The Vetiver System (VS) relies on a unique tropical plant, vetiver grass - *Chrysopogon zizanioides*, which has been proven and used in some 100 countries for soil and water conservation, slope stabilization, land rehabilitation, pollution control, water quality improvement, disaster mitigation and many other environmental applications that can mitigate the impact of global warming and climate change. It has future potential for atmospheric carbon sequestration and as bio-fuel for power generation and cellulosic ethanol. The Vetiver System is easy to use, low cost and if applied correctly works! This handbook describes its most important uses for the agricultural sector where it should be a key farm technology for farmers of any scale, but particularly small farmers and rural communities in tropical and sub-tropical countries. Its on-farm application could change the lives of many thousands of people, particularly at this time of high food prices and potential crisis in food supply, through the provision of a sustainable method of farming, and an improved quality of life and income benefits. In doing so it would help assure that future generations would have protected and productive land.

This well illustrated handbook has been written to show farmers and rural communities how the technology has been used in the recent past and how it can be used in the future. For more detailed information relating to vetiver research and actual practice the reader is invited to visit the Vetiver Network International's website at: www.vetiver.org

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Published by:
The Vetiver Network International.
A US tax empt non-profit foundation
under US IRS code 501 (3) (c)
dedicated to the world wide
promotion of the Vetiver System.

Paul Truong   Tran Tan Van   Elise Pinners

THE VETIVER SYSTEM FOR AGRICULTURE

Proven and Green Environmental Solutions

THE VETIVER SYSTEM

FOR

AGRICULTURE

Dedicated to

John C Greenfield

The "Father" of the Vetiver System

1st Edition 2008
Published by The Vetiver Network International

Cover by Lily Grimshaw

PREFACE

THE VETIVER SYSTEM FOR AGRICULTURE

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

Vetiver grass can be used for applications that will protect river basins and watersheds against environmental damage, particularly from point source factors relating to: 1. sediment flows (often associated with agriculture and infrastructure), and 2. toxic chemical flows resulting from excess nutrients, heavy metals and pesticides in leachate from agriculture and other industries. Both are closely linked. Vetiver grass also has a number of other important agricultural uses that should make it attractive to farmers and the rural community as a whole.

This handbook is a modified extraction from ***Vetiver Systems Applications - A Technical Reference Manual*** by Paul Truong, Tran Tan Van, and Elise Pinners, and focuses on the Vetiver System for agriculture. It draws on ongoing vetiver work in Vietnam and elsewhere in the world. Its technical recommendations and observations are based on real life situations, problems and solutions. The handbook is aimed primarily at agriculturalists and others responsible for introducing the Vetiver System to farmers and rural communities.

Dick Grimshaw
Founder and Chairman of The Vetiver Network International.

FORWARD

Based on the review of the huge volume of Vetiver System research and application, the authors considered that it was time to compile a new publication to replace the first World Bank published handbook (1987), Vetiver Grass - A Hedge Against Erosion (commonly known as the Green Book), prepared by John Greenfield. This handbook is one of three and focuses on the use of the Vetiver System for agriculture and related uses.

The handbook includes the most up to date R&D results and numerous examples of highly successful results from around the world and particularly from Vietnam, where an intensive country wide vetiver program has been introduced since 2000. The main aim of the handbook is to introduce VS to planners, agriculturists, farmers, and other potential users, who often are unaware of the effectiveness of the Vetiver System for agriculture and community development. Additional supporting information is available online at www.vetiver.org

Details about the authors, and acknowledgments of those who contributed to this handbook can be found in the master manual ***Vetiver Systems Applications - A Technical Reference Manual*** **(2008)**. It is suffice to say that we deeply acknowledge and appreciate all those involved in this handbook production.

The principle author of this handbook is Elise Pinners who is an independent agricultural consultant, and an associate director of the Vetiver Network International.

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

THE VETIVER SYSTEM FOR AGRICULTURE

PART 1
VETIVER GRASS - THE PLANT

CONTENTS

1. INTRODUCTION

The Vetiver System (VS), which is based on the application of vetiver grass (*Vetiveria zizanioides* L Nash, now reclassified as *Chrysopogon zizanioides* L Roberty), was first 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' extraordinary characteristics, VS also has important application 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 stabilizations and rehabilitation, and phyto-remediation. Being vegetative it is also environmental friendly. When planted in single rows vetiver plants will form a hedge which is very effective in slowing and spreading run off water, reducing soil erosion, conserving soil moisture and trapping sediment and farm chemicals on site. Although any hedges can do that, vetiver grass, due to its extraordinary and unique morphological and physiological characteristics described below, can do it better than all other systems tested. In addition, the extremely deep and massively thick root system of vetiver binds the soil and at the same time makes it very difficult for it to be dislodged under high velocity water flows. This very deep and fast growing root system also makes vetiver very drought tolerant and highly suitable for steep slope stabilization.

The Extension Workers Manual, or the Little Green Book
Complementing this handbook is the slim green extension workers pocket book first published be the World Bank in 1987 and referred to on page ii as Vetiver Grass - A Hedge Against Erosion, or more commonly known the “little green book” by John Greenfield. This handbook is far more technical in its description of the Vetiver System and is aimed at technicians, academics, planners and government officials and land developers. For the farmers and field extension workers the "little green book", that can fit in to a shirt pocket, is still an excellent handbook.

