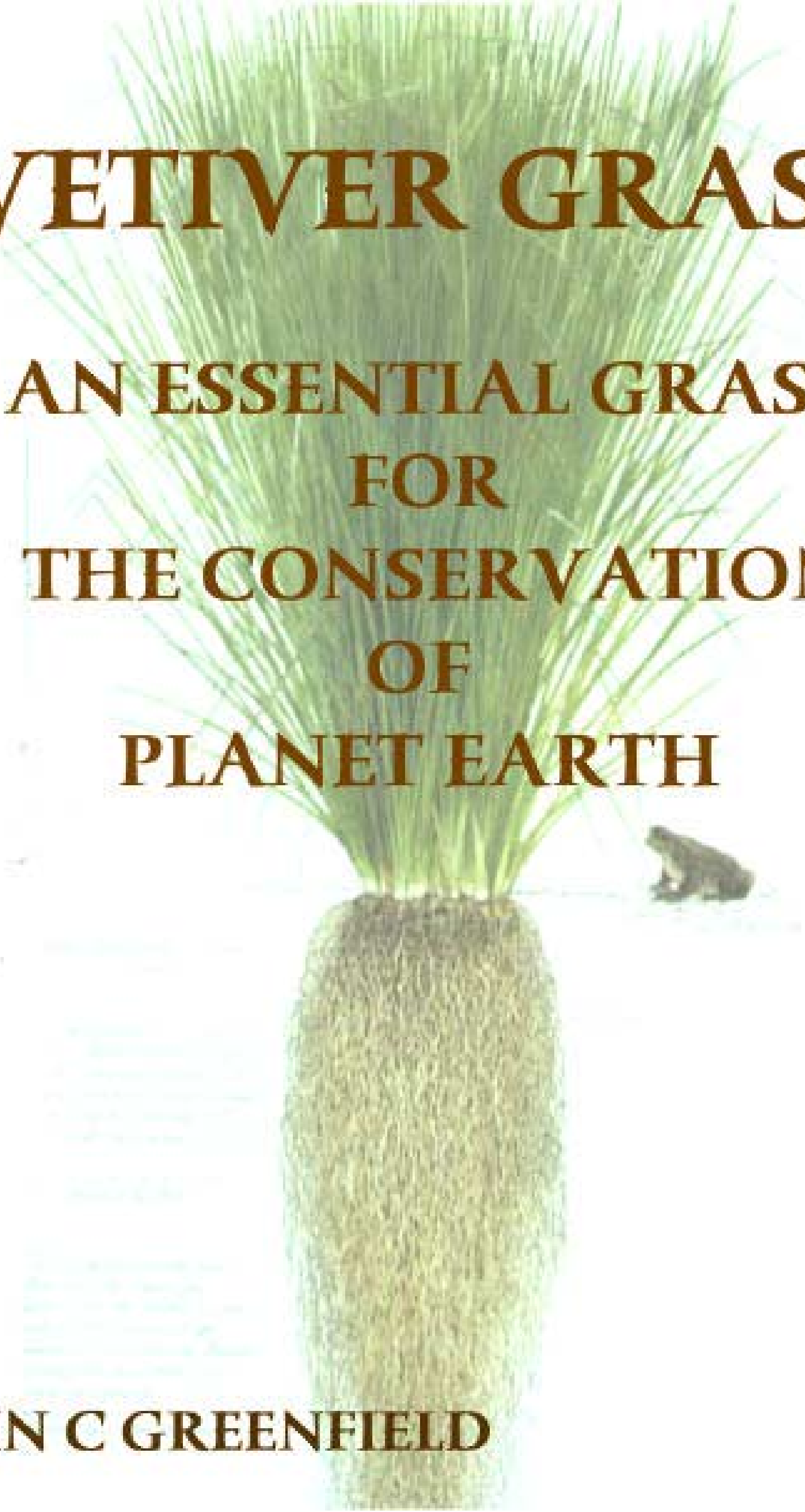

VETIVER GRASS

AN ESSENTIAL GRASS FOR THE CONSERVATION OF PLANET EARTH

JOHN C GREENFIELD

A vetiver hedgerow, under drought conditions in India, used for soil erosion control and insitu moisture conservation

Society is always taken by surprise at any new example of common sense.

Ralph Waldo Emerson (1803-82)

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Preface

Soil conservation generally has been accepted as an essential principle in all good farm management systems since 1935 when Hugh Hammond Bennett, who wrote *Soil Conservation*, persuaded the United States government that it had a duty to help farmers cultivate their land in such a way that it did not deteriorate with use (Bennett 1939). Centuries before that recent time, a well-understood principle stood as an unwritten rule: *When a man hands over his farm to his son, he should always aim to turn it over in a condition that is at least as good as when he inherited it from his father*.

Today, with the problem of increasing population densities, indigenous systems of farming in the tropics and sub-tropics are changing. To address the population increase, and thus the need for more food crops, farmers have increased the proportion of land under cultivation in any one year and reduced the time for the land to lie fallow. At the same time, they have begun cultivating land that once was considered marginal. This change in farming practice goes against all principles of conservation.

Cultivating land that traditionally was considered unsuitable for the purpose and overcultivating the good land have led to massive problems of soil loss and runoff. The original system of soil conservation devised in Bennett's time is no longer appropriate or applicable in the tropics and never really was. His system was designed and developed over the years for temperate climates with low-intensity, well-distributed rainfall. In the tropics, high-intensity storm water running off the soil surface disperses and carries away not only the soil but also the nutrients—and today, the pollutants of population pressure.

Today, farming in the tropics calls for a more appropriate conservation system that (1) is adapted to the local farmers and the region, (2) is a form of natural control that farmers can afford and apply without any outside help, (3) can withstand the extreme forces of nature and yet remain effective for decades at little cost to the farmers and the regions that need it, and (4) has a major impact on groundwater reserves that are essential for the future.

This book introduces the *Vetiver System*—a natural system of conservation—as a method for bridging the gap between the agriculturalist and the engineer, both of whom are striving to stabilize the land they work with. Ideally, experienced specialists should plan and carry out agricultural development, but most developing countries have not yet built up this expertise. This book aims to provide planners in the government and private sectors with as much information as possible on this natural system of conservation for future application. It does not cover the entire subject, however; it takes shortcuts, and in places, oversimplifies for clarity.

Launching the Vetiver System worldwide would have been impossible without the help of many talented and tireless workers in the field. Richard Grimshaw has been outstanding in his efforts to get the vetiver grass (*Vetiveria zizanioides*) technology recognized. He started The Vetiver

Network and has built this into a worldwide network, including a site on the World Wide Web, www.vetiver.org. He has lectured around the world at top international forums explaining the new Vetiver System. Others whose hard work has contributed to spreading the word about the Vetiver System are Noel Vietmeyer and Mark Dafforn of the National Academy of Sciences in the United States, who had the vision to be our first public supporters; the World Bank, who supported our initial efforts and published our first “green book,” *Vetiver Grass: The Hedge against Erosion*; P. K. Yoon of the Rubber Research Institute of Malaysia (RRIM), who conducted our first research trials; His Majesty, the King of Thailand, who saw the advantage of the Vetiver System over all other methods of conservation and gave his full support to the system in Thailand, together with the staff of the Royal Development Projects Board, which has carried out extensive research, training, and development, with the king’s support, throughout the country; Jim Smyle, currently the president of The Vetiver Network and who introduced the Vetiver System to Central America; Joan Miller, who helped promote the Vetiver System in Latin America by setting up the Latin America Vetiver Network and now coordinates The Vetiver Network; Paul Truong, of the Queensland Department of Natural Resources (QDNR), who has been the major research worker in Australia, America, Africa, and the Far East; Diti Hengchaovanich, a talented road engineer from Thailand who has lectured in many parts of the world on the benefits of vetiver grass stabilization of road cuts and fills; and Criss Juliard, project manager, who has used vetiver in Madagascar and now in Senegal.

Creating this book adds to the effort for spreading the word about the benefits of vetiver grass. Mark Dafforn, Richard Grimshaw, Diti Hengchaovanich, Criss Juliard, and Paul Truong contributed to the content of the book; Richard Grimshaw and Joan Miller handled the logistics; and Linda Wolfe Keister edited the manuscript.

Introduction

Around the world, as nations develop infrastructure to participate in the global economy, countries clear forests for agriculture, roads, railways, mines, and reservoirs. As a result, billions of tons of soil are permanently lost each year with the consequential pollution and damage of downstream resources. This book relates for the first time the story of the Vetiver System, an organic system that helps stop such damage. It is the story of vetiver grass (*Vetiveria zizanioides*), an outstanding performer in the grass family and a unique plant that forms a *thin green line against erosion*.

Vetiver grass, when planted as a slim hedge, can recharge aquifers, thus replenishing essential groundwater supplies, at the same time filtering out many of the noxious chemicals resulting from today's increasing pollution of the earth's water supplies. The grass can control the leachate from landfills, mines, and sewerage systems and prevent it from reaching clean aquifers. At least 38 uses have been documented for this amazing plant that for centuries has been waving its stiff, little leaves, saying, "Here I am! Use me!" but that, until now, has been neglected.

Rich countries must mobilize global science and technology to address the specific problems that help keep poor countries poor. The global community urgently needs creativity to address agricultural productivity, environmental degradation, and demographic stress confronting these countries. The problem is that the technological gains in wealthy countries with more temperate climates do not readily diffuse to poor countries mainly in the tropics. New technologies will not take hold in poor societies if investors fear for their property rights or technicians fear for their lives in corrupt or conflict-ridden societies. Aid without policy reform is easily wasted—and policy reform without the backing of appropriate technology and management systems will be just as wasted.

The research and development of new technologies usually are directed at rich country problems; currently, the international system fails to meet the scientific and technological needs of the world's poorest. The poor live in different ecological zones, face different health conditions, and must overcome agronomic limitations that are different from those of rich countries. To address the special conditions of these poor countries, the global community must first understand their unique problems and then use its ingenuity to overcome them.

Science follows the market. This statement is especially true when technological leaps require expensive scientific equipment. Biotechnology could mobilize genetic engineering to breed hardier plants that are more resistant to drought and less sensitive to pests. But such engineering advancements lie years down the road for most developing countries that need help now. Even if such technologies were available now, like current technologies, they may not exist in appropriate forms.

The Vetiver System of farming, as a technology, has been proven to meet the needs of the poorest people in the poorest countries. It does little good to reduce infant mortality in a poor country if the country cannot produce food to feed the growing child. Why bring children into a life of poverty and famine to let them die slowly of hunger and thirst or water-borne disease? The increase in yields and sustainability in rainfed areas using vetiver technology is no longer anecdotal; more than 10 years of research have shown that moisture conservation resulting from contour vetiver hedges has increased yields and made subsistence cropping sustainable and even profitable.

With the Vetiver System, the subsistence farmer can expect to get the full genetic expression out of any new crops developed, can expect his farm to remain stable and protected from erosion, and can expect his crop yields to be sustainable.

No longer can international development specialists state that the international system has failed to meet the scientific and technological needs of the world's poorest people. The Vetiver System not only meets the needs, it requires little in the way of funds. After the government, the aid agencies, or the farmer develop the nurseries to produce the initial planting material, the system becomes the farmers' at no further cost. With a little care to assure that the hedges are established correctly during the first two seasons, and with occasional weeding and maintenance, the farmer and his descendants will have the means to sustain production of good crops for generations at no further cost.

The uniqueness of the Vetiver System is not its sole use for soil and water conservation, for which a number of competing technologies exist, but rather its wide range of application in contrast to the single use of other technologies. Since the early 1990s, nonagricultural applications of the Vetiver System have become a dominant feature that has attracted increasing interest. The Vetiver System has a huge role to play in stabilizing infrastructure and reducing the environmental damage from soil-related pollutants.

This book explains the Vetiver System in detail, clearly shows how simple the system is, and is fully referenced for those who want additional information or further verification of the statements made.

