would otherwise be lost to deeper, unreachable layers of the soil. This is useful when Vetiver grass is cut and used as mulch.

Table 1: Effects of Vetiver System on soil loss and runoff in 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	95.0	88.7	20.2	64.1	50.0	21.9
Venezuela (15% slope)	16.8	12.0	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			
		14.4	3.9		23.3	15.5

(Truong and Loch, 2004)

In Vietnam Tephrosia and wild pineapple are also used as conventional methods of reducing soil loss with hedges (sometimes in combination with terracing). But the effectiveness of wild pineapple is quite low (the mounds created by the thick stems can even increase erosion because water is concentrated and forced to pass through the tight space in-between the mounds) and the effectiveness of Tephrosia only for as long as the plant remains established (it dies after 2-3 years). Terracing is often recommended on moderate slopes, but it is often very labor demanding, and the promotion of Vetiver hedges can be a valuable alternative.

Picture 5: Organic school garden: Vetiver grass on 50^{o} slopes (East Bali poverty project)

Another, quite different project was a research project in Dong Nai province in south west Vietnam (lead by Dr. Pham Hong Duc Phuoc, Nong Lam University), testing VS for soil conservation in coffee plantations on sloping land.

Picture 6: Vetiver planting for erosion control in coffee plantation in the Central highlands

2.6 Design and extension: farmers' considerations

Experience with Vetiver for on-farm soil erosion control has made one thing very clear: there are many considerations that farmers have to take into account, before deciding on whether or not to use Vetiver, and how to use it (Agrifood Consulting International, March 2004). Some light was shed on the discrepancy between adoption of Vetiver and other measures by *research* farmers (who were subsidized for carrying out the trial, generally they are the better off farmers) and other exposed farmers; adoption of improved plant varieties and chemical fertilizer was highest, and adoption of Vetiver as main soil conservation measure was variable, depending on considerations explained here.

It is certain that once farmers are well informed on the principles, they are much better placed to weigh the different considerations than any outsider researcher or extension worker. Farmers have to see for themselves how far short-term and long-term impacts are. Hence the importance of putting farmers in the centre of the approach: if any guidelines are written here (e.g. recommendations on spacing of hedges, or on multiplication), the farmers still have to adjust these to their own situation. The use of subsidized inputs or other material incentives for farmers to collaborate in the trial and adoption is not recommended, as it will undermine the replicability of results.

The following ‘check-list’ of often interrelated considerations that farmers take into account may illustrate the key issues.

Picture 7: Making soil loss visible (CIAT cassava project)

Checklist for feasibility of large scale adoption of Vetiver System for Soil and Water Conservation

1. The **importance of the soil erosion problem**.

- how deep is the soil profile?
- ***visibility*** of soil loss to farmers (on-site or downstream?).

the extent or value of the soil loss; if fertilizer is applied then farmers are more willing to make an effort to prevent losing it through runoff or leaching to deeper layers (e.g. soluble Nitrogen that quickly leached to unreachable lower layers can partly be recovered by the deep-rooted Vetiver).

how erosion prone is the soil: slope gradient and soil texture?

the practice of other erosion control methods (e.g. contour ridging, stone contour lines, plastic mulch, and plant varieties that are low-branching, have a fast closing canopy) and how these compare to VS?

2. The importance of the cropping system, compared to other parts of the farm: farmers are more interested to invest in conservation practices when the particular plot produces a crop that economically very interesting.

the relative value of the piece of land and (ability to invest labor, money).

the general position of the farmer: how much labor/money can he/she invest in this plot (what are alternative uses of her/his time and money, e.g. paddy land or off-farm labor)?

is the farmer sufficiently sure of land tenure to justify efforts improving it?

what is the distance from homestead to the field(s) to justify labor efforts?

the farmer being able to make complementary use of other Vetiver applications (see next chapters).

Picture 8: Dong Rang farmers planted Vetiver grass hedgerows in cassava plots to reduce erosion

Possibilities to multiply Vetiver (space for nurseries?) or obtain it otherwise.
Policies that may encourage or enforce application of measures against soil- and water conservation.
Ecological limitations. For example, Vetiver does not establish well under shade. But once established, the shade is less of a problem.