2. SPECIAL CHARACTERISTICS OF VETIVER GRASS

2.1 Morphological characteristics:

- Vetiver grass does not have stolons or rhizomes. Its massive finely structured root system 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 water currents.
- Stiff and erect stems that can stand up to relatively deep water flows - photo 1.
- Highly resistance to pests, diseases and fire - photo 2.
- A dense hedge is formed when planted close together acting as a very effective sediment filter and water spreader.
- New shoots develop from the underground crown making

vetiver resistant to fire, frosts, traffic and heavy grazing pressure.

- New roots grow from nodes when buried by trapped sediment. Vetiver will continue to grow up with the deposited silt eventually forming terraces, if trapped sediment is not removed.

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

2.2 Physiological characteristics

- Tolerance to extreme climatic variation such as prolonged drought, flood, submergence and extreme temperature from -14ºC to +55ºC.
- Ability to re-grow very quickly after being affected by drought, frosts, salinity and adverse conditions after the weather improves or soil ameliorants added.
- Tolerance to wide range of soil pH from 3.3 to 12.5 without soil amendment.
- High level of tolerance to herbicides and pesticides.
- Highly efficient in absorbing dissolved nutrients such as N and P and heavy metals in polluted water.
- Highly tolerant to growing medium high in acidity, alkalinity,

salinity, sodicity and magnesium.

- Highly tolerant to Al, Mn and heavy metals such as As, Cd, Cr, Ni, Pb, Hg, Se and Zn in the soils.

2.3 Ecological characteristics

Although vetiver is very tolerant to some extreme soil and climatic conditions mentioned above, as typical tropical grass, it is intolerant to shading. Shading will reduce its growth and in extreme cases, may even eliminate vetiver in the long term. Therefore vetiver grows best

Photo 2: Upper: Vetiver grass surviving forest fire; lower: two months after the fire.

in an open and weed free environment, weed control may be needed during establishment phase. On erodible or unstable ground vetiver first reduces erosion, stabilizes the erodible ground (particularly steep slopes), then because of nutrient and moisture conservation, improves its micro-environment so other volunteered or sown plants can establish later. Because of these characteristics vetiver can be considered as a nurse plant on disturbed lands,

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

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

2.4 Cold weather tolerance of vetiver grass

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

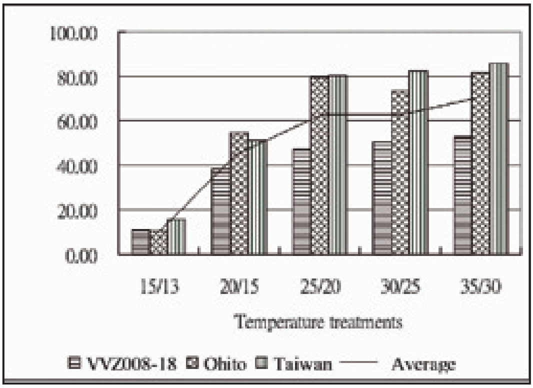

Figure 1: The effect of soil temperature on the root growth of vetiver.

2.5 Summary adaptability range

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

Condition characteristic	Australia	Other Countries
Adverse Soil Conditions		
Acidity (pH)	3.3-9.5	4.2-12.5 (high level soluble Al)
Salinity (50% yield reduction)	17.5 $mScm^{-1}$	
Salinity (survived)	47.5 $mScm^{-1}$	
Aluminium level (Al Sat. %)	Between 68% - 87%	
Manganese level	> 578 $mgkg^{-1}$	
Sodicity	48% (exchange Na)	
Magnesicity	2400 $mgkg^{-1}$ (Mg)	

Continued on next page ....

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

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

2.6 Genetic characteristics

Three vetiver species are used for environmental protection purposes.

2.6.1 Vetiveria zizanioides reclassified as Chrysopogon zizanioides

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

2.6.2 Chrysopogon nemoralis

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

Photo 5: Vetiver leaves, upper: *C. zizanioides*, lower: *C. nemoralis.*

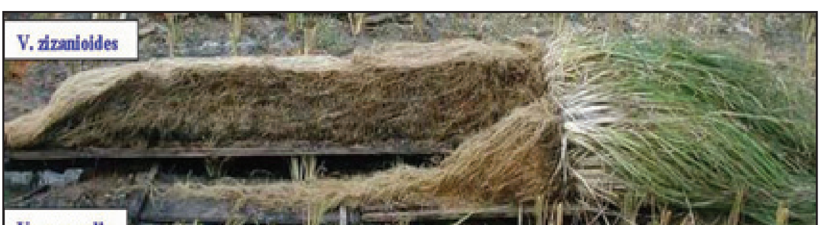

Photo 6: Difference between *C. zizanioides* (upper) and *C. nemoralis* roots (lower).

Photo 7: Vetiver shoots, upper: *C. nemoralis*, lower: *C. zizanioides.*

Photo 8: Vetiver roots when grown in soil (upper) and when grown/suspended in water (lower).

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

Photo 9: *C. nemoralis* on a rice field bund Quang Ngai (upper), and in the wild in the Central Highlands of Vietnam (lower).

2.6.3 Chrysopogon nigritana

This species is native to Southern and West Africa, its application is mainly restricted to that continent, and as it produces viable seeds its application should be restricted to their home lands - photo 10.

2.7 Weed potential

Vetiver grass cultivars derived from south Indian accessions are non-aggressive; they produce neither stolons nor rhizomes and have to be established vegetatively by root (crown) subdivisions. It is imperative that any plants used for bioengineering purposes will not become a weed in the local environment; therefore sterile vetiver cultivars

Photo 10: *Chrysopogon nigritana* in Mali, West Africa. Note how green the vetiver is compared to the nearby non vetiver grasses.