The Vetiver System, which I revitalized and which my colleagues expanded worldwide, virtually replaces the expensive and inappropriate engineered system of soil and moisture conservation in the tropics—and it replaces that system at virtually no cost. It is the most versatile, useful system yet developed, and it will have the greatest impact on the lives of all those in developing countries and island nations.

In the following pages, my colleagues and I establish and explain many features of the Vetiver System.

- We tell the history of vetiver grass and its use in India thousands of years ago.
- We ask: Why choose vetiver grass and not some other grass? What is so special about it?
- We explain what causes erosion and how much of a problem is it.

- We show how vetiver grass can be used to prevent erosion and increase moisture conservation.
- We discuss how the Vetiver System contributes to protecting the environment.
- Although experts have neglected rainfed agriculture, saying it is too hard to control the moisture requirements of crops, we explain how the Vetiver System has made rainfed agriculture more reliable, productive, and sustainable.
- For 15 years, engineers on the Malay Peninsula have been trying to find a biological system to stabilize road cuts and fills on their major highways, and we tell the story of how the Vetiver System has provided them with the answer.
- We boast a bit about how the Vetiver System has now been accepted internationally, in more than 100 countries, for a multitude of uses.
- We demonstrate how the Vetiver System has presented a solution to the problem of rehabilitating mine wastes.
- With the Vetiver System's accelerating popularity, we explain why increased propagation of planting material is essential.
- We describe how and why networking is necessary for gaining acceptance of a new technology.
- We present a model for establishing a new technology in a foreign country.
- We present the work undertaken in Australia and China that uses the Vetiver System to purify garbage leachate. We discuss the whole issue relating to the Vetiver System's ability to remove excess phosphates, nitrates, and pesticides found in sediment flows from agricultural enterprises such as cotton, sugarcane, sewerage systems, and feedlots.
- We show how the Vetiver System can remove highly toxic heavy metals from landfills, mine dumps, and electrolytic factories.
- We give the reader the opportunity to see this vegetative technology at work through a photographic record of the Vetiver System in use around the world.
- We include statistical information about Vetiver System development costs.

—John C. Greenfield

1. Vetiver Grass—A Unique Plant

Famines in Ethiopia, Sudan, and Rwanda. Floods in Bangladesh, Brazil, and China. Mudslides in Central America, the Philippines, Peru, and California. Toxic leachate from mine dumps poisoning water tables. Effluent from garbage dumps, landfills, feedlots, and farms polluting the groundwater, rivers, and lakes. Decreased groundwater recharge leading to shortages of potable well water. Continued unabated soil erosion from croplands. New development areas such as roads, construction sites, and airports. All of these are very serious problems that face the world in the twenty-first century. To date, few if any real low-cost, effective solutions to these dilemmas have been found. This situation is worsening and must be addressed.

I consider we have an answer—it is not a cornucopia, but it works; and after decades of field trials and research, we now have the proof that there is another solution to the complexity of high-cost engineering and structural designs requiring drawn-out bureaucratic accounting and bidding procedures to control erosion and pollution.

The Vetiver Network promotes a very special plant that can be established as a slim hedge (50 centimeters wide) on the contour, or more easily and more effectively, just across the slope. In the tropics and subtropics, this hedge establishes quickly and acts as a rainfall runoff filter holding the soil back above the ground, while holding nutrients and moisture back under the ground in its massive vertical root system. In the process, it slows down and spreads out runoff encouraging rainfall to soak into the ground and find its way to the aquifers where it is stored. Right now, with increasing population pressure on the land, rainfall is being lost as runoff, depriving countries, and especially island nations, of their essential drinking water; and in the process, the runoff is silting up rivers, lakes, and harbors and is destroying protective coral reefs.

The vetiver plant is a pure product of nature that, when planted correctly, can form a stiff hedge that can prevent erosion, form natural terraces, increase soil moisture storage, and protect companion crops it does not compete with. Once established, this plant can withstand droughts, floods, and inundation; will grow in highly acid or alkaline soils; can reclaim mine dumps; and can stabilize road cuts and fills, railway embankments, and riverbanks. This unique plant's roots can absorb surplus nitrates and phosphates and can tolerate high levels of toxic elements, such as arsenic, mercury, aluminum, nickel, iron, chromium, and manganese, and contain their spread.

Vetiver is a plant that can protect dams and harbors from siltation. It is a plant that can improve crop production through moisture and nutrient conservation. A plant that is fire tolerant and live stock resistant, but a plant that will grow only where man plants it. A plant that can last over 200 years as a natural hedge, but can be easily 'destroyed' if it is no longer wanted.

Vetiver Grass

For centuries, the people of India have known about a plant—a tropical grass—that, in the West, has been little known and greatly neglected in the recent past. Among its many attributes, the grass offers practical and sustainable control of erosion—simply, cheaply, and on a huge scale in tropical and semi-arid regions. The Indian people call it *vetiver* grass (*Vetiveria zizanioides*).

The term *grass* covers a multitude of plants that number about 10,000 species within 660 genera. Grass is the most ecologically and economically important of all the plant families. Many people think of grass as lawns or fields; they consider that one grass is little different from another and that all grasses are fairly temporary by nature.

In savannas, prairies, and steppes, grasses dominate vegetative growth. And because they contain all the cereals that are the staple diet for human beings, they are the most important family of plants economically. Yet vast differences exist among the grass species, from the massive bamboos of Asia to vetiver, each is a special grass. As far as scientists can ascertain, no other grass is like vetiver.

Vetiver had not been positively identified nor botanically classified until 1896 when Western scientists and chemists, who did not have the tools we have today for classifying plants, worked in laboratories, greenhouses, and fields to uncover the secrets of vetiver, already well known in traditional myth. These early attempts at classification resulted in the distillation of an aromatic oil from its roots.

People in India continue to use vetiver grass and its products for household needs, desert cooler mats, perfume, and ayurvedic (ancient Hindu) medicine. Before 1896, it was not a plant of much importance except in Indonesia, where entrepreneurs used it to produce vetiver oil. This production was carried out in a rapacious manner by planting the grass in rows up and down the sides of ash mountains. In the process of harvesting the roots, workers pulled the plants out of the deep ash, leaving gully scars for erosion to cascade down. In fact, because of the erosion caused by this method of root harvesting, vetiver gained a bad reputation, although it was not the plant that caused the problem.

In the early twentieth century, vetiver was recognized for a different purpose: farmers planted hedges of the grass across the field on the contour to stop erosion in tea gardens and sugarcane fields. This early attempt at vegetative soil conservation seems to have coincided with the world's sudden awareness for the need to do something to stop soil erosion, or at least, contain it.

The United States of America, the country that in the 1930s first recognized the need for action to control soil erosion, considered the problem to be one of engineering. Engineers took on the task of designing constraints to erosive forces that would work in the field. Such constraints included contour banks, diversion banks (described by one author in an article in *The Economist,* September 20, 1986, as *curvilinear mole-hills*), waterways leading to dams, and absorption banks, all of which require surveyors and engineers together with vast amounts of power, in the form of earth-moving equipment, or labor and money to construct them. These works were to be the answer to erosion because they produced an immediate, though unnatural and unsustainable, system of control. The engineered works, however, built from the soil they were made to protect, needed constant, costly repair and maintenance or they would last just five years at most in temperate climates, and far less in tropical climates. The system had been designed for the low-intensity rainfall of temperate climates.

Unfortunately for rainfed agriculture, the constructed system of banks and waterways was the wrong concept. It was designed to conduct rainfall runoff as quickly and safely as possible to the drainage network, giving it time to neither soak into the ground nor recharge aquifers. The basic advantage of the system was that it was a *quick fix* that could be set to formulas, taught at universities, and written in textbooks. It also held engineers accountable if their designs of the systems failed. The disadvantage of the system was that the fast diversion of runoff to the drainage outlet overloaded the natural drainage network, often causing massive floods.

Yet conservation specialists trained in engineering techniques usually were not attracted to using vegetative methods of erosion control, for at the time, and even now, there is nothing in temperate areas that compares with vetiver. Nature has no formulae, they argued, and there was no accountability if the measures failed. They did not know how long such a system would last, and they definitely did not consider that a natural system would outlast their constructed methods of control. So they did not pursue vegetative methods.

From the 1930s until the 1950s, vetiver grass's only importance was for its essential oil, mainly produced in Java by steam distillation and exported to the perfume industries of the world. During this period in other parts of the world, the plant was virtually unheard of.

Since the 1950s, and especially through the 1980s and 1990s, vetiver grass has undergone a renaissance—first as a vegetative hedge preventing erosion in sugarcane fields in the Fiji islands, and then in the late 1980s as a major component of a series of large-scale, World Bank-financed watershed development projects that I was closely associated with.

In India, the design and layout of the vetiver hedges were modified from strict contour to *across-the-slope*, thus addressing the importance of moisture conservation and in situ terracing, while making it easier for the farmers to adapt the system to conform with the shape of their fields when plowing and cultivating.

Unlike the constructed system of soil conservation, in which the banks have to be placed exactly on the contour to assure flow along them, vetiver grass hedges did not transport runoff; they filtered it at a slow but steady pace. In the process, the runoff's silt load was deposited behind the hedge, which meant that the hedges could be placed across the slope, crossing gullies and rills that fill up with the retained silt. Either end of the hedge was placed at the same elevation, ensuring that both silt and runoff were held on the slope to build natural terraces and improve moisture conservation. The ends of the hedge could be turned up, if desired, to ensure that more runoff would be retained.

The hedges worked perfectly, conserving both soil and moisture. The problem was, how long would they last? Would the grass become a weed? Would it become an intermediate host for pests and diseases of other economic crops? With biological or natural systems of control, the questions seemed endless, and the skeptics were irrepressible. In 1987, however, we found some of the answers in the state of Karnataka in southern India.

In a small settlement known as Gundalpet, the farmers had used vetiver hedges as boundary markers for 200 years; the hedges are still there and in perfect condition. They have proved to be so permanent in fact, that the state's survey department recognized them as permanent boundary markers (benchmarks). The grass did not spread (or *escape*), we learned, because vetiver grows only where people plant it. Vetiver (*V. zizanioides*), when grown away from its natural swampy conditions, is a sterile plant with no rhizomes (underground runners) or stolons (aboveground runners). It is a climax plant capable of outlasting any other under extreme conditions. It became obvious that this plant had tremendous potential for conservation, but we needed more information about its performance in other parts of the world, and about whether there had been any problems with it.

In response to the need for additional information, Richard Grimshaw (United States) established an informal vetiver network at the World Bank to spread the vetiver grass technology and ascertain whether vetiver grass exhibited any problems in countries throughout its natural, tropical habitat.

At the same time, the U.S. National Research Council (NRC), an independent, nonprofit organization that conducts scientific evaluations under the auspices of the National Academy of Sciences, carried out an in-depth review of vetiver. At heart, this study, funded by the U.S. Agency for International Development (USAID) with contributions from the U.S. Department of Agriculture (USDA) and World Bank, was to evaluate the claims that I made during the watershed development projects in India. The study was a project of the Board on Science and Technology for International Development (BOSTID), a division of the NRC, and was prepared under the auspices of BOSTID's program on technological innovation, established in 1970. This program evaluates unconventional scientific and technological advances with particular promise for solving problems of developing countries.

On January 26, 1993, vetiver won a new boost when the investigating panel of the NRC gave vetiver grass its *thumbs up* in a new book: *Vetiver Grass: A thin green line against erosion* (National Research Council 1993). Based on reports from more than 50 countries, the book, written by a panel chaired by Nobel laureate Norman E. Borlaug (Mexico), agreed that vetiver works as a practical and powerful solution to soil erosion and water conservation.

Since 1986, throughout the world, countries have used vetiver hedges with confidence. They have used vetiver—

- For soil and moisture conservation, flood control, and gully control;
- For stabilizing highway and railway systems, irrigation and drainage networks, and rural roads and tracks;
- As a buffer against wind erosion;
- As shade and shelter for sheep in semi-arid tropical areas;
- For protecting dams for fish farms and water storage;
- For stabilizing rice paddies, terraces, and sea walls; and

- For rehabilitating mine wastes and dumps.