It is recommended to encourage farmers 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

Picture 9: Stem borers (Chilo partellus)

Stem borers are important pests of maize, sorghum, rice and millets in Africa and Asia. The larvae lay their eggs on the leaves of the crop. Professor Johnnie van den Berg of Potchefstroom University, South Africa found that when Vetiver is planted around the crop, the larvae prefer to lay the eggs on Vetiver leaves instead of on the maize or rice crop: most eggs (about 90%) are thus placed on Vetiver instead of on the crop.

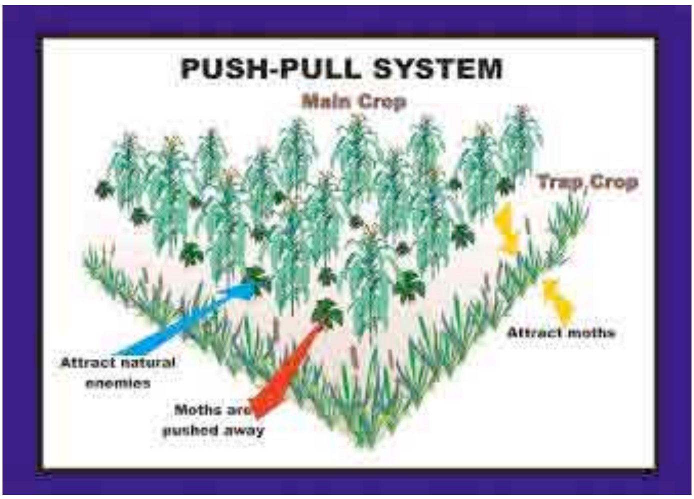


Figure 2: The Push-Pull system: attracting the insect to lay where it has little survival chance

Because the Vetiver leaves are hairy, the larvae that hatch on it have difficulties to move around: they drop off the plant and die on the ground. This results in an extremely high mortality of the larvae (again about 90%). In addition, Vetiver also harbors many beneficial insects, the predators of pests that attack crop.

Practical application of this effect for rice is currently being investigated at Can Tho University and preliminary results are very promising. This work is in cooperation with Professor Johnnie van den Berg, entomologist, School of Environmental Sciences and Development, Potchefstroom University, South Africa.

Picture 10: Low stem borer larvae survival on Vetiver due to hairy leaves

Picture 11 (below): On-farm application to control maize stem borer (Zulu land, South Africa)

3.2 Animal feed

Vetiver is readily eaten by cattle, goats and sheep. Table 2 shows its nutritional values as compared with some other subtropical grass in Australia. It shows that ***young*** Vetiver grass is quite nutritious, comparable to mature Rhodes and Kikuyu grass. However, the values for mature and older grass are not so good, in terms of protein.

From a study in Vietnam (Nguyen Van Hon, 2004) we know that ***young*** Vetiver grass can partially replace mature *Brachiaria multica* grass for growing goats.

Table 2: Nutritional values of Vetiver, Rhodes & Kikuyu grass in 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

Analytes	Units	Vetiver grass			Rhodes	Kikuyu
		Young	*Mature*	*Old*	*Mature*	*Mature*
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

However, generally Vetiver should not be consider as a fodder grass, but a useful by-product of soil and water conservation measures. Nevertheless, under certain conditions it can be planted as the main fodder crop, as in the case of Ninh Thuan Province (where it was used for soil rehabilitation, see 4.2). Vetiver shoots are nutritious when **young leaves are cut (pruned) at intervals between 1 and 3 months depending on climatic conditions.** This is typical characteristics of many tropical grasses that nutrient content varies according to seasons, growth stage and soil fertility.

But when Vetiver is used for other purposes, the added value may be interesting in some cases. In Quang Binh province, after an extremely cold winter, Vetiver appeared to be the only green fodder available, when most other grass had died. And (Pingxiang Liu 2003) notes that Vetiver grass growing on pig farm waste can have interestingly 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).

Picture 12: Left: buffalo grazing Vetiver on dike; right: feeding cattle young Vetiver

3.3 Mulch to control weeds and conserve soil water

Due to its higher silica content than other tropical grasses such as *Imperata cylindrica,* Vetiver shoots take a longer time to break down than other tropical grasses. This will make it an ideal product for mulch and roof thatching.

Weed control*:* When spreading evenly on the ground surface, stiff Vetiver shoots either chopped up or in whole, form a thick matt and suppress weed emergence. Vetiver mulch is used successfully for weed control in coffee and cocoa plantations in the Central Highlands and tea plantations in India.