(such as Monto, Sunshine, Karnataka, Fiji and Madupatty) from south Indian accessions are ideal for this application. In Fiji, where vetiver grass was introduced for thatching more than 100 years ago, it has been widely used for soil and water conservation purposes in the sugar industry for over 50 years without showing any signs of invasiveness. Vetiver grass can be destroyed easily either by spraying with glyphosate

(Roundup) or by cutting off the plant below the crown.

3. CONCLUSION

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

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PART 2
VETIVER GRASS - PROPAGATION

CONTENTS

1. INTRODUCTION

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

2. VETIVER NURSERY

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

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

Photo 1: Upper: Machine planting; lower: manual planting.

3. METHODS OF PROPAGATION

The four common ways to propagate vetiver are:

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

3.1 Splitting mature plants to produce bare root slips

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

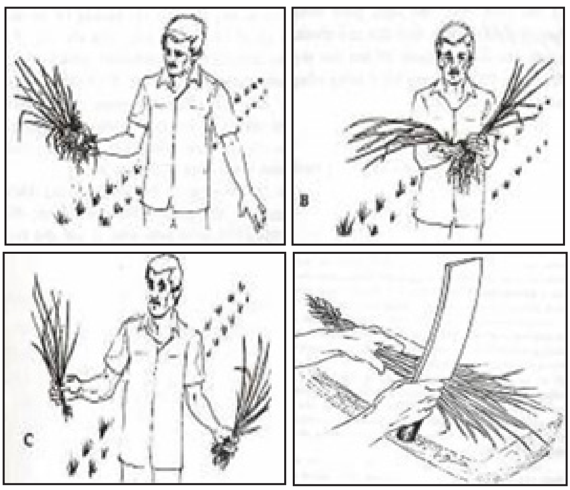

Figure 1: How to split vetiver slips.

3.2 Propagating vetiver from plant parts

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

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

A culm is the stem or stalk of a grass. The vetiver culm is solid, stiff, and hard; it has prominent nodes with lateral buds that can form roots and shoots when exposed to moist conditions. Laying or standing, cut pieces of culms under mist or on moist sand will cause roots or

Photo 2: Bare root slips ready for planting out (upper); being dipped in clay mud or manure slurry (cow tea) (lower).

shoots to develop rapidly at each node. Le Van Du, Agro-Forestry University, Ho Chi Minh City, developed the following four-step method of propagating vetiver from cuttings:

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

Photo 3: Old tillers (upper) and young tillers (lower).

3.2.1 Preparing vetiver cutting

Vetiver culms:

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

Vetiver tillers:

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

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

Vetiver crown or corms:

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

3.2.2 Preparing water hyacinth solution

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

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

- Strain the solution and maintain in a cool place until use.

3.2.3 Treatment and planting

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

3.2.4 Advantages of using bare root slips and culm slips

Advantages:

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

Disadvantages:

- Vulnerable to drying and extreme temperatures.
- Limited on-site storage time.

- Requires planting in moist soil.
- Needs frequent irrigation in the first few weeks.

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

- Recommended for good nursery sites with easy access to irrigation.

3.3 Bud multiplication or micro propagation

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

- Inducing lateral bud development.
- Multiplying new shoots.

- Promoting root development on new shoots.
- Promoting growth in shade house or glasshouse.

3.4 Tissue culture

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

4. PREPARING PLANTING MATERIAL

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

- polybags or tubestock.
- planting strip.

4.1 Polybags or tube stock

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

4.2 Planting strip

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

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

4.2.1 Advantages and disadvantages of polybags and planting strips

Advantages:

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

Disadvantages:

- More expensive to produce.
- Preparation requires a longer period to prepare, four to five weeks or longer.

- Transporting large volume and increased weight is expensive.
- Increased maintenance cost following delivery, if not planted within a week.

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

5. NURSERIES IN VIETNAM

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

Photo 9: In the south, upper: Can Tho University; lower: An Giang province.

Photo 10: In the centre south, in Quang Ngai (upper) and Binh Phuoc (lower).

Photo 11: In the north, in Bac Ninh (upper) and Bac Giang (lower).

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PART 3
ON-FARM EROSION CONTROL AND OTHER USES FOR VETIVER

CONTENTS

1. INTRODUCTION

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

2. SOIL AND WATER CONSERVATION

2.1 Soil and water conservation principles

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

Therefore the main goals of water erosion control practice are to protect the soil surface from being dislodged by the impact of the raindrops, to reduce the volume of runoff water using vegetative covers, and to control or lower the overland flow velocity. Contour/diversion banks (terraces) by design, divert runoff to a safe outlet, or waterway, or the drainage network. Vegetative barriers such as vetiver hedges planted across the slope or on the contour control the runoff, spreading it out and slowing it down as it slowly filters through the hedge. Since the erosive power of both water and wind erosion is proportional to the flow velocity (the speed of the downhill water and the force of the wind), the main principle of soil conservation is to reduce the speed of water and air. Correctly installed, vetiver hedges effectively control both water and wind erosion. The objective of water conservation practice is to increase water infiltration to the soil body. This goal can be achieved most readily using vegetative cover, particularly vegetative hedges. When planted across the slope or on contour lines, dense vetiver hedges form a slowly permeable barrier that spreads runoff water and reduces its velocity. This allows more time for soil to absorb the water and the hedge to trap sediment.