More recently, research has shown us what an amazing plant vetiver really is.

Vetiver grows as a pioneer where no other plant can survive. For example, vetiver grows in the mine dumps of Southern Africa, Australia, and Malaysia, where in some cases, the pH is equivalent to that of battery acid, and the substrate contains toxic elements such as cyanide and arsenic. Vetiver is used successfully to rehabilitate such monumental scars on the landscape.

Vetiver roots have proven to be living *soil nails* or dowels that can pin the soil together. Vetiver roots have been recorded at depths of 6 meters and are capable of punching through hardpan and weathering rock, thus improving drainage. Vetiver has the root strength (average 75 MPa, or megapascals, a physical measurement of strength) equivalent to one-sixth that of mild steel. Vetiver roots improve the shear strength of soil at 0.5 meters deep by as much as 40 percent. The major advantage of vetiver roots over other grass roots is that they penetrate the soil profile going straight down vertically and do not spread laterally to compete with companion crops for nutrients.

Vetiver hedgerows have been demonstrated in Malaysia, Thailand, Australia, and China to be a relatively low-cost and effective means of stabilizing highway and railroad cut and fill slopes. In China, the cost of stabilizing slopes with vetiver is less than 10 percent of the cost of the traditional stone-based technologies, and once established, vetiver hedgerows are more efficient and long lasting, requiring virtually no maintenance. Under China's new regreening policy, the Vetiver System will be a key component for the regreening of highways, railroads, and quarries.

In China, when tea was grown on steep slopes in conjunction with vetiver grass hedges, thus increasing moisture conservation and the retention of soil and nutrients, tea yields increased by 40 percent. As a bonus, vetiver hedges proved to be much cheaper and more effective at conserving moisture than stone-faced terraces, which in itself is a major breakthrough, considering China has persisted with terrace technology for hundreds of years.

On the red, acid soils of China, vetiver grass hedgerows reduced rainfall runoff by 32 percent, reduced soil losses by 21 tons per hectare to acceptable levels, and increased crop yields by 34 percent. According to the Chinese workers on the project, the hedgerows also reduced summer soil temperatures and winter frost damage.

The Centro Internacional de Agricultura Tropical (CIAT) in Cali, Colombia, has shown in its cassava trials that in the plots with vetiver hedges planted across the cassava fields, runoff was extremely low, representing only 3.6 percent of the total rainfall received, and the soil loss was an insignificant 1.3 tonnes/hectare compared with 142 tonnes/hectare in the bare, fallow plot.

In personal communication with Richard Grimshaw, Douglas Laing, Deputy Director General of CIAT wrote the following:

We are convinced at CIAT, both in our on-station and on-farm research with farmers in the mid-altitude acid soil tropics, that vetiver grass is probably the best living barrier one could possibly *ask for in terms of its low competitiveness with the associated crops and its extremely effective erosion control.*

In China, along the extensive coastal areas of Fujian Province, fish farmers have used vetiver successfully to stabilize fishpond dikes, inside embankments, located next to the sea. During a typhoon in 1997, those parts of the dikes of a large fishpond that were not protected by vetiver hedges were destroyed by the waves, requiring the fishermen to rebuild the stone walls of the dikes. In this location, vetiver is exposed to salt spray and is growing successfully under acid sulfate soil conditions.

Vetiver hedgerows provide excellent windbreaks to prevent wind-blown sand from covering farmlands and blocking irrigation ditches. Vetiver hedges also have protected crops from severe wind damage.

Again in China, at the South China Institute of Botany, Guangzhou Province, research workers have shown the beneficial effects of vetiver on purifying eutrophic water. When grown as *floating islands* on lake water, after just four weeks, vetiver removed 99 percent of water-soluble phosphates and 82 percent of total nitrates.

In Australia, scientists have shown that vetiver tolerates most heavy metals at much higher levels than do other plants. They have demonstrated that vetiver is a key plant for rehabilitating contaminated sites such as mine tailings and landfills, as well as for stabilizing railway and road cuttings. Australian scientists also have proven the effectiveness of the Vetiver System for preventing excess nitrates, phosphates, and pesticides that attach to soil particles from reaching the drainage and river systems. In response to the effectiveness of this prevention measure, the Queensland Department of Natural Resources (QDNR) requires all cotton growers in Queensland to include vetiver systems in farm planning.

Foresters have used vetiver hedges most effectively in conjunction with tree planting (*Eucalyptus* spp.) to rehabilitate the so-called *Red Desert* in Guangdong Province, China, where moisture conservation is essential. Trials conducted on a eucalyptus plantation over a period of three years showed that using vetiver hedgerows reduced rainfall runoff by 51 percent, making for better growth of the plantation and far less erosion compared to the untreated control. But, because vetiver cannot tolerate being established in the shade, such hedges must be planted in full sunshine when the forests are being established.

Although proponents of vetiver grass have told individual success stories over the years, the special attributes of vetiver grass are no longer anecdotal. Research workers have already completed and are still carrying out much research, proving the usefulness and “safety” of vetiver over a wide range of applications. (To reference and support such applications and to bring this work up to date, I have included photographs in the following chapters.)

Because vetiver grass is truly an essential *plant for the planet* in this millennium, such research will continue in this new century. And because agricultural scientists and engineers are carrying out research and development with the grass through demonstrations in the field, in international workshops, and throughout the worldwide, regional, and national vetiver networks, a new global field using an ecologically sensitive and environmentally attuned method of conservation has opened up.

For those of us who recognize and promote the value of vetiver grass, we now need policy makers to recognize this natural system of land management as the obvious companion or even successor to the past constructed systems for preventing erosion. Using the constructed system of soil conservation was the wrong approach to rainfed farming in the tropics; it cost far too much, was counterproductive (the country of Lesotho is a perfect example; see Chapter 6), and provided only a temporary solution to the problem of erosion, while offering no solution to the problems of groundwater recharge or pollution

Today vetiver is a recognized and respected worldwide technology that belongs to all people. Its greatest potential is in the tropics, or at best 30 degrees north and south of the equator. The region between the tropic of Cancer (north of the equator) and the tropic of Capricorn (south of the equator) is regarded as the tropics. These two boundary lines are parallel to the equator and are 28° north and south of the equator. This region, three-quarters of which is covered with water, accounts for about 40 percent of the earth's surface and receives over half of the world's total rainfall.

The variability and intensity of the rainfall patterns over the tropics contribute to widely differing soils, vegetation agricultural patterns, soil loss, and runoff—all of which are addressed by the Vetiver System, a simple and inexpensive method of natural soil conservation that meets the needs of the present without compromising the ability of future generations to meet their own needs. (Although vetiver is a tropical grass, it will grow successfully in mircoclimates outside the tropics. It is now being grown successfully as far north as 37° latitude in Lorca, Spain.) In this book, I emphasize the use of the Vetiver System in the humid tropics since these areas have more agricultural potential than do the desert regions, which I also discuss, although to a lesser degree.

Vetiver is at its best in the humid tropics. The soils found here range from slightly weathered entisols (young soils without clearly developed horizons, such as alluvials) to highly weathered oxisols (older, weathered soils, such as laterites). According to Revelle, "much of the potentially arable land in the tropics is of poor quality and would require major capital investment for development (Revelle 1974). Consequently, agricultural use of these lands would be difficult, requiring a good deal of adaptive research to determine workable systems." As populations expand, however, such lands must be used, and now can be used when the Vetiver System is correctly applied.

Today, the most basic division of agriculture in the tropics is between modern agriculture and traditional agriculture. Modern agriculture accounts for industrial products and certain food crops largely on a plantation basis, and with a relatively efficient use of modern technology. Traditional agriculture accounts for most of the food produced in the tropics, and the technology used is relatively primitive. Yet with the Vetiver System, and at little cost to the poor farmer, traditional agriculture can be vastly improved.

Farmers who practice shifting cultivation roughly clear away forests and burn the residues to plant crops, then move on when the soil becomes depleted of nutrients. With this short-term solution, farmers must continually move to new, forested areas for fertile land, abandoning the farmland, which may take more than a century to return to its former state.

Sanchez defined shifting cultivation as a continuing agricultural system in which the cropping period is shorter than the fallow period (Sanchez 1973). In 1957, the United Nations Food and Agriculture Organization (FAO) estimated that shifting cultivation was the predominant practice on 44 percent of the potentially arable and grazing land in the tropics. By employing the Vetiver System, in which vetiver hedges conserve soil and moisture, farmers can shorten such fallow periods, or abolish them altogether, and greatly increase the production of their crops.

Because of population pressure, the future of shifting cultivation is in doubt. Where the nature of the soil permits, systems need to be devised that allow cropping on a sustained basis. Such systems must solve erosion problems and also prevent decreases in soil fertility. We have proved that by using the Vetiver System, farmers can solve erosion problems and retain fertility in situ.

Low fertility has been a problem with most soils in the tropics since people began to farm. In past centuries, farmers made many attempts to retain the soil's inherent fertility, using such methods as applying ashes, mud, seaweed, dung, or compost; but few of these methods have been widely adopted for a long period of time because no method was available to prevent these applications from being washed away during heavy rain. Shifting cultivation, as a technology, was the major exception; but now that technology has become impossible because of shortage of land—the farmers have no new land to move to and start anew. Vetiver hedges, however, by preventing runoff and loss of nutrients, have stabilized the use of traditional fertilizer applications, bringing a whole new concept to subsistence farming.

Yet, although nearly half of the land area of the world with nearly 50 percent of the world's population is located in the tropical zone, only a little more than 20 percent of the fertilizer consumed in the world is used in the tropics. I believe that this lack of fertilizer use, lack of fertility, and lack of the effectiveness of innovation in the past, which lead to a lack of sustainable crop production, resulted from one major constraint virtually unresolved in rainfed areas throughout the world—moisture conservation.

Moisture is key to successful fertilizer use. No matter how accurate the fertilizer advice for a given soil type may be, or how drought tolerant the particular crop seed is, or how well managed the whole farm may be, none of this will influence yield or crop growth if sufficient moisture is not available at the time it is needed.

Agriculture and animal husbandry are impossible without appropriate soil moisture. With irrigation farming, farmers control their crops' water requirements; with rainfed agriculture, farmers are at the mercy of the *elements*.

Runoff and soil loss have been the major problems of all rainfed agriculture throughout the world, with no sustainable answer to this problem. My colleagues and I now feel confident that the Vetiver System of hedges across the slope offers a useful and economic remedy to this major dilemma. We show from recent research and field work, however, that vetiver grass has far greater benefits than just soil and moisture conservation. People in China and Australia have used vetiver hedges successfully for cleaning up toxic wastes from landfill effluents, garbage leachates, and septic tank drainage fields. Others in Australia and South Africa now use vetiver hedges to stabilize mine dumps and rehabilitate these man-made eyesores where all other efforts have failed. In the chapters that follow, we fully explain our confidence in this amazing grass.

2. The Plant: Its History and Use

Vetiver grass belongs to a genus of swamp grasses traditionally considered to include about 10 Old World species, one of which is now distributed worldwide. People have used vetiver for at least 3,000 years, and possibly as long as 5,000 years, mainly as a source of fragrance and medicine. Of the species, *Vetiveria zizanioides* (L.) Nash (2n = 20) has proven to be the most widely used and in this text has been the only species recommended (where available) for use in erosion control. In Malawi and West African countries, *V. nigritana* is widely used for soil and water conservation, which is good enough except in critical, long-term applications where it might be replaced, as appropriate, by *V. zizanioides*, with its larger, more effective root system.