Picture 13: Vetiver planting for erosion control and mulching in coffee plantation in the Central Highland

Picture 14: Vetiver planting for erosion control and mulching in Tata tea plantation, southern India

Water conservation*:* The thick cover of the mulch will increase water infiltration and reduce evaporation, these are particularly important under hot and dry climate of the coastal provinces like Ninh Thuan. In addition this cover would also protect the soil surface from rain drop impact, which is one of the major causes of soil erosion.

4. FARM LAND REHABILITATION AND PROTECTION OF FLOOD-ESCAPING COMMUNITIES

4.1 Sand dune stabilization

Sand dunes occupy more than 70,000 ha along the coast of Central Vietnam. These dunes are highly mobile due to strong wind and highly erodible during heavy rains. Unless stabilized they will invade valuable farm land, destroying crops, fill up rivers and streams causing enormous losses to local farmers. Traditional methods of stopping the movement of these dunes, which include the planting Casuarinas trees and wild pine apple, and constructing small dikes made of sand, are ineffective. Vetiver planting offered the best solutions to date.

The following case study will illustrate the problem: In Quang Bing Province 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 sand was moved by the stream undercutting the dune foot slope, and then deposited on irrigated farms downstream. Farmers tried to divert the sand-stream with dikes made of just dune sand, but this only moved the problem to other farms. The situation resulted conflicts between farmers, and with the Forestry Enterprise (diverting the stream away from its nursery, towards the dune). Four rows of Vetiver grass were planted on contour lines on the slope of the sand dune starting from the edge of the stream. After 4 months Vetiver formed closed hedgerows and the sand dune toe was stabilized. The Forestry Enterprise was so pleased that it decided to mass plant the grass on other sand dunes and even for the protection of a bridge abutment. The grass further surprised local people by surviving the coldest winter in ten year, when the temperature lowered down below 10^{o}C, forcing the farmers to replant twice their paddy rice and Casuarinas. After 2 years, local species such as Casuarinas, wild pineapple etc. re-established between the Vetiver rows. The grass itself faded away under the shade of these trees but it had accomplished its mission. The project again proved that with proper care Vetiver grass could survive very hostile soil and climatic conditions.

For dune slope protection a few important things have to be kept in mind:

1. Assessing and ***planning together with local communities is very important;*** a community can:

   i) provide valuable ideas during planning
   ii) contribute financially
   iii) participate during implementation
   iv) ensure protection and maintenance.
2. Training local people: very useful to include other uses of Vetiver (fodder, handicraft) in training on multiplication, planting and maintenance..
3. Multiplication: local people can be contracted to multiply Vetiver. The local nurseries supplied bare root slips of Vetiver, which turned out to be good enough: no difference with use of polybags.
4. Maintenance and monitoring: the dry sand easily moves down, sometimes half burying the young grass, sometimes even washing it away.

The following two Pictures show where Vetiver rows were planted in dunes in Le Thuy district, Q. Binh province. The last Picture shows how the local community extended the practice (local foresters provided some support).

Picture 15: Early April - one month after planting; note mulching above the uppermost row

Picture 16: Mid October 2002 (7 months): note establishment of Casuarinas in-between rows

Picture 17: February 2003: a new site established in October 2002; the grass survived well the coldest-ever winter in Quang Binh

Vetiver grass could also be equally effective in reducing blowing sand. For this purpose, the grass should be planted across the wind direction, especially at low places in-between sand dunes, where the wind velocity is expected to increase. This has been tested on coastal dunes in Senegal (Picture 18), as well on Pintang Island . off the East China coast.