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

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

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

- Its vertical root system, with very little lateral root growth. This ensures that the plant, when intercropped, generally does not compete with adjacent crops for nutrients and water.

Part 1 of this handbook addresses the characteristics of vetiver in more detail. This part focuses on the important role in farming played by the first two characteristics: Vetiver's soil-binding root system and its ability to form dense hedgerows. Vetiver's strong root system is unmatched by any other plant used for on-farm erosion control. On flat lands and on gully floors, where the velocity of raging floodwater can be devastating, vetiver's deep, strong roots prevent the plant from dislodging. This grass can withstand extremely strong currents.

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

In addition to reducing surface erosion on sloping land, vetiver's massive root system also contributes to slope stability. As described in Part 1, the deep, fibrous roots reduce the risk of landslide or collapse.

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

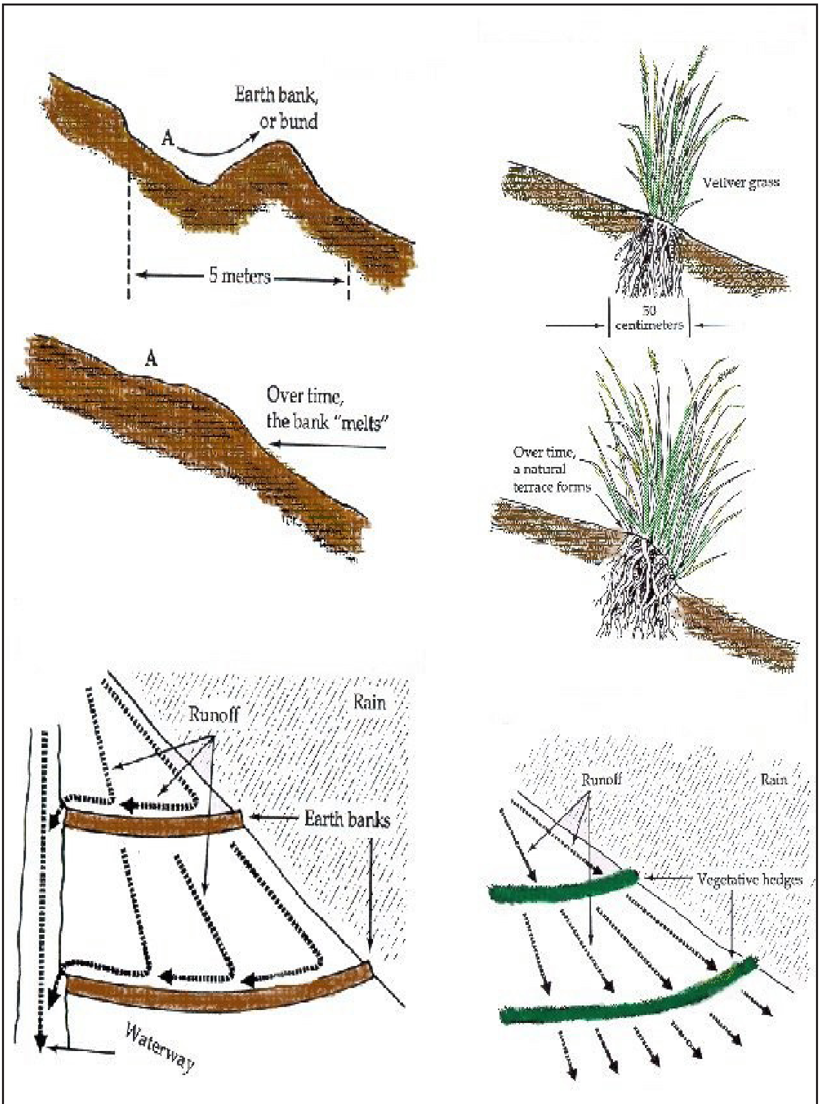

Figure 1: Above left: contour bank; below left: banks divert the water; above right: Vetiver hedges create banks or terraces over time; below right: Vetiver hedges slow the runoff to increase infiltration, and the water remains in the field (Greenfield 1989).

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

A review conducted for the World Bank compared the effectiveness and practicality of different soil and water conservation systems. It found that constructed measures must be site-specific and require detailed and accurate engineering and design. Furthermore, all hard systems require regular maintenance. Most evidence also suggests that constructed works reduce soil losses, but do not reduce runoff significantly. In some cases, they have a negative impact on soil moisture (Grimshaw 1988). On the other hand, when planted across the slope or on the contour, the vegetative conservation system forms a protective barrier across the slope that slows the runoff water and hoards sediment deposits. Since the barriers only filter the runoff and often do not divert it, water seeps through the hedge, reaching the bottom of the slope at lower velocity without causing any erosion and without being concentrated in any particular area. This is the flow-through system (Greenfield 1989), a sharp contrast to the contour terrace/waterway system in which runoff water collects by the terraces and is diverted quickly from the field to reduce its erosive potential. Since all runoff water is collected and concentrated in waterways where most erosion occurs on agricultural lands, particularly sloping lands, this water is forever lost from the field; and also unavailable for groundwater recharge. The flow-through system, on the other hand, conserves water and dispenses with the need for waterways - figure 1.

This water conservation practice is very important in low rainfall regions such as the Central Highlands and Central Coastal Vietnam. Ideally, species to be used as barriers for effective erosion and sediment control should have the following features (Smith and Srivastava 1989):

- Form an erect, stiff and uniformly dense hedge that offers high resistance to overland water flow, and have extensive and deep roots that bind the soil and prevent rilling and scouring near the barrier.
- Survive moisture and nutrient stress and re-establish top growth quickly after rain.