Classification and Taxonomy

When first encountered by westerners, vetiver labored under many names, which may account for its confused botanical recognition through the recent centuries. The taxonomy was long entangled: *Vetiveria zizanioides* was recorded in the literature under a score of botanic names and literally dozens of common and local names. Its most widespread common name is possibly the Hindi *Khus* or *Khus Khus* (or *Khas Khas*), from its native India. This name seems to have reached other areas in the tropics by way of ancient trade routes and more recent human migrations, but is nowadays sometimes indiscriminately used for any vetiver, northern or southern India. The other widespread common name, *vetiver,* comes from the Tamil of southeast India and Sri Lanka, and seems to refer historically to the "nonflowering" southern India type. Outside southern Asia, it seems to be most common in western nations and other countries where it was likely introduced as an essential oil plant.

Much of the confusion over the naming and classifying of *V. zizanioides* (which from here on will be called *vetiver grass*) results from the fact that people have used the plant's fragrant roots for millennia in medicine and ritual, and for centuries as a source of valuable aromatic oil with a high commercial value. Perhaps every ancient trader had a different name for it—communications then were not quite as fast as they are today, and an abundance of common names persists. Vetiver apparently was first described (in western botanical literature) by Linnaeus as *Phalaris zizanioides* in the *Mantissa* of 1771, between two other fairly common grasses of the East: *Saccharum spontaneum*, the common wild sugar cane that grows along waterways, and *Panicum* (now *Brachiaria*/*Urochloa*) *distachyon,* a common weed from India to Thailand (Linnaeus 1771). In 1783, vetiver was again described, this time by Retzius who described the grass as *Andropogon muricatus* (Retzius 1783). We do not know why such fairly common and economically valuable plants were not described earlier, but botanical names for vetiver have been changing over the years, either to keep botanists employed, or because botanists have become better classifiers. *V. zizanioides* itself has labored under at least eleven synonyms: seven of them as *Andropogon* spp., two as *Anatherum* spp., one as *Agrostis* sp., and one as *Phalaris* sp. Such confusion has now been much clarified by combining the marvels of DNA typing and basic botany (see Chapter 3).

Although botanists now believe that the genus *Vetiveria* is a natural component to include in the genus *Chrysopogon*, today—with our vast and recent knowledge of the plant's capabilities—it is the specific name *zizanioides* that seems inappropriate. It means *by the river*—or *riverine*. When first botanically named, it was cultivated in India on the silty alluvium of the riverbanks, making it easy to harvest the roots for oil. Three hundred years ago nobody considered it an ideal plant for soil conservation, or knew that it could survive in the worst possible environment, even growing in salty arid areas away from its natural swampy environment. Instead, everyone was focused on its traditional riverside uses.

A wealth of information on vetiver's history and current status is available on the World Wide Web, especially at The Vetiver Network site (www.vetiver.org). Earlier, the National Research Council (NRC) provided a current but brief historical synopsis (National Research Council 1993). A more in-depth (though somewhat dated) discussion appears under the entry for "Vetiver" in the encyclopedic *Wealth of India*, which in turn draws much of its information from Virmani and Datta (*Wealth of India* 1976 and later editions; Virmani and Datta 1975). They provide an overview of topics such as propagation, agronomy, and distillation for the northern and southern India types of vetiver (including a survey of world vetiver oil production), and they include a bibliography of 245 papers. A basic reference is Otto Stapf's 1906 treatise distinguishing among vetiver and other oil grasses, which is a fascinating and remarkable exercise in the economic botany of that time (Stapf 1906).

Early History

Thousands of years ago, growing quietly in the steamy swamps of Keoladeo, Bharatpur, India, the local tribes people noticed vetiver grass. Its roots, when pulled from the swamp and dried, held on to their delightful fragrance and, when dampened, perfumed the air. They were used to scent the water for ritual washing at the entrance to holy buildings, and even today it often seems a Hindu temple is incomplete without a vetiver plant or two. In the first half of the eighteenth century, Herbert de Jager wrote, "In Golconda, this 'Schoenanthus' is used in powder form for washing hands on account of the very pleasant odor it imparts very quickly to the water; but the odor ceases as soon as the hands are dry" (de Jager 1732). The so-called *"Schoenanthus*" powder that de Jager found in use was most likely *Khus Khus* powder (rather than geranium grass, *Cybopogon schoenanthus*) (Stapf 1906).

The *Pharmacographia Indica*, first published in 1890, highlights the importance of vetiver in the following passage (Dymock et al. 1890):

In Vedic times the ancient Hindus were instructed to build their houses in a place where "Virana" [**author's note:** vetiver] *and "Kusa" (*Desmostachya bipinnata, *Stapf* [**author's note:** dub grass]*) were abundant.*

Indeed, much of what is known was recorded in Sanskrit, the ancient Indic language. In the late eighteenth century, Jones identified the *Usira of Kalidasa* as *Khus Khus* (Jones 1795). In the mid-nineteenth century, Hessler did the same in his translation of the Sanskrit medicinal books of the Ayurvedas (which means the *science of life* in India) (Hessler 1850). Among the more recent interpreters of Sanskrit plant names, Dutt came to the same conclusion, and the consensus is that *usIra* or *ushIra* is vetiver's most common name in Sanskrit. Other Sanskrit names that have been interpreted in the same sense are *Virana*, *Lamajjaka* (or *Lamaja*), and *Bala* (Dutt 1900). Vetiver has long played an important role in the ancient annals of ayurvedic medicine, where the grass is also called *sita-mulaka* (having cool roots) and *suganti-mulaka* (sweet smelling). The many medicinal uses of vetiver, both ancient and modern, are outside the scope of this book, but the roots seemed to have "magical" properties. When made into a potion, the dry roots are said to have curative properties, and ground roots are the base of an *Abir*, or perfumed powder, used by the Hindus at their Holi festival. The roots were also found to have the ability to repel insect pests and to prevent fungal infestations.

This combination of traits made vetiver popular throughout southern and southeastern Asia. Six hundred years ago, the Moghuls encountered this grass and its wondrous roots that, when dampened, smell like sandalwood. Architects responsible for designing and constructing the Moghuls' palaces, formal gardens, reflecting pools, and fountains learned that mats made from the roots, then hung over the openings in the walls and kept moist, would act as *desert coolers*, reducing the heat inside the palaces. The increase in humidity, together with the hot desert air drifting through the mats, would have created fungal havoc for the inhabitants had it not been for the fact the roots of this particular grass are not only aromatic, but the oil they contain is an effective fungicide. As a result, the Moghuls had cool, clean, sweet-smelling living quarters.

Even today, probably the greatest use of vetiver is weaving the long roots into mats that are hung as refreshing and insect-repelling curtains. Stapf himself noted the "…property of the dried *Khus Khus* roots emitting a pleasant odor as often as they are wetted" (Stapf 1906). Jones also mentioned this use of vetiver: "It has led from early times to their being woven into screens and mats (or "tatties" in India), which are hung over doors or set in windows; in hot weather, when frequently sprinkled with water, they cool and perfume the air" (Jones 1795). These uses of vetiver represent perhaps the first attempts at air-conditioning, and the beginnings of desert coolers, because of their fragrance and resistance to bacterial matting.

In India, *Khus* root remains a standard stuffing over which water flows in evaporative coolers, at least those that cool human "palaces." Poultry farmers west of Delhi (India) told me that they had used *Khus tatties* for years as desert cooler screens to keep the temperature down in their poultry houses; unfortunately, the high cost of replacing the screens forced them to convert to bags of wet wood shavings. The air forced through the wet shavings cooled the air but produced horrendous fungal diseases among the birds, something they had never seen with *Khus* roots with their fungicidal properties.

Because of vetiver's distinctive qualities, a great interest in cultivating vetiver grass has existed throughout Asia for millennia. Initially, the roots pulled out of the swamps were probably too short for making good mats, or *Chics* as they were called; but when the plant was grown on the elevated, sandy sides of the swamp, or on a riverbank, it had to send its roots down 3 to 4 meters to reach the water. These longer roots made much better mats. The plant with its longer roots was also observed protecting the riverbanks from erosion, a point not lost on the canny traders of the past, who sold the plants for stabilizing irrigation schemes. Over time, simple selection genetically locked in long roots.

Planting material must have been taken from the Indian swamps or riverbanks as an item of trade to many other countries throughout southern and southeastern Asia (and perhaps even toward the Middle East by Arab traders). I. H. Burkill, who from 1912 to 1925 was the Director of Gardens, Straits Settlements (and before that was officiating Reporter on Economic Products to the government of India), wrote the following (Burkill 1935):

A very tough, wiry grass (vetiver), found in a wild state across northern India and Indo-China, and now cultivated throughout the tropics. Its cultivation in India is very ancient, for apparently it was used in Sanskrit times as a perfume, and was known as 'usira', 'Virana' and probably also 'bala'. 'Bala' has given rise to a series of names now employed in India; but none of the three Sanskritic names seem to be represented in Malay, though a series of Sumatran names—'useur', and 'usa' extending as 'usar' in Sudanese, has a similarity to the Sanskrit 'usira'. The Malay name 'nara wastu', came to Malaya from Sumatra, and, in a variety of forms, it is met with through Java to Celebes.

Harvesting these long roots was labor intensive. Workers had to dig or pull them from the soft sides of the swamps or rivers where they had been planted, wash them clean of all the soil, dry them in the sun, and then roughly weave them into thick mats to be hung over "windows" and doorways, or over openings around the palace. People were amazed that the mats could last for three seasons and still perfume the buildings before they had to be replaced. What other plant roots kept continually moist and "muddy" in a hot climate could survive even one season without rotting?

In these names there is no clear indication of the introduction of the grass from India; yet it certainly was introduced from outside. It occurs "wild" near Batavia (Jakarta) and on the Kangean Islands; but there, as in other parts of the world, we must regard it as only remnant from plantings. (In our recent research we find that vetiver does not run wild; it grows only where people have planted it. So somebody planted it—perhaps the early traders.)

Vetiver has been in southern India and even Sri Lanka since antiquity. On the Malay peninsula, it has been found in gardens for perhaps 1,000 to 1,500 years and perhaps even longer, brought most likely via Tamil traders. Apparently it also has long been known in much of Indonesia, and perhaps as well even further east. Like Indonesian sugarcane, it seems likely that the root reached even Mediterranean markets in very early times.

The first great migration of vetiver was primarily across and out of India to the south and east. A second migration took place in the nineteenth century, when sugarcane workers from India were in high demand at sugar mills around the world. Traveling as indentured "guest" workers, their contracts allowed them to bring their possessions, one of which was often vetiver, which they used in all the ways they knew from home. It also was planted to mark new boundaries, and came to line the roads, ditches, and field edges of cane plantations. This was an especially important route by which vetiver reached British possessions around the world, such as the southern Caribbean, Southern Africa, and Fiji, for example, where in the 1950s I found the

Hindu population well aware of vetiver. It is still unclear whether the idea of protecting the landscape with vetiver hedges came from bosses or workers.

One final point from vetiver history: Vetiver has probably been in the United States ever since the French occupied the state of Louisiana in the seventeenth century. Many years before the American Civil War, planters around New Orleans imported vetiver, most likely from Haiti or other French Caribbean islands where vetiver is commonplace. Although an oil industry never became important in Louisiana (because of labor costs), since 1843 a vetiver perfume called *Kus Kus* has been formulated continuously by Bourbon French Parfums; it is advertised as "the original scent of New Orleans." The company's Web page describes *Kus Kus* as "Sweet with spicy undertones….a perennial favorite because men find it so alluring. Wear it when you're feeling mischievous."

People in Louisiana still use vetiver roots for perfumed sachets, which they have placed with stored clothing to protect it from mildew, moths, and other pests since long before scientists knew about fungicides or pesticides. An old document from Louisiana discusses the use of vetiver as a pesticide (Vetivert Essential Oil Corp. Early 1900s):

There are many plants, minerals, and other nature products in this universe, that more or less protect the human race against the bothersome insects of life. It seems that the insect life has an absolute distaste for vetivert. We have found in the growing of this plant that no insects of any kind ever came near it. We also find that in the powdered form, the tops mixed with the residue of the oil repel any and all insects. It is for that reason, so important that this plant be given every consideration and not be allowed to grow wild as heretofore has been the case in this country. It is as necessary to have vetivert as it is to have salt in your food.