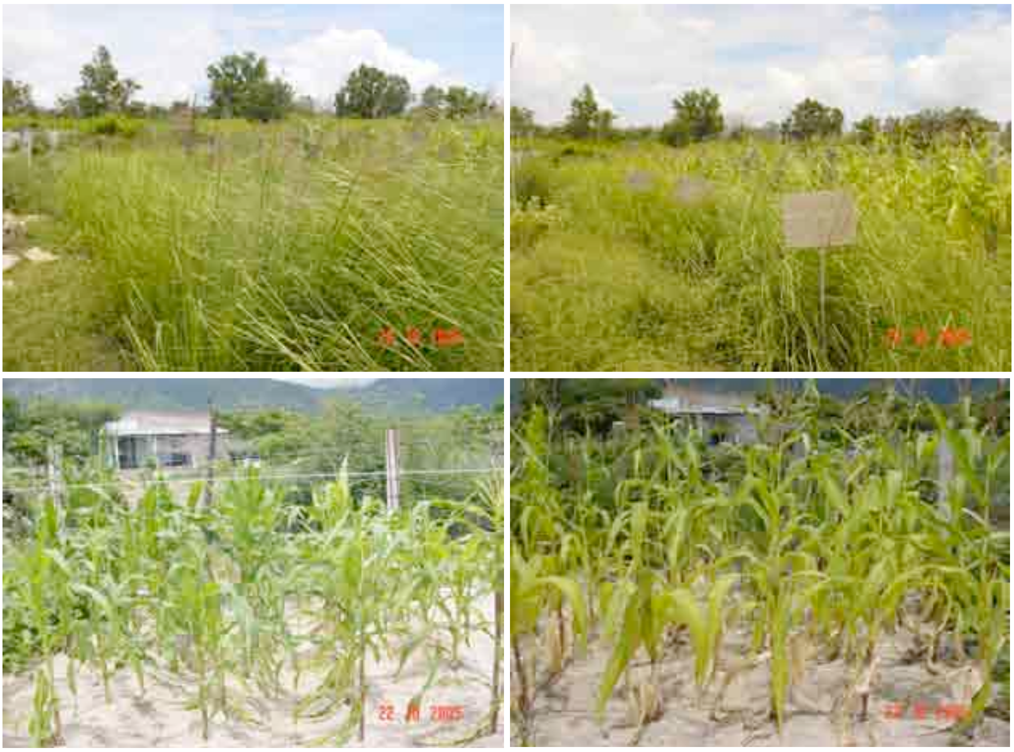
Picture 18: Dune protection at a beach resort in Senegal (Mamadou Sy)

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

Ninh Thuan and Binh Thuan in central Vietnam are the two coastal provinces that have a very peculiar climatic condition. Although they situated right on the coast, they experience a semi arid condition, with annual rainfall often less than 300mm, resulting in extreme shortage of fresh water for cropping and animal husbandry. In addition, the "soil" or more correctly the coastal dune is saline, alkaline, and sodic with a compacted (sodic-petrocalcic) layer very close to the surface, it is also prone to wind erosion and water erosion when it rains, hence very sparse in vegetation and fodder for livestock. These factors give rise to extreme hardship and poverty to the local population.

During the period of 2003-2005, Mr. Le Van Du and his students from Ho Chi Minh City Agro-Forestry University planted Vetiver on these saline sodic soils to find out whether VS could improve the productivity of farms in desert like conditions with annual rainfall of just 200-300 mm (in south central Vietnam). Agricultural production in that region is very limited, partly due to the adverse soil conditions - a thin compacted gypsum layer in the topsoil effectively prevents roots to penetrate to the more humid layer underneath - and partly to the lack of rainfall. But once established under initial irrigation, Vetiver survived and grew exceptionally well. In three months its roots went down 70 cm penetrating the compacted the gypsum layer, reaching ground moisture which the local crops (maize and grapes) and other plants could not reach.
Vetiver grass grew 2-3 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 the first 2 months.

A great improvement in soil fertility was noted only 3 months after Vetiver planting, pH and soluble salt were greatly reduced. Soil pH reduced up to 2 units from surface layer down to 1m depth and dissolved salt content. Especially sodium content was reduced more than half resulting in very large improvement in productivity of local crops such as corn and grapes, whereas soil pH has hardly changed after 3 years of grape cultivation (Pictures 19-20).



Picture 19 : While Vetiver roots penetrated the compacted barrier to tap ground water and flourished; corn and grape could not and died if not irrigated

Picture 20: Left: sandy soil in its original state; right: the same soil after rehabilitation using Vetiver biomass as mulch, now being used for grape growing, with Vetiver biomass as mulch

4.3 Erosion control on extreme acid sulfate soils

To develop agriculture and aquaculture in the acid sulfate soil region, it is essential to build an effective and stable drainage and irrigation system for watering. In addition the acid sulfate zones are of low in topography and are flooded annually, causing extreme hardship to local population. The common feature of this region is to use local soil – high clay, low pH and high in toxic elements - to build infrastructure, hence very prone to soil erosion due to lack of vegetation covers.