- Result in minimum loss of crop yield (the barrier should not proliferate as a weed, not compete for moisture, nutrients and light, and not host pests and diseases).
- Require only a narrow width to be effective.
- Supply materials that have economic value to farmers.

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

2.4 Application on flood plains

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

Vetiver hedges on flood plains:

- Reduce flow velocity that can lodge crops, and the run off's erosive power.
- Trap fertile alluvial soil on site, which maintains the fertility of the plain.
- Increase water infiltration in low rainfall regions such as Ninh Thuan province.

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

In a large field trial at Jondaryan (Darling Downs, Queensland, Australia), six rows of vetiver totalling more than 3000m (900 linear feet) were planted on the contour at 90m (180 feet) spacing.

These rows provided permanent protection against floodwaters. Data collected from a small flow over the site shows that the hedges reduce significantly the depth and resulting energy of water flowing through the hedges. At a low depression, a single hedge trapped 7.25 tons of sediment. Results over the last several years, including several major flood events, confirm that VS successfully reduces flood velocity and limits soil movement, with very little erosion in fallow strips (Truong et al. 1996, Dalton et al. 1996a and Dalton et al. 1996b). This trial demonstrates that VS is a viable alternative to strip cropping practices on Australia's flood plains.

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

2.5 Application on sloping land.

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

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

Similar results have been reported on a range of slopes, soil types, and crops in Venezuela and Indonesia. In Natal, South Africa, vetiver hedges have increasingly replaced contour banks and waterways on steep sugarcane lands, where farmers have concluded that the vetiver system is the most effective and low-cost form of soil and water conservation in the long term (Grimshaw 1993). A cost-benefit analysis conducted on the Maheswaran watershed in India considered

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

both engineered structures and vetiver vegetative barriers. The vetiver system was adjudged more profitable even during its initial stages due to its efficiency and low cost (Rao 1993).

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

- Flood erosion control on the flood plains of the Darling Downs.
- Erosion control in acid sulfate soil.

- Contour bank replacement in steep sugar cane lands in North Queensland.

In Vietnam most of the on-farm experience with the Vetiver System was gained from 'the cassava project' (a Nippon Foundation project: 'Enhancing the Sustainability of Cassava-based Cropping Systems in Asia', in China, Thailand and Vietnam, 1994-2003), implemented in collaboration with Thai Nguyen University of Agriculture and Forestry (TUAF), National Institute for Soil Fertility (NISF), and Viet Nam Agricultural Science Institute (VASI, now VAAS). This project worked with farmers in northern mountainous areas in Yen Bai, Phu Tho, Tuyen Quang, and Thai Nguyen, in mountainous parts of Thua Thien Hue province, and the southwest. Note: Cassava (*Manihot esculenta*) is one of the most important staple crops in humid tropical regions, but as a tuber crop typically planted in monoculture it is one of the most erosive crops in the developing world. Hence the importance of promoting more sustainable Cassava production systems. In this project farmers tested several combinations of measures including: 1. intercropping (e.g. contour farming with groundnut); 2. introduction of improved planting material (low-branching varieties to reduce impact of rain) combined with increased (organic and chemical) fertilization, and last but not least; and 3. anti-erosion hedgerows. The application of VS proved to be among the most effective measures to reduce soil loss (see CIAT cassava project).

2.6 Effects on Soil Loss

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

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

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

Photo 5: Soil trapped behind a vetiver hedge in Dong Rang, northern Vietnam. It also provides in-situ mulch, stops runoff and erosion, and reduces the slope by forming natural terraces.

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

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

Countries	Soil loss (t/ha)			Runoff (% of rainfall)		
	Control	Conven-tional	VS	Control	Conven-tional	VS
Thailand	3.9	7.3	2.5	1.2	1.4	0.8
Venezuela	95	88.7	20.2	64.1	50	21.9
Venezuela (15% slope)	16.8	12	1.1	88	76	72
Venezuela (26% slope)	35.5	16.1	4.9	-	-	
Vietnam	27.1	5.7	0.8	-	-	
Bangladesh	-	42	6-11	-	-	
India	-	25	2	-	-	

(Truong and Loch, 2004)

Dr. Pham Hong Duc Phuoc, Nong Lam University, led researchers in tests of vetiver's soil conservation properties on coffee plantations on sloping land in Dong Ngai province (southwest Vietnam). In Indonesia the introduction of VS on-farm has been very effective through a school organic gardening education program. In the Bali Poverty Project VS is planted by school children in gardens, as well as on local roads.

Photo 7: Vetiver hedges protect organic school garden on 50% slopes (East Bali Poverty Project).

2.7 Design and extension: farmers' considerations

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

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

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

A. How important is the soil erosion problem?

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

mulch, and plant varieties that are low-branching, have a fast closing canopy)?

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

B. How important is the cropping system, compared to other parts of the farm? Farmers are more interested to invest in conservation practices that produce a profitable crop:

- What is the relative value of the piece of land (willingness to invest labour, money)?
- What is the general position of the farmer? How much labour/money can he/she invest in this plot? What compete with her/his time and money (e.g. paddy land or off-farm labour)?
- Is the farmer sufficiently sure of land tenure to justify efforts improving it?
- Does the distance from homes to the fields justify labour investment?
- Can the farmer use vetiver in complementary applications?