Strawberries that were grown in the Southland have been more or less contaminated by insects, and although pine needles and other things have been used to safeguard against these pests of nature, a great loss was wrought against the strawberry crop. We have found from experimental work that the tops of vetivert, in the same formation of mixture with the residue of the roots, will make an absolute repellent for the insects that may hurt the crop.

A few years later, Harold Levey wrote of vetiver in Louisiana (Levey 1940):

An interesting fact observed in connection with the growing of the vetiver plant in close proximity to the other crop which originally emanated from India, viz., sugar cane **[author's note:** now known to be from Indonesia]*, is that the vetiver inhibited to a very substantial degree the attack upon the sugar cane of certain entomological organisms such as the cane borer. This procedure was used to a limited extent some years ago, but has no longer become necessary in view of the fact that the newer types of sugar canes originally cultivated in Java are now practically immune from such attacks by their very nature.*

People have extolled the virtues of vetiver as a pesticide for thousands of years and even into this scientific age, yet it is only recently that researchers' ears have been open to hearing this common knowledge. Now finally, promising results are being shown on many fronts, such as using vetiver as a repellent for cattle ticks in Thailand, as an entrapping toxicant for stem borers at the Grain Crops Institute in South Africa, and as an intoxicant for disorienting (and thus neutralizing) Formosan termites at Louisiana State University (information via www.vetiver.org). In view of this information, why has more work not been done with this plant, especially today when scientists are looking for safe forms of biological control in our increasingly polluted environment?

Oil Production

Vetiver became known throughout the tropics through a third route—perfumery, through the value of the famous oil in the vetiver roots. It seems that the people of northern India were the first distillers of vetiver oil. Because distillation is a difficult task using early, elementary equipment, it took little hold there, supplying primarily the domestic market. Even today, one can find scattered distilleries around Kannauj, Uttar Pradesh, modeled on the technologies introduced to India by the Moghuls hundreds of years ago. Stapf wrote (Stapf 1906):

While the use of the roots of Vetiveria zizanioides for medicinal purposes and in perfumery has been universal in India for a very long period, I have failed to find, among the earlier writers, any definite and indisputable reference to the extraction of an oil from them. Indeed, the distillation of vetiver oil in India seems to be very limited and there is hardly any export (1905). The oil was mainly produced in European distilleries from the imported roots; but even the importation of the roots as a regular article of commerce appears to be of comparatively recent date.

It was only in the late 1700s that vetiver oil was produced in any quantity for export, and then not in India. It was grown at first, almost exclusively, by the Dutch (Indonesia) and French (Réunion, Mauritius, and Haiti) colonial powers, after perfumers realized that vetiver is the least volatile of all the essential volatile oils, and thus serves as an excellent “fixative.” It can be distilled and chemically manipulated so that it has little fragrance, but the remaining oil evaporates only very slowly, thus allowing more ephemeral (and expensive) scents (such as “oakmoss”) to linger in the finer perfumes. Most jobbers found it more reliable to import the root to a central location (originally this meant Europe) and perform their own distillation, and vetiver became a specialized commodity crop of the tropics.

The first modern analysis of vetiver oil was performed in 1809 on oil from Réunion island. Before the French Revolution, Réunion had been called “Bourbon” island, after the royal family; hence even today, the highest-quality vetiver oil from Réunion carries the appellation “Bourbon Oil.”

Many others in various geographical locations attempted producing vetiver oil. For example, the former Belgian Congo was once a major oil source, while attempts failed in Germany’s African possessions and most other locations because of high labor costs. Wherever vetiver was introduced, however, the essential oil industry may have failed, but the plant itself persisted. In 1893, it was tried on the Perseverance Estate in Singapore; soon after this, a demand grew for the grass by planters who were prepared to try it as an essential oil crop. Indeed, in the 1800s, the vetiver plant as a source of essential oil became an important part of every British agricultural research station’s “museum” plots, where researchers grew the plant to determine its possible viability as an economic plant for the country. Throughout the Commonwealth's tropical colonies, vetiver was introduced as a possible essential oil crop to be tested in the area. In many of those research stations (Misamfu in Zambia, for example), the plots have survived intact to this day. All the accompanying plots planted to other species at the same time have long since disappeared, which is a testimonial to vetiver's outstanding powers of survival.

Because of the difficulty of harvesting the roots, no oil industry was developed in the British Straits Settlements (Malay Peninsula and Singapore) after the 1893 trial at Perseverance Estate. On the ash mountains of Java, however, the oil industry had succeeded because they avoided their biggest problem and greatest cost—digging up the roots—by ignoring the basic principles of soil conservation and planting the vetiver in lines *straight up* the sides of cinder cones of volcanic ash so they could simply pull the roots out of the soft ash in the process, washing away gullies uphill. This method, however, left deep trenches down the mountainside that created massive erosion problems and a very real danger of mudslides. This dangerous situation led at one time to restrictions on vetiver cultivation. Today, with greater understanding of vetiver's actual conservation qualities, the use of vetiver is now "legal," but this planting technique is taboo.

The Wealth of India summarizes vetiver and the constraints on oil of vetiver production (*Wealth of India* 1976):

Vetiveria zizanioides. *A small genus of perennial grasses found in the tropics of the Old World. Two species are found in India, of which* V. zizanioides, *commonly known as Vetiver, is the source of the well-known Oil of Vetiver, which finds use in medicine and perfumery. Vetiver Oil was the original product making this an essential oil plant, but because of the extreme difficulty in digging up the roots, together with the cost of the operation, vetiver oil is not being produced in any quantity today.*

These observations were made at a time when labor was much less expensive; with today's cost of labor, manually harvesting the roots is almost out of the question except for niche, contract markets. The demand for the oil is not great, although the recent surge in "aromatherapy" has led to the oil's wider use as a source of "tranquility" and similar virtues. World production in the secretive world of essential oils recently was estimated at about 140 tonnes, with Haiti, Réunion island, and Indonesia (Java) the principal producers.

Interestingly, the oil (like the grass) is one of the most complex of the essential oils. Its chemistry is complicated and not yet fully understood, so its extraction is held to the highest standards. Further, because vetiver oil overlaps the density of water, steam distillation is challenging and slow; but as the least volatile of the essential oils, the oil retains its place in perfumery to fix more volatile, expensive oils. In distillation, to obtain the highest quality, producers generally use specially designed separators. Although the viscous oil is difficult to manipulate with the usual apparatus, the dried roots can be transported to distant stills without loss of the low-volatility oil. Vetiver root as a raw commodity is still shipped today as far away as Europe, the United States, and Japan for specialized distilling and value-added processing into derivative constituents such as vetiverol and vetiveryl acetate.

The oil of vetiver trade is highly specialized, with some links among growers, processors, exporters, distillers, chemists, and perfumers going back for centuries. There is little risk of a vetiver hedge being ripped out because of vetiver oil market opportunities. Nonetheless, it was the insatiable colonial desire for new plantation-grown "commodity crops" that created a third (and pantropical) "migration" of vetiver grass. Demand for unprocessed vetiver root provided an important ticket by which vetiver was long ago introduced throughout the tropics, where it has awaited its new destiny as the premier plant for landscape soil and water conservation.

On the other hand, oil production remains a challenge from field to finish. D. H. Grist refers to *V. odorata (=V. zizanioides)* as follows (Grist 1936):

A perennial grass, about four feet high (1.2 m), with stiff erect leaves and aromatic roots. The essential oil is obtained from the roots by distillation and is used exclusively in perfumery on account of its fixative properties, which when mixed with other essential oils, prevents them from volatilizing too rapidly.

This grass is propagated by divisions of the root, which are planted in rows three feet (0.91m) apart. The plants are ready for lifting after six to eight months, or just before flowering when the oil content is at its maximum.

The yield of oil is highly variable and ranges from 0.5 to 3.3% according to the condition of the roots when lifted. With two crops per annum, each yielding about 1,000 pounds (454 kg) of dry roots per acre (0.4 ha), and with an oil content of 2%, the yield of oil approximates to 40 pounds per acre (45 kg/ha).

Owing to the ramifications of vetiver grass roots, it is an expensive crop to harvest and on this account it is very doubtful whether its cultivation with paid labor would be a profitable undertaking under local conditions.

With today's high price of labor and the extreme difficulty of digging out the roots, vetiver oil as a nonmechanical crop is virtually out of the question, except for elite, long-established specialty growers, making the grass a better proposition for soil conservation. Root harvesting is not only extremely difficult, but digging the deep-rooted plants can cause severe erosion in the planting area. It is that very quality, in the balance of things, that makes vetiver so desirable, as Grist also observed (Grist 1936):

The grass is of value for the purpose of holding up silt-pit bunds on steep and undulating land. The root system is very vigorous and assists materially in forming a compact bank of soil (a natural terrace).

Even earlier, Heyne wrote from the Dutch East Indies (Heyne 1927):

The communications about the culture of this grass are extremely rare. For large scale culture it is planted in Java, according to Publication No. 4 (1920) of the Department of Trade, only in one plantation in Surabaya and one in Madiun, which together have 35.5 hectare unmixed and 2.8 ha mixed plantings [**author's note:** probably in gardens, temples, or along paths].

Vorderman says that it is cultivated near Slopeng by the natives along maize fields. Rather frequently one meets it in Kedu near Wonosobo. In West Java it seems to be planted along water runs to prevent scouring. In the Indische mercuur [Amsterdam] *of 1913, p. 816,* djoekoet wangi *rightly is recommended as very suitable for planting on steep slopes and margins of gutters, because it grows easily, forms a thick hedge and a very extensive root system, which prevents crumbling of the soil in the dry period, and—even extending below the bottom of the gutter—prevents washing-out.*

In 1908, an experimental plot was started at Kuala Lumpur, where the grass is easily raised (Agricultural Bulletin Straits and Federated Malay Straits 1908). According to Bunting and Milsum, many years later it was still used for holding up steep banks, and they noted that it was well known to be good for this purpose (Bunting and Milsum 1931). Yet, as elsewhere and even earlier, this fact remained obscure to "conservationsists" and in the literature until, in Malaya for example, P. K. Yoon's work with vetiver in the early 1990s (Yoon 1991). Observations about a more substantial use of the grass were being made in many places, but it would still be decades before vetiver's importance as a soil conservation measure would finally be appreciated worldwide.

Other Common Uses for Vetiver

Koenig recorded in the diary of his visit to Malacca in 1778 that vetiver roots were used for making fans and the roofs of palanquins (Koenig 1894). These uses had been borrowed from India; and just as the litter has gone out and with it a demand for the grass for its roof, so also, these fans seem to have gone from Malaya (the roots were probably too costly to dig up); but fans are still made in the Philippine Islands. As the scent suggests, fans sent from the Philippine Islands to America as sandalwood fans actually are vetiver fans.

In the Philippine Islands, people also use the culms of vetiver to make hats. They dip the flower stalks into boiling water and dry them in the sun, scrape them clean, and weave them. Some people also make brooms from the stalks (Brown 1920). As a plant used for making paper, its leaves are second class (Bulletin of the Imperial Institute 1914). But with a little research, perhaps a useful "weevil-proof" paper could be produced.

The pliable leaf is excellent for plaiting because it is long (>1 m) and of uniform width (c. 1 cm). In Thailand, during the Second International Vetiver Conference in January 2000, the Thai Department of Industrial Promotion exhibited a wide range of beautifully handcrafted items made by local villagers from vetiver leaves, stems, and roots. These items included fans, place mats, baskets, hats, and even picture frames and slippers. Such craftwork is a value-added benefit of having vetiver hedges, which can produce enormous amounts of leaf.