Although different in geographical distribution, the soils are all extreme acid sulfate, pH from 2.0-3.0 in the dry season and with high level of Al, Fe, SO_4^2. Due to the high clay content of the soil, it cracks on drying, resulting in large holes and letting water in, causing erosion in the rain and flood seasons. Because of these features, very few endemic plants can establish and survive during the dry season, including those considered locally as tolerant species

Vetiver grass was used for embankment stabilization and canal bank erosion control at 5 sites located on extreme acid sulfate soils: one flood protection dike (protecting a people cluster or flood-escaping community) in Tien Giang province, three in Long An provinces and one on a section of a flood protection dike near Ho Chi Minh City.

There was no problem with establishment when using polybags, but without polybags (planting directly in the fresh acid sulfate soil) all Vetiver bare root slips died. However it could survive and grew normally on that soil with a small amount of lime, good topsoil or manure added to the furrows first. The survival rate was more than 80% and Vetiver grew normally as planted on good soil.

The following results were recorded:

- over a period of four-months, once Vetiver was established, soil loss by erosion was markedly reduced. On bare canal banks the soil loss was 400-750 tons/ha as compared with only 50-100 tons/ha on a channel embankment protected by Vetiver.
- soil loss was negligible after 12 months.
- when Vetiver was trimmed to 20-30cm height and the shoots were used as mulch covering the bare area of the bank, the banks were completely stabilized (Le van Du and Truong, 2006).

Picture 21: Before and after Vetiver planting on an embankment in extreme acid sulfate soil in Tien Giang province

4.4 Protection of flood-escaping communities or people clusters

In An Giang and Tien Giang Provinces of the Mekong Delta of southern Vietnam major floods occur every year. These floods are usually up to 6-8m deep and can last up to 3-4 months. As a result unless houses are built inside the land protected by major dike systems, they are flooded every year. Therefore people cannot build their permanent homes, they have to rebuild every year causing extreme hardship to subsistent farmers.

To over come this problem, local government select a relative high area and further top it up with soil from the surrounding land, high enough to escape the annual prolonged flood. These are called **Flood-Escaping Communities or People Clusters**. But the banks of these clusters are themselves highly erodible. They need to be protected from the strong current and waves during the flood season. Vetiver planting has been highly effective in protecting these clusters against flood erosion with the added benefit of treating the community effluent and waste water during the dry season.

Picture 22: Flood Escaping Community (or people clusters) in Tan Chau District, An Giang Province (left) and the bank of the cluster (right)

4.5 Protection of farm infrastructure

VS has been widely used to protect farm infrastructure the major uses are aquaculture dikes, rural roads, farm dam etc

In this picture Vetiver is reducing the impact of a gully that drains water from the seasonally flooded farm area (background), towards the river. This gully threatens the shrimp pond (right), and therefore the banks of the pond are also protected with Vetiver, especially in the most vulnerable place, where the farmer drains the water from the pond into the gully.

Picture 23: Protecting a shrimp pond near a natural gully, near a river (Da Nang province); this model was established in the first Vetiver project in Vietnam financed by the Royal Netherlands Embassy

Picture 24: Protecting shrimp pond dikes in Quang Ngai

Picture 25: The right section of this rural road in Quang Ngai is protected by Vetiver and the left section is unprotected

VS stabilizes dirt roads, preventing landslide in mountainous region and river bank erosion on the flood plain. These roads are need for daily access for taking farm produce to market, bringing supply and children to go to school.

In the Philippines and India Vetiver is also widely used to stabilize the narrow dikes separating the paddy fields on sloping land. This planting reinforces the sides of these dikes, so the width of the dikes can be reduced, hence increasing the land area available for cropping. Another added bonus is this planting will provide fodder to the cattle and buffalo during the dry season.

More about stream bank protection in PART 3.

5. OTHER USES

5.1 Handicraft

Vetiver leaves are being used in Thailand, Indonesia, Philippines, Latin America and Africa to produce high quality handicrafts. This is an important aspect of providing works for low income rural community.

For a good handicraft manual we refer to a very well-illustrated, practical guideline “Vetiver Handicrafts in Thailand” by the Pacific Rim Vetiver Network (see references, giving details on how to obtain this guide).
The Royal Development Projects Board of Thailand offers ***free training courses*** to foreign participants on Vetiver handicraft making.