- Is there enough nursery space to propagate vetiver, or otherwise obtain it?
- What policies militate against applying soil and water conservation measures?
- What ecological limitations affect the use of vetiver? (e.g. Vetiver does not tolerate shade; once established, however, shade is less of a problem).

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

Photo 9. A 2007 Google Earth image of farmland in Fiji that John Greenfield planted with vetiver hedgerows in the 1950s'. The hedgerows are still there (red arrows) after 50 years.

3. OTHER MAJOR ON-FARM APPLICATIONS

3.1 Crop protection: stem borer control in maize and rice

Stem borers attack maize, sorghum, rice and millets in Africa and Asia - photo 10. The moths lay their eggs on the leaves of the crop. Professor Johnnie van den Berg, entomologist, (School of Environmental Sciences and Development, Potchefstroom University, South Africa.) found that the moths prefer to lay eggs on the leaves of vetiver planted around the crop instead of on the maize or rice crop itself. Given the option, about 90% of the eggs are deposited on vetiver instead of on the crop. This is known as the "push pull" system - figure 2.

Photo 10: Stem borers (*Chilo partellus*).

Because vetiver leaves are hairy, the larvae that hatch on them cannot move around easily. The larvae fall off the plant - photo 11, and die on the ground, resulting in very high mortality, about 90%. Vetiver also harbours many helpful insects that are predators of pests that attack crops. In cooperation with Dr. van den Berg, Can Tho University is currently studying the practical application of this effect on rice. Preliminary results are very promising. Van den Berg also reports that the sugar cane borer, *Eldana saccharina* prefers to lay its eggs on vetiver. In India *Chilo partellus* also is found in cane. Vetiver grass hedgerows - photo 12, provide very good habitat for beneficial insects such *Chrysopidae sp*. Vetiver alone is not enough to control pests and must be part of an overall IPM package that manages crop health.

Photo 11: Vetiver's hairy leaves make it an inhospitable host; stem borer larvae drop off and die on the ground.

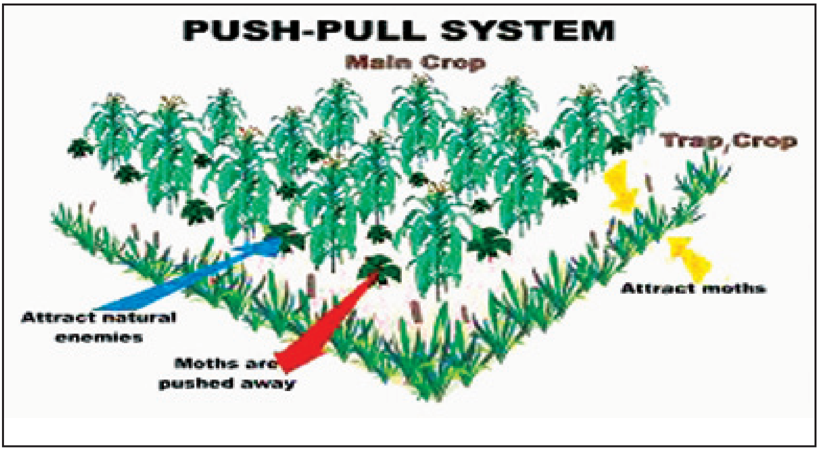

Figure 2: The Push-Pull system: Vetiver attracts the insect to lay eggs where they have little chance of survival.

Photo 12: Maize stem borer control (Zululand, South Africa).

3.2 Animal feed

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

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

Vetiver leaves are generally useful by-products of soil and water conservation measures. Vetiver leaves are nutritious when cut (pruned) at intervals between one and three months, depending on climatic conditions. Their nutrient content, like many tropical grasses, varies according to season, growth stage and soil fertility. In India when vetiver is chopped by a manual forage chopper domestic buffaloes find the grass totally palatable.

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

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

When vetiver is used for other purposes, fodder may prove an added value. After an extremely harsh winter in Quang Binh province, vetiver was the only green fodder available; the cold had killed the other grasses. Further, vetiver grass growing on pig farm waste contains high contents of crude protein, carotene and lutein, relatively lower contents of Ca, Fe, Cu, Mn and Zn, and acceptable levels of heavy metal, Pb, As and Cd (Pingxiang Liu 2003).

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

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

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

Photo 13: Upper: buffalo graze on vetiver bordering a dike; lower: cattle eat young vetiver.

3.3 Mulch to control weeds and conserve soil water

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

Weed control: When spread evenly on the ground, whole or desiccated vetiver leaves form a thick matt that suppresses weeds. Vetiver mulch successfully controls weeds in coffee and cocoa plantations in the Central Highlands of Vietnam and tea plantations in India.

Photo 14: Vetiver controls erosion and its mulch suppresses weeds in coffee plantation in the Central Highlands of Vietnam.

Water conservation: The thick cover of vetiver mulch increases water infiltration and reduces evaporation, particularly important under the hot, dry conditions of the coastal provinces like Ninh Thuan. It also protects the soil surface from the impact of raindrops, a major cause of soil erosion. Research in India, Nigeria and Thailand and other countries demonstrate improvement in crop yields - see para 2.5.

As mentioned earlier vetiver hedgerows reduce rainfall run off significantly. Much of this reduction finds its way to the groundwater as recharge. This is a very important aspect as there is plenty of evidence that this improved recharge results in increased and prolonged stream flow, subsurface recharge of farm ponds, and improved spring flows - all important to small farmers and the community as a whole.