Cattle will eat the young leaves. When the leaves are old, however, they are too harsh to be used as fodder (low digestibility and high silica), although they make good pest-free litter for animals to bed down on. The fact that animals will not readily eat the plant is a vital point for its use as a conservation measure. When vetiver grass is used as an essential hedge to prevent erosion and conserve moisture on the farm, the last thing a farmer would want is for the grass to be eaten into the ground by livestock during a drought. When the drought breaks, it usually does so as a major high-intensity rainstorm, causing a lot of erosion where land lacks ground cover, but the vetiver hedges remain and protect the farm from this deluge. (Vetiver's underground crown also protects it from the trampling of hooves.)

When first introduced to the Vetiver System, farmers often ask—What else can the grass do? Can it be used as a fodder like elephant grass? The answer is—Yes; it can be used as fodder if it is managed correctly. When managed for a dual purpose—forage and hedgerow—it probably does a great deal of good since regular cutting encourages tillering. What farmers must understand, though, is that without vetiver grass hedges (or their equivalent, yet to be found), they, in time, would not have a farm. The soil would have been eroded away.

For those who appreciate vetiver in soil and water conservation, however, perhaps the most important other use comes from the unprocessed cut leaves, which make superb mulch and thatch. Mulch is much in demand in agriculture and horticulture; thatch is still sought after wherever good-quality materials can be close at hand. Available in abundance as a result of normal hedge maintenance, vetiver yields about the best leaf for such purposes, because its high carbon-to-nitrogen ratio ensures it is long lasting when confronted with the rotting heat and humidity of the tropics. By using this valuable by-product, growers need waste nothing of vetiver.

Vetiver grass has been a unique plant for centuries. Chemists, botanists, sultans, sheiks, kings, farmers, traders, and even the "tax man" in the tropics have devoted more time to this particular plant in the past than just about any other. Yet in recent history, because of the low availability of labor and the high cost of harvesting vetiver roots, the plant has lain dormant, waiting to be rediscovered and used to its full benefit—namely, for conserving soil and moisture, rehabilitating wasteland, purifying polluted waters, providing shade and shelter for sheep in tropical areas, and stabilizing dam walls, seawalls, and the like. Vetiver truly is an incredible plant; and at the beginning of the new millennium, we are only just uncovering its potential and importance in a world where we seem to have lost our way in the environment. In the chapters that follow, my colleagues and I will show just how this grass really is unique.

3. Identification and Characterization of Vetiver

As I pointed out in the previous chapters, for centuries botanists have mulled over the true identity of all plants, including the grasses. Most grasses are not really important enough to spend too much time or money on accurately categorizing because they are not called upon to do a specific task. But vetiver grass *(Veteveria zizanioides)*, because of its outstanding qualities, has now become important enough to definitely classify and separate from its close relations. With such a system, there would be little doubt that countries taking up the Vetiver System would know that they were indeed using the correct species and types.

Confusion about the positive identification of *V. zizanioides* is nothing new, nor is the abiding concern that the wrong species or type might be chosen for use. Originally, the fear was in producing inferior-quality vetiver oil (Stapf 1906). More recently, the apprehension was that the wrong germ plasm simply might not work as well as expected in hedges, or even unwittingly create a weed problem. As the promise of vetiver for conservation became apparent, it became essential that this species (and its many types) be unequivocally identified and separated from its relations.

For nearly 100 years, until 1999, vetiver's taxonomic classification (that is, the complete accepted scientific name) had been *Vetiveria zizanioides* (L.) Nash. The "L." stands for Linneaus, the great botanist who standardized the use of botanical binomials (two names) in the late 1700s: he placed vetiver in the genus *Phalaris*, and it has been changed many times since. The other binomial currently in common use (especially in Europe) has been *V. zizanioides* (L.) Stapf, which refers to precisely the same species of plant. Ironically, Stapf relied on Nash's 1903 definition of *V. zizanioides* in his 1906 masterpiece cited above.

Vetiver now has a new scientific name: ***Chrysopogon zizanioides* (L.) Roberty**. **It is important to note that this new species name refers to exactly the same cluster of similar plants as the two older scientific names given above; only the genus name has changed.** This revision was reluctantly determined by J. F. Veldkamp, editor of grasses for the *Flora Malesiana* at Leiden University and long-time volunteer advisor to The Vetiver Network, after a multiyear study of the genus *Vetiveria*, published in the peer-reviewed botanical journal *Austrobaileya* (Veldkamp1999). Veldkamp's classical taxonomic documentation confirmed the long-standing belief among botanists that there are no consistent morphological (floral) differences between the genus *Vetiveria* and the genus *Chrysopogon*, a conclusion supported by DNA fingerprinting (Adams et al. 1998). Because *Chrysopogon* was the first-named genus, under the rules of botanical priority, Veldkamp had no choice but to "reduce" (combine) *Vetiveria* into *Chrysopogon*. Veldkamp noted that the name *Vetiveria* "doubtlessly will continue to be widely used with the usual complaints about taxonomists always changing names." This author accepts that insight, and will continue to refer to vetiver as *Vetiveria* throughout this book.

In this chapter, rather than focusing on generic taxonomy, I first highlight the work of scientists who confirmed traditional and scientific knowledge of vetiver diversity by fingerprinting its DNA. I then look at the characteristics of one special type that I long-ago dubbed "*ubique*" (Latin for ubiquitous) because, although I'm not a botanist, I could see that it was everywhere. (In Chapter 4, see "Essential Criteria for a Vegetative Soil Conservation Plant.") Finally, I examine some of the characteristics of this special vetiver grass.

DNA Fingerprinting

DNA work over the past 10 years has succeeded in confirming that (1) *V. zizanioides* is indeed a clearly distinct species from any other grass that may superficially look the same: (2) a number of highly desirable clones have low or no fertility, which works splendidly for conservation applications; and (3) most if not all of the vetiver outside its native southern Asia is similar, or they are identical clones. The following brief explanation of the state of knowledge in about 1990 will help explain the importance of these things.

Cultivated vetiver. Elite germlines of *V. zizanioides* (L.) Nash, traditionally called "nonflowering," have long been cultivated for their fragrant roots, which contain the essential oil of vetiver. This oil (first analyzed in 1809), which is widely used in perfumery, is clearly distinguished chemically and in commerce from *Khus* oil, which comes from natural (fertile) populations of *V. zizanioides* on the Ganges plain of northern India (Council of Scientific and Industrial Research 1976).

Because of its commercial value, planting material for oil of vetiver (commercial, essential oil type) has long been propagated vegetatively throughout the tropics (the history of much of this "vetiver migration" is surely held in the proprietary records of the great perfume houses, where it sadly remains unavailable). One of its desirable features is that it is non-fertile (produces no seed, or seeds do not produce viable seedlings), and so it must be propagated from cuttings (clumps of root stock). Because it does not reproduce by seed, for centuries it has been a well-behaved grass throughout the tropics and sub-tropics. It has not escaped cultivation or become a weed. The mere fact that vetiver propagation is always by cuttings, however, could lead to widespread cultivation of one single clone. This is a vulnerable situation because an insect or disease adapted to a particular genotype could spread and decimate millions of plants, as has happened with many other monocultures. (This is also one reason all international shipments of vetiver must also go through plant-protection inspections. See Chapter 11.)

By 1990, it was clear that the amount of vetiver was increasing enormously through widespread plantings to form hedges for stabilizing soil and controlling water flow. Most users acquired their plants locally, and although botanists could usually confirm that they were indeed *V. zizanioides*, no one was really sure of their germ plasm's characteristics: each new accession had to be treated as a total unknown. These unknowns were often being propagated by the millions, leading to the short-term risk of using low-quality (or even seedy) material and the long-term vulnerability that only one kind of essential-oil vetiver was being planted everywhere. The 1993 National Research Council (NRC) report called for specific research on these topics.

Early DNA investigation of vetiver. DNA work began in the early 1990s when Steve Kresovich was convinced by the NRC study then underway that new technologies for DNA fingerprinting should be applied to vetiver to answer some very basic questions of genetic relatedness. It was only about this time that DNA analysis became a viable alternative for investigating diversity. Kresovich and his colleagues initially investigated genetic variability and reported on the seemingly limited vetiver variation in the United States (Kresovich et al. 1994). They used Random Amplified Polymorphic DNAs (RAPDs) and found that RAPD patterns were very stable within clones, meaning that their results could be replicated. The patterning showed that the non-fertile 'Huffman' and 'Boucard' cultivars were identical (>.99+), and that these cultivars were clearly distinct from the seed of wild material from northern India (Simla, Punjab; USDA PI 196257). Further, they found that three samples of this single USDA accession, though similar, were genetically distinct from one another, a sign of sexual (non-clonal) reproduction. Unreported in their paper but of historical interest is that they also tested the USDA cultivar 'Sunshine' and found it similarly identical with the other two cultivars; the fact that all three clones from three separate sources were all the same was the first hint that one genotype might dominate outside southern Asia (Dafforn, personal communication).

Kresovich and his colleagues further concluded that RAPDs would be useful for identifying truly distinct sources of genetic diversity in vetiver. In 1996, at the First International Conference on Vetiver in Bangkok, Pattana Srifah and colleagues of Kasetsart University in Thailand (where vetiver is ancient, if not indigenous) confirmed the usefulness of RAPDs by showing they were a "simple, quick, and reliable alternative" to easily distinguish among the confusing landraces of *Vetiveria* in Thailand (Srifah, Sangduen, and Ruanjaichon 1998). This new knowledge allowed a rationale evaluation of Thailand's massive propagation efforts by ensuring the identity of propagules while avoiding duplications.

Adams' and Dafforn's DNA analyses. Before the 1996 Thai vetiver conference, Robert P. Adams (an essential-oil chemist then at Baylor University and now with the Bishop Museum in Honolulu) had volunteered the use of his facilities and students to perform DNA fingerprinting for The Vetiver Network. At the conference, Mark Dafforn, in the name of the Vetiver Network's "Vetiver Identification Program," put out a call to attendees to submit preserved tissue samples for testing. The response from the vetiver community was outstanding, and within a few months more than 100 specimens from around the world had been submitted.

Working together, Adams and Dafforn, with numerous other contributors, have now published a series of papers on vetiver diversity. Their plan was to assemble vetiver samples from around the world and compare their genomic and physionomic attributes to known wild and related materials using molecular biology combined with standard grow-outs. The overall goal was to clarify the diversity of vetiver using taxonomic, morphologic, and genetic methods to understand similarities and variations among vetiver clones. This is of course useful in determining if clones in various places are actually different; but the purpose was twofold: providing vetiver users with reliable information on the clones they were using as well as understanding the variability of the genus, the species (especially *Vetiveria zizanioides*), and its forms—especially those used in vegetative hedges—so that a high level of scientific confidence could be maintained in the vetiver technology. A summary of their work on the DNA "fingerprinting" of vetiver appears in the following paragraphs. (Detailed technical results appeared in 1997 in The Vetiver Newsletter and at www.vetiver.org. They were reprinted in Adams, R. P., and M. R. Dafforn. 1999. DNA fingerprints of the pantropical grass vetiver, *Vetiveria zizanioides. AU journal of technology* 2(4)(Apr. 1999):173-180. A general summary of work-to-date appeared in Adams, R. P., and M. R. Dafforn. 1998. Lessons in diversity: DNA sampling of the pantropical vetiver grass (*Vetiveria zizanioides*) uncovers genetic uniformity in erosion-control germ plasm. *Diversity* 13(4)(1997-1998):27-28.) More recent information is under analysis.

When Adams and Dafforn did an initial screening of 53 samples, they found almost no diversity among cultivated materials, which formed a distinct cluster when plotted against wild (seedy) materials: there was a tidy match between genotype and phenotype. Further, and equally notable, within the experimental error of the probes used in these experiments, there was essentially no variation in the 27 vetivers collected outside southern Asia (except for one quite-similar accession from Malawi). A second analysis of 68 samples, using only one highly discriminating genetic probe, had the same surprising result, while the overall clustering patterns of both analyses corresponded to the existing botanical species, as well as to field observations of visible characteristics such as reports on fertility. This genetic evidence provided independent proof that planters (and botanists) in the past had a keen eye for understanding the variation in vetiver: they could judge an accession based on experience alone (no need for biotech), which probably explains why seedy vetivers remain so rare both in cultivation and outside the Indian subcontinent.