Picture 26: Handicraft products from Thailand

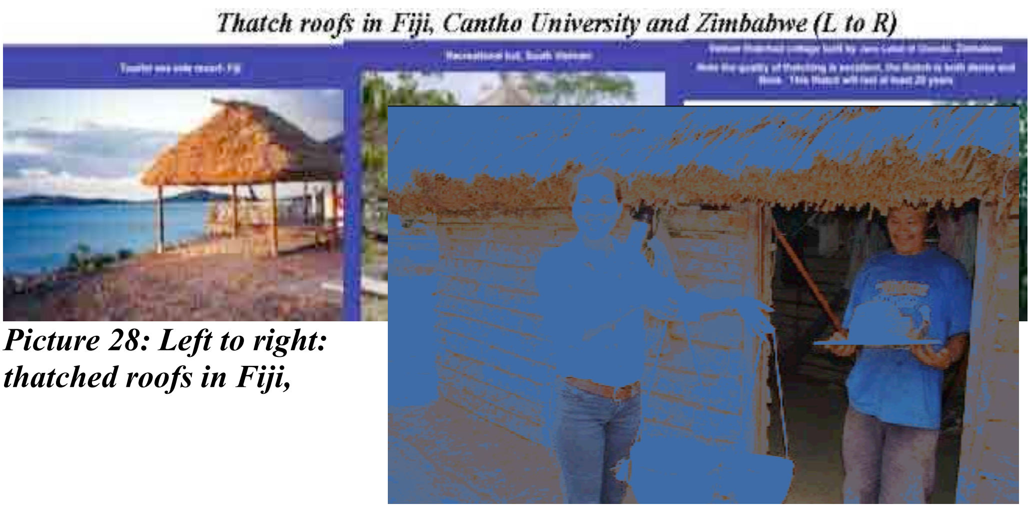
Handicraft products in Thailand




Picture 27: Handicraft products from Venezuela

5.2 Roof thatching

As mentioned above Vetiver tops will last longer than *Imperata cylindrica*, at least twice as long according to farmers in Thailand and Africa. So it is very popular in many countries particularly the south Pacific Island people for thatching purposes. One characteristic is interesting for roof thatching and brick making: the leaves, due to their strong smell, do not attract termites.



Picture 28: Left to right: thatched roofs in Fiji,

Can Tho University and Zimbabwe

Picture 29: Roof thatching in Venezuela

5.3 Mud brick making

Vetiver straw has been widely use in Senegal, Africa, to make mud bricks to , reduce the cracking In Thailand , Vetiver could be used with clay composite for substituted bricks and columns for housing construction. The prefabricated wall has rather low thermal conductivity which makes it comfortable and energy saving. It is truly a labor based appropriate technology.

5.4 Strings and ropes

As rice growing is the main crop of the Mekong Delta, farmers also find another use for Vetiver grass. It can be used as string to bind rice seedlings and rice straw. They prefer Vetiver grass as it is pliant and tough, even more pliant and tougher than other kinds of strings commonly used, as banana, rush and Nipa palm string.

Picture 30: Left: Vetiver growing to reinforce a wooden structure along a river; right: the leaves are cut to make strings for rice binding

5.5 Ornamentals

When mature, Vetiver has light purple and very attractive flower heads, which can be used as cut flowers, potted plants or around the gardens and other public open spaces such as lakes and parks.

Left, *young plants and* Right, *mature flowering plants*

Picture 31: Around a lake on an expensive suburb in Brisbane, Australia

Nice flower heads in Australia and cut flower display in China

Potted plants at Thien sing company, Saigon, Vietnam

Picture 32: Different ornamental applications in Australia, China and Vietnam

5.6 Oil extraction for medicinal purposes and cosmetics

Vetiver roots are widely used in Africa and South America for medicinal purposes, ranging from common cold to cancer treatment. Research in America shows oil extracted from Vetiver roots has anti-oxidant characteristics that are cancer reduction/prevention. In Thailand, research also shows that Vetiver oil has a calming effect on rats, therefore a good ingredient for aromatherapy.

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

Table 3: Production and use of Vetiver root oil in the world
http://www.cimap.res.in/

Chemical composition *vis-à-vis* applications of Vetiver oil:

Perfumery applications:

- pure oil (perfume in its own right) - base note with slow evaporation rate, e.g. Ruh Khus, Majmua
- Vetiverol - weak aroma and high solubility in alcohols, renders best fixative and blending qualities
- diluted forms - flavoring, refreshing and refrigerating applications. e.g. "Vetiver pour Homme" and "Vetivert"

Medicinal aromatherapy:

- skin care, CNS benefits
- useful in bleeding nose and to treat bee stings.

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Links to well illustrated websites:

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