Photo 15: Vetiver mulch controls weeds in a tea plantation, southern India (P Haridas).

3.4 Vetiver seedlings.

Due to the growing demand for vetiver in VS applications for non-agricultural sectors the production of vetiver seedlings (slips) as a marketable product is an expanding actuality. Vetiver slips are easy to produce in very large quantities. The most common forms of production are bare rooted or containerised. Under good conditions (adequate water and nutrients) it is quite possible to produce at least 500,000 slips (with three tiller each) per ha per year. In most countries this would gross at least US $15,000 per ha. It is therefore to the benefit of farmers if farmers groups or their representatives lobby other sectors to use the Vetiver System for slope protection, pollution control, and disaster mitigation. In countries, such as India, Indonesia, and Haiti where vetiver is grown for the aromatic oil, the sale of plant material (only a small portion of the root is sacrificed when slips are produced) should prove a very good bi-product, and would make, what is often a marginally business a lot more profitable at very little extra cost. It is conservatively estimated that in south India 15-30 billion slips a year might be available as a biproduct from vetiver oil producing farms.

Photo 16: A potential source of plant material - a 15 ha aromatic oil farm in Tamil Nadu, India with a potential of 7.5 million slips a year (Bharat Singh).

4. FARMLAND REHABILITATION AND PROTECTION OF FLOOD REFUGE COMMUNITIES

4.1 Sand dune stabilization

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

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

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

Several issues should be considered when addressing dune slope protection:

1. Assessing and planning together with local communities is very important a community can:
    - provide valuable ideas during planning.
    - contribute financially.
    - provide labour for implementation.
    - protect and maintain the plantings.
    - benefit from employment associated with the establishment and maintenance of the site.
2. Training local people: When teaching local people about vetiver

multiplication, planting and maintenance, provide instruction about its other uses (fodder, handicraft).

3. Propagation: Local nurseries can be contracted to propagate vetiver and supply bare root slips for installation.
4. Maintenance and monitoring: The local community can monitor and maintain the plantings. Dry sands shift, sometimes burying or even washing away the young grass, so maintenance at early stages is important.

Photos 17 and 18 - Community vetiver hedges on dunes in Le Thuy district of Quang Binh province.

Photo 17: Upper, Early April 2002 – vetiver one month after planting. Note: Mulch was put above the top row. Lower, mid October 2002 - seven months after planting.

Photo 18: Shows the way the local community extended the practice, with support from local foresters. February 2003: hedgerows established in October 2002 survived the coldest-ever winter in Quang Binh.

Vetiver is equally effective in reducing blowing sand. For this use, the grass should be planted across the wind direction, especially in troughs between sand dunes, where wind velocity typically increases. This use has been tested on coastal dunes in Senegal - photo 19a, and on Pintang Island, off the East China coast - photo 19b.

Photo 19a: Vetiver protects dunes at a beach resort in Senegal.

Photo 19b: Pingtang Island, China from wind erosion. Also forms a windbreak to protect crops.

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

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

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

From 2003 to 2005, Professor Le Van Du and his students from Ho Chi Minh City Agro-Forestry University planted vetiver on these saline sodic soils to determine whether VS could improve the productivity of farms in desert-like conditions. They learned that, once established under initial irrigation, vetiver grew exceptionally well. During the first two months, vetiver grew two to three times faster than any

Photo 20a: Vetiver roots penetrated compacted gypsum barrier to tap ground water and flourished.

other crop, yielding a fresh biomass of 12 tons on non-saline sandy soils (96% sand) and 25 tons on alkali-sodic soils. In three months, its roots penetrated 70 cm (26.5”), through the compacted gypsum layer, reaching ground moisture that local maize, grapes, and other plants could not reach. The scientists noted a great improvement in soil fertility after only three months, specifically that soluble salt and pH had been greatly reduced. Although soil pH had hardly changed after three years of grape cultivation, following the vetiver installation soil pH declined up to 2 units from the surface layer to a depth of 1m (3’), and dissolved salt content. The reduction in sodium content by more than half dramatically improved the productivity of local crops such as corn and grapes.

Photo 20b: Upper: Sandy soil in its original state; lower: the same soil, now used for a vineyard, following rehabilitation using vetiver mulch.

4.3 Erosion control on extreme acid sulfate soils

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

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

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

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

The following results were recorded:

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

4.4 Protection of flood-refuge communities or people clusters

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

Photo 21: Before (upper) and after (lower) vetiver installation in extreme acid sulfate soil on an embankment in Tien Giang province, Vietnam.

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

Photo 22: Upper: Flood-Refuge Community (or People Clusters) in Tan Chau District, An Giang Province; lower: the bank of the Cluster.

4.5 Protection of farm infrastructure

VS is widely used to protect farm infrastructure by stabilizing farm dams, aquaculture dikes, and rural roads, among other applications. Photo 23 shows vetiver reducing the impact of a gully that drains water from the seasonally flooded farm area (background) towards the river. Since the gully also threatens the shrimp pond (right), vetiver also protects the banks of the pond, especially in the area where the farmer drains the water from the pond into the gully, the most vulnerable place. Vetiver stabilizes slopes bordering dirt roads and rivers, preventing landslides in mountainous regions and riverbank erosion on the flood plain. In the Philippines and India, vetiver is also widely used to stabilize the narrow dikes that separate paddy fields on sloping land. This planting reinforces the sides of these dikes and as a result reduces the width of the dikes, thus releasing more land available for cropping. An added bonus is that the planting will provide fodder for cattle and buffalo during the dry season.