Indeed, of 60 total samples submitted from 29 countries outside southern Asia, 53 (88 percent) were a single clone. Records showed that at least two-thirds of these samples were first accessioned from traditional, in-country sources (for example, oil producers, herbalists, botanical gardens, and other planted sites). Therefore, it seems safe to consider them representative of the pantropical (ex situ) vetiver diversity as it existed before the interest stirred up by the World Bank. It seems that one ubiquitous essential-oil clone (called ‘Sunshine’ because it was the first of this type to be named) is densely distributed throughout the tropics.

Records show that vetiver was introduced to different locations certainly before World War II and most likely before the twentieth century. For instance, the oldest traceable occurrence is currently ‘Vallonia’ in South Africa, introduced there from Mauritius around 1900. We also know that ‘Monto’ has been in Australia since the 1930s, ‘Sunshine’ has been in the United States since the 1960s; and MY044693 and MY081268 was first vouchered in Venezuela in 1982. So by 1940 ‘Sunshine’ was on two continents and by 1982 it was certainly on four continents, and had probably been there much, much longer. Since these are also the four oldest records we have of any identifiable genotype of vetiver, the odds are that this distribution is representative of something that happened quite a while back. Further, such a consistent genetic identity across time and space in an essentially random sample implies that virtually all of the *V. zizanioides* outside southern Asia could be of the single ‘Sunshine’ genotype, which today certainly dominates soil stabilization and water flow control usage. This should provide enormous reassurance to vetiver users that the material they find in their own country is also this non-fertile type (though that should always be tested), and also that this is the type that was long ago selected as being the most desirable. (What a pleasant outcome for research that was essentially a blind shot.)

There is always a downside, however, which in this case is that most everywhere introduced vetivers are more or less the same, so they all share the same vulnerabilities. Discontinuities of geographic and genetic patterns in the DNA analyses, however, implied that much of vetiver’s variability awaited discovery, so a critical need was to screen other, reportedly non-fertile vetivers to uncover additional diversity. (An especially intriguing “gap” in the data was that no ‘Sunshine’ types have been recorded from southern Asia, the region of vetiver’s early distribution, so the “origin(s)” of non-fertile vetivers remains a mystery.)

A second phase of research, using high-resolution RAPD analyses, has already revealed more than a dozen non-fertile genotypes that are similar yet consistently distinct from the ‘Sunshine’ type. Many of these, thanks to the generosity of the USDA Plant Quarantine Center in Beltsville, Maryland, have been run through exceptionally rigorous phytosanitary testing and then distributed to collaborating researchers around the world. Evaluation trials of these accessions are underway, and variations in growth, oil-yield, environmental tolerance, and other characteristics are already evident. This germ plasm remains in reserve, forming a bulwark of biodiversity that holds promise for reducing the vulnerable genetic uniformity in what is now essentially a pantropical monoculture of an economically and environmentally important plant resource.

Worldwide Identification of Vetiver

Vetiver Identification Program research has now entered a third phase: the search for and documentation of biodiversity. Joining Adams and Dafforn are more than a dozen collaborating specialists from around the world, all voluntarily devoting their time and resources to understanding vetiver. The quest received a special boost when Yue-Wen Wang of Taiwan National University, like Adams, volunteered access to his laboratories and field plots. The island of Formosa is an incredibly diverse location where vetiver thrives and is desperately needed. At the Second International Conference on Vetiver, held in Thailand in 2000, Wang joined Adams in collecting additional vetiver samples solicited by Dafforn. Since then, even more clones have been identified and analyzed, and have entered common garden trials. This new burst of multidisciplinary analysis is opening whole new vistas on vetiver diversity, adaptability, fertility, and many other characteristics, the directions of which are just becoming apparent. Now, with Adams' move to Hawaii, it appears The Vetiver Network will have access to two first-class tropical research facilities, and much is anticipated.

Coupling DNA fingerprinting with reports from users and the historical literature, it appears that top-quality vetiver is likely to be found in every tropical and subtropical country, with the current exceptions of Iraq, Iran, Syria, Libya, Chad, Morocco, and Western Sahara, for which surprisingly (given their histories and geography) there are no reports. Vetiver is probably even now in these places and—as has been discovered so often in the past in so many other locations—has perhaps been there, undocumented, for hundreds of years. DNA fingerprinting has shown that the southern India type of *V. zizanioides* is the main cultivar used for essential oil production. This is the same ubiquitous genotype that, because of its unique and desirable characteristics, is being used and recommended around the world for soil and water conservation purposes. Veldkamp wrote in his vetiver-as-*Chrysopogon* article, "science means progress, and progress means changes" (Veldkamp 1999). In the case of vetiver, ten years of science done by volunteer labor on shoestring budgets has greatly progressed our understanding of vetiver identities, thus helping positively change its acceptability in the eyes of both believers and skeptics around the world.

Table 3-1 illustrates the extent of *V. zizanioides* distribution throughout the world.

Table 3-1. Worldwide Distribution of *Vetiveria zizanioides*

Africa	Burkina Faso, Burundi, Cameroon, Congo, Ethiopia, Gabon, The Gambia, Ghana, Guinea, Kenya, Malawi, Niger, Nigeria, Rwanda, Senegal, Somalia, South Africa, Tanzania, Togo, Uganda, Zambia, Zimbabwe
Central America	Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, Panama
East Asia	Cambodia, Indonesia, Laos, Malaysia, People's Republic of China, Taiwan, Thailand, Vietnam
Europe	Albania, Italy, Portugal, Spain, United Kingdom
Indian Ocean	Madagascar, Mauritius, Réunion, Seychelles
North America	Mexico, United States
The Pacific	Australia, Cook Islands, Fiji, Guam, Hawaii, New Zealand, Papua New Guinea, the Philippines, Samoa, Solomon Islands, Tonga, Vanuatu
South America	Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, French Guiana, Paraguay, Peru, Suriname, Uruguay, Venezuela
Southern Asia	Buthan, India, Myanmar, Nepal, Pakistan, Sri Lanka
West Indies	Antilles, Cuba, Dominican Republic, Haiti, Leeward Islands (part of the Lesser Antilles), Puerto Rico, Windward Islands (part of the Lesser Antilles)

Special Characteristics of Vetiver Grass

What makes vetiver grass special? The answer is found in the roots, in the plant's physiological and ecological characteristics, and in its inherent ability to grow without becoming a weed and without attracting pests.

Vetiver roots. Vetiver grass has a massive, finely structured root system that is unique. We have found no other plant with any root similarities to vetiver's roots. The vetiver root has a characteristic that sets it apart from other grass and tree roots; that characteristic is the root's power of penetration. The innate strength and vigor of the vetiver root enables it to penetrate through difficult soils, hardpan, or rocky layers with weak spots; it even manages to punch through asphaltic concrete pavement. With no rhizomes or stolons, the plant's roots grow straight down as a mass as dense as the amount of leaves it produces above the ground. These roots penetrate 3 to 4 meters into the substrate before slowly thinning out; but in one case in Thailand, they were found to reach a depth of 6 meters

A photo taken by Diti Hengchaovanich (see Figure 16-2 in Chapter 16) shows the density of vetiver roots on a single plant that is 13 months old. The root system, 2 meters long by 50 centimeters wide, demonstrates why the vetiver plant is so efficient as a biological dam while holding the soil together below the surface.

The roots are of special interest because of their outstanding tensile strength. Research carried out by Hengchaovanich and Nilaweera shows that the tensile strength of vetiver roots was in the order of 75 MPa (megapascals—measurement of unconfined tensile strength)—or approximately one-sixth that of mild steel—and varied from 40 to 120 MPa (Hengchaovanich and Nilaweera 1996). In the field, of course, the use of steel is expensive and sparse, and steel starts to deteriorate as soon as it is installed. On the other hand, vetiver roots are cheap, dense, and only proliferate over time, helping to explain why it is becoming a favorite of revettment engineering.

As a result of their research into highway slope stabilization, Hengchaovanich and Nilaweera stated that vetiver roots basically behave like living “soil nails,” or dowels, commonly used in “hard approach” slope stabilization work. (Chapter 8 summarizes much of the work done by Diti Hengchaovanich on the use of vetiver for bioengineering.)

Vetiver’s deep root system also makes the plant capable of withstanding quite severe droughts. In the early 1990s, it not only survived the worst drought in Queensland, Australia, but it continued to grow throughout the drought.

With vetiver, new roots and shoots develop from the crown and nodes when the plant is buried by trapped sediment. The plant will continue to grow and fill in at surface level, with the new ground level eventually forming a terrace. In India, where vetiver was planted across a 2 percent slope as part of a farm boundary marker more than 100 years ago, it formed a terrace more than 3 meters high, which is a perfect example of the amount of soil the farmer would have lost from his farm had the vetiver hedge not been planted.

Physiological characteristics. Vetiver grass is a “climax plant,” which survives conditions under which other plants cannot live. It will tolerate prolonged drought, fire, flood, submergence, and extreme temperatures from -15°C to 55°C (in Australia) and higher (in India and Africa). In some cases it may be the only plant to survive. Its ability to regrow quickly after being affected by drought and especially by fire, as well as by frost, salt, and other adverse soil conditions, is quite outstanding and is unequalled by other plants. It can withstand a wide range of pH growing in soils with an acidity of 3.0 and can survive in alkalinities with a pH as high as 10.5 to 11.

Vetiver can tolerate a high level of soil salinity, soil sodicity, and acid sulfate, making it a unique conservation plant under these conditions (Truong et al. 1996). Its uniqueness is especially displayed where the plant has been used to stabilize and rehabilitate mine wastes and landfills, because it is highly tolerant of toxic levels of aluminum (Al), manganese (Mn), cadmium (Cd), chromium (Cr), nickel (Ni), copper (Cu), and arsenic (As) (Truong and Claridge 1996).

Ecological characteristics. Because of its above-stated qualities, vetiver grass can be considered as a nurse plant on wastelands or disturbed lands. Planted as a hedge, or as a series of hedges, vetiver stabilizes the erodible ground (particularly steep slopes) as it creates a microclimate so other plants have a chance to establish. In this respect, it has proved itself in rehabilitating mine sites and stabilizing highway cuttings, railway embankments, and quarries.

After the trees and shrubs have established on these sites, they begin to shade the vetiver hedge out, replacing it as the stabilizing agent. Therefore, vetiver is highly regarded as a non-intrusive land rehabilitation pioneer.

For example, in the late 1980s, a block of land cleared of jungle in Trinidad was clean-cleared, burned, and planted to citrus. Immediately after the burn, when the land was bare and vulnerable to erosion, two vetiver hedges rapidly materialized and prevented any problems with soil erosion. Although these hedges had been planted years before, the land had since been neglected and had reverted to jungle. The hedges were totally overgrown and "shaded out"; however, the tenacity of the grass was well demonstrated by its return after years of persisting in shady obscurity.

Likewise, this tenacity of sustained viability under dense shade is strongly exhibited in the Fiji sugar fields, where contour hedges of vetiver grass are completely covered by the cane crop for at least 10 months when the crop canopy has closed over, thus demonstrating an outstanding feature of vetiver's resilience. When the sugarcane is harvested, the hedge is immediately exposed to full sunlight, a shock that would kill most plants. And if that is not enough of a shock for the plant, it is then often burned with the cane trash—or in areas where they do not burn the trash, the hedges are cut to the ground because the leaves make an excellent, long-lasting thatch. Despite this horrendous treatment, the hedges continue to perform perfectly.

The Fiji cane growers also have found that when the vetiver hedges are green, they make a perfect fire break for burning off cane trash.

Although vetiver is tolerant of some extreme soil and climatic conditions, it is highly intolerant of shading during establishment. To obtain a good sustainable hedge, it must be planted and developed in full sunlight.