Photo 23: Vetiver protects a shrimp pond near a natural gully that drains water into a river (Da Nang province); this model was established as part of the first vetiver project financed by the Royal Netherlands Embassy in Vietnam.

Photo 24a: Vetiver, installed in a cross-hatched pattern, protects shrimp pond dikes in Quang Ngai.

Photo 24b: Vetiver, installed in a cross-hatched pattern, protects shrimp pond dikes in Quang Ngai; photo shows both left and right side of dike.

Photo 25: The right section of this rural road in Quang Ngai is protected by vetiver; the left section is unprotected.

5. OTHER USES

5.1 Handicraft

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

Photo 26a: Typical Thai handicrafts supported by the Royal Development Projects Board of Thailand.

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

Photo 26b: Typical Thai handicrafts supported by the Royal Development Projects Board of Thailand.

Photo 27: Vetiver handicrafts from Mali made by weaving vetiver root into a " fabric" for pillows and throws.

Photo 28a: Vetiver handicrafts made by a Venezuelan women's cooperative supported by the POLAR Foundation.

Photo 28b: Vetiver handicrafts made by a Venezuelan women's cooperative supported by the POLAR Foundation.

5.2 Roof thatch

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

Photo 29: Left to right: Thatched roofs in Fiji, Vietnam and Zimbabwe.

Photo 30: Roof thatching in Venezuela.

5.3 Mud brick making

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

5.4 Strings and ropes

Farmers who grow rice, the main crop of the Mekong Delta, have discovered another use for vetiver leaves as string to bind rice seedlings and rice straw. They prefer vetiver string because it is pliant and

Photo 31: Left: Vetiver reinforces a wooden structure along a river; right: cut vetiver leaves make string for use as rice binding.

tough, even more pliant and stronger than the banana, rush and Nipa palm string commonly used.

5.5 Ornamentals

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

Photo 32: Vetiver borders a lake in an expensive suburb (Brisbane, Australia).

Photo 33: Different ornamental applications in Australia, China and Vietnam.

5.6 Oil extraction for medicinal purposes and cosmetics

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

Table perfumery applications:

- Pure essential oil (perfume in its own right) - known as Ruh Khus, Majmua. Note, because of the oils low volatility it provides a base for other fragrances to adhere to.
- Vetiverol - weak aroma and high solubility in alcohols,

renders best fixative and blending qualities.
- Diluted forms - flavouring, refreshing and refrigerating applications (colognes, toilet waters).

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

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

Vetiver root Oil : Vetiver Oil

U.C. Lavania

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

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

5.7 Relationship between different uses of vetiver

Table 4 gives some indication of the different uses and applications of vetiver and their relationship to both environmental and economic benefits. As can be seen they are very much interlinked, and the potential for sector wide linkage to the farming community is high.

Table 4. Vetiver Systems – Relationship between type of application and grower owner benefits.

POTENTIAL BENEFITS TO GROWER OR OWNER - cost savings or net income gain	Investment savings	Maintenance redu	Production increas	Forage	Mulch	Paper	Energy Biomass	Handicrafts	Aromatic Oil	Medicinal	Industrial materials	Planting material	Carbon credits	Social Benefits
APPLICATION TYPES														
Agriculture														
Soil and water conservation	+	+	+	+	+	+	+	+			+	++	+++	+
Land Rehabilitation			+	+	+	+	+	+			+	++	+++	+
Soil Fertility improvement	+	+	+	+	+	+	+	+			+	++	+++	+
Pest Control	+	+	+	+	+	+	+	+			+	++	+++	+
Farm infrastructure Protection	+	+	+	+	+	+	+	+			+	++	+++	+
On Farm pollution control	+	+		+	+	+	+	+			+	++	+++	+
Fish pond enhancement	+	+	+	+	+	+	+	+			+	++	+++	+
Non agricultuture														
Slope protection and stabilization	+	+		+	+	+	+	+			+	++	+++	+
Land Rehabilitation	+	+		+	+	+	+	+			+	++	+++	+
Water quality improvement	+	+		+	+	+	+	+			+	++	+++	+
Pollution control	+	+		+	+	+	+	+			+	++	+++	+
River bank, dam, canal, drain, levee	+	+		+	+	+	+	+			+	++	+++	+
Mine tailing rehabilitation	+	+		+	+	+	+	+			+	++	+++	+
Municipal waste stabilization	+	+		+	+	+	+	+			+	++	+++	+
Health (drying up wet areas)	+	+		+	+	+	+	+			+	++	+++	+
Constructed wetlands	+	+		+	+	+	+	+			+	++	+++	+
Coastal protection	+	+		+	+	+	+	+			+	++	+++	+

Continued on next page ...

POTENTIAL BENEFITS TO GROWER OR OWNER - cost savings or net income gain APPLICATION TYPES	Investmant savings	Maintenance redu	Production increase	Forage	Mulch	Paper	Energy Biomass	Handicrafts	Aromatic Oil	Medicinal	Industrial materials	Planting material	Carbon credits	Social Benefits
Specialized planting														
Plant material production				+	+	+		+				+	+++	+
Root production (oil)									+			+	+++	+
Medicinal										+			+++	+
Climate change														
Bio-mass for fuel							+						+++	+
Carbon sequestering				+	+	+	+	+			++		+++	+

+ entirely feasible; ++ dependent on other sector demand; +++ definitely sequesters carbon (carbon credits not yet established).

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