Weed and pest potential. It is important that any plants used for environmental protection or economic cropping must not escape and become weeds or intermediate hosts for pests of other economic crops. Many cultivars of vetiver grass (*V. zizanioides*), the only species we recommend for soil erosion control and other uses (as mentioned later in this book), have been rigorously tested for its sterility in the United States, Australia, India, and many other countries where it is being used extensively. In India, where vetiver grass has been used for hundreds of years as an essential oil crop, it has not shown any invasive potential outside the range of its wild, seedy ancestor, the swamps of Keoladeo.

4. Why Vetiver Grass?

Grass is defined variously in the dictionary as “herbage suitable or used for grazing animals,” even as “...a state or place of retirement—an old horse put out to grass.” Grass has many connotations, but none of them leave the reader with a feeling of a plant that can do much more than feed an animal or cover a field.

When vetiver grass (*Vetiveria zizanioides*) is described as having great potential as a conservation plant, the usual response has been negative—“A grass is a grass. How can one be any better than another? Surely we know all the grasses now; how can vetiver grass be different?” As I explain in this chapter, vetiver grass is not just “any grass,” any more than rice, wheat, or bamboo is just “any grass.”

Once vetiver grass had been reasonably well identified, it retained its importance as an essential oil crop; but because of the difficulty of harvesting its roots, it had a limited production potential. Its other attributes were unknown at that stage, and consequently, they were given no consideration. In the 1930s, individual tea and coffee planters on some estates in Africa tried using vetiver as a soil conservation hedge; it performed very well. Little if anything was written about it, however, and because the information was not shared with other planters, this use of vetiver was soon lost to the outside world.

Although colonial authorities had learned about the vetiver hedge through their experience with Hindi and Tamil caneworkers in the nineteenth century and had occasionally encouraged its use, it was not until the late 1940s that the sugar industry, through the International Society of Sugarcane Technologists (ISSCT) conferences, actively promoted the idea of using vetiver grass hedges as a means for controlling erosion in sugarcane fields. As happens with many campaigns, this one lost steam; the industry did not persist with the idea, and the notion was adopted only sporadically in a few places such as St. Vincent in the Caribbean (Velez 1952; National Research Council 1993). In the islands, some old-timers still recall listening outside the circle of gaslight when local caneplanters were enjoying their Friday night card games and talking about the “new” idea of using vetiver hedges (Stanley Mullings, Castries, via Dafforn; personal communication). Being a biological method of erosion control, with unknown ramifications, sugarcane technologists decided that the cane itself was capable of providing its own soil conservation needs. No quantitative figures were available to back up the favorable qualitative outcome of vetiver’s erosion control and stability enhancement of slopes. Planters were unsure about whether it would become a weed or a menace in the sugarcane fields, so it went into obscurity and was rarely mentioned again.

In the early 1950s, the Colonial Sugar Refining (CSR) Company of Fiji needed to expand its cane-growing operations into the hills, the only area left with any potential. But they knew erosion would be a major problem that they would need to address before committing these areas to clearing, cultivation, and planting.

In the 1950s, with both fuel and post-World War II earth-moving equipment in abundance, the accepted method of soil conservation was to construct earthworks that (1) collected the runoff and channeled it away safely either by way of a diversion bank to a waterway or directly into a “safe” natural drainage network; (2) moved it at a “safe” but fast pace into a constructed dam; or (3) held it in place to be absorbed into the ground by constructing an absorption bank. All these systems had proven themselves since the 1930s and were first developed in the United States when the Soil Conservation Service was created to control the massive erosion problem brought about by the rapid expansion of cultivation in the central and western states.

Soil erosion was considered to be “an engineering problem.” Engineers and technicians were trained in the new soil conservation technologies; they were taught how to use “dumpy levels” (engineers’ transits), how to lay out accurate contours, how to survey in the correct gradients for diversion banks, and how to operate or supervise the use of heavy earth-moving equipment for constructing banks and low dams.

Soil conservation became an agricultural science. Textbooks were written. Design formulas were devised and published. Agricultural students and engineers all over the world were taught to use this new technology. In addition to its great expense, there was another major thing wrong with this system—it was of limited value in the tropics under extreme rainfall conditions.

In the tropics, rainfall intensities can be extreme and almost totally unpredictable. So the soil conservation banks designed and constructed in Fiji to withstand a maximum intensity storm of 1 in 50 years were totally destroyed when 500 mm of rain fell in three hours. If soil conservation works are wiped out, they have to be reconstructed at great expense, which can become a never-ending battle. In addition to the recurring expense, safety becomes an issue, with massive erosion episodes in which banks blow out and soil is lost, or dams collapse, or worse.

At the same time as the banks were being constructed in the Fiji experiment, a natural system of soil conservation using hedges of grasses and shrubs was being tested. Live hedges would possibly be more appropriate for the extreme tropical conditions because they would at least “regenerate” after a major storm. This approach meant finding a plant, or plants, that would form a natural hedge, taking the place of the expensive constructed earthworks.

The following plants were tested at CSR’s Agricultural Experiment Station, Lautoka, Fiji, for use as a biological means of soil conservation by forming hedges, grass strips, or living porous barriers that would slow down runoff water and trap sediment.

Atriplex spp.
Brachiaria brizantha
Cajanus cajan
Cymbopogon nardus
Cynodon dactylon
Eragrostis curvula
Eulaliopsis binata
Festuca arundinacea

Leucaena spp.
Panicum clandestinum
Panicum maximum
Paspalum notatum
Paspalum vaginatum
Pennisetum clandestinum
Pennisetum purpureum
Saccharum bengalense
Saccharum spontaneum
Setaria sphacelata
Tripsacum laxum
Vetiveria zizanioides

With the exception of vetiver grass, none of the above grasses or shrubs proved effective in controlling runoff. Most these plants were sown as seed. Cultivars grown from seed are individuals and will never join together, as a clone will, to form a dense ground-level hedge. Not only will gaps always exist between the individual plants, but the risk of spreading their seed and becoming weeds also is possible.

Even some species planted vegetatively, from cuttings and not from seed, will not grow together. Unless the plants form a dense hedge, the runoff will channel between the individual plants, leaving them standing on a pedestal of their own roots. Eventually, they will be undercut and eroded out of the ground, losing all the early benefits of terrace forming and erosion control. This problem is especially the case with the *Cymbopogons* (*C. nardus*, *C. citratus*) and also with *Eulaliopsis binata* and *Saccharum bengalense*, which often are wrongly used as conservation plants; these plants are short lived and either are washed out or die.

Trees and shrubs in the tropics have trunks or stems that preclude them from forming a dense ground-level hedge; their root systems usually are shallow and widespread, and they compete with companion crops. Trees do not prevent erosion, as I know simply by observing how many trees I have seen standing on their roots, the soil eroded from under them.

In the CSR's Lautoka trials, vetiver grass was the only plant that, as a hedge, withstood the high-intensity storms and prevented erosion. The roots of vetiver grass do not spread laterally but penetrate vertically and deeply into the soil, or subsoil, "nailing" it in place, and offering little or no competition to companion crops.

The above list of plants tested at Lautoka is not exclusive; other plants, unknown to us, could be as hardy, diverse, and useful as vetiver grass. Despite a reward program and a worldwide search over the past 15 years, no scientist or individual has yet come forward with a plant of equal attributes. Vetiver grass, however, is a tropical/subtropical plant and can be recommended for use only 30 degrees north or south of the equator. It will grow in fringe microclimates beyond these limits, such as in Mediterranean climates, where the summer is very hot, but is not recommended for the temperate zone and certainly not for cold climates.

Why none of the plants listed above succeeded as conservation plants, and why until now no plant has really shown great promise in the realms of biological erosion control, is because the criteria for a conservation plant are, of necessity, very exacting. Vetiver grass is the only plant tested that has met all the essential requirements.

Essential Criteria for a Vegetative Soil Conservation Plant

For a plant to be useful in soil and moisture conservation and to be accepted as safe, it should have the following characteristics. The plant should—

- Not spread by seed, and it should not produce stolons or rhizomes so it will not escape and become a weed.
- Have a crown that is below the surface so it can resist fire, as well as overgrazing and trampling by livestock.
- Be capable of forming a dense, ground-level, permanent hedge as an effective filter, preventing soil loss from runoff. Only species planted as clones will grow "into" each other to form such a hedge.
- Be perennial and permanent, capable of surviving as a dense hedge for decades, but growing only where people plant it.
- Have stiff, erect stems that can withstand a water flow of at least 1 cubic foot per second (.028 cumec), 12 inches (0.3 m) deep.
- Be both a xerophyte and a hydrophyte if it is to survive the forces of nature. Vetiver grass, once established, is little affected by droughts or floods.
- Have a deep, penetrating root system capable of withstanding the tunneling and cracking characteristics of soils. The roots should penetrate vertically to at least 10 feet (3 m).
- Be capable of growing in the full range of soil types, regardless of nutrient status or pH, and regardless of the soil's levels of sodium, acid sulfate, or salinity. These soils include sands, shales, gravels, and mine tailings—and even more toxic soils.
- Be capable of developing new roots from nodes when buried by trapped sediment, and it should continue to grow and fill at the new ground level, eventually forming natural terraces.
- Not compete with the crop plants it is protecting.
- Be resistant to common pests and diseases, and it should not be an intermediate host for pests or diseases of other plants.
- Be capable of growing in a wide range of climates—from 200 mm of rainfall to more than 6,000 mm and from temperatures of -15ºC to more than 55ºC.
- Repel rodents and snakes. (The sharp leaves and aromatic roots of vetiver make it hostile to vermin and other pests; it is also relatively unpalatable to livestock.)
- Be cheap and easy to establish as a hedge, and the farmer should easily maintain it at little cost.
- Be easily removed if the farmer no longer wants it.

These characteristics describe *Vetiveria zizanioides*—a truly remarkable plant. At this stage (circa 2000s), no other plant is known to share its hardiness or diversity as a conservation plant. Other plants besides vetiver (such as those used in the Lautoka trials) can be used in a vegetative hedge system; the concept of slowing runoff and dropping sediment remains the same. The drawback is that they lack the ground density of a vetiver hedge, as well as the longevity and disease resistance.

Vetiver Seediness and Pestiferousness

Where it grew in its natural environment in the steamy swamps of Keoladeo, India, the wild, seedy vetiver was used for centuries as grazing for water buffalo, which unlike other livestock will eat just about anything. Here, an interesting incident took place. The "environmentalists" seeking to help and protect water birds that had also been using the swamp for centuries had the government ban grazing to give the birds more free water access. The result could not have been worse.

The birds, the buffalo, and the swamp vegetation had been in perfect harmony for centuries until people interfered. By removing the water buffalo, the vetiver grass, no longer grazed, took over and covered all the areas of open water leaving no space for the water birds. In all our research worldwide, this is the only case we know of in which seedy vetiver grass became a dominant "weed"; but here it was native and in its natural habitat. Fortunately, somebody in authority had a sudden attack of common sense and let the farmers' buffaloes back into the area, thus resolving the problem.

Experience also shows that, if it is desirable, it is easy to eliminate vetiver either chemically or mechanically. Vetiver grass can be controlled easily by spraying with herbicide (it is especially sensitive to glyphosates such as Roundup®), turning the crown with a sod plow, or roguing (uprooting it and drying it out). Perniciousness is not a problem. Importantly, even seeding northern India types are not reported invasive, although they are codominants in fluvial Ganges grasslands.

As far as vetiver's being a host for pests of other economic crops, or even being attacked by pests, we have had no feedback from all our inquiries over the past 15 years. But I did get an interesting point from a coffee planter in Zimbabwe.

Sandy Scott, of Chipinge, Zimbabwe, who has been farming coffee all his life, not only had to deal with soil erosion but also with pests. Unfortunately, when he sprayed his coffee to control pests, he also wiped out the useful predators. Since the early 1990s, Scott has been using vetiver hedges to control soil erosion. Once he had established his vetiver hedges among the rows of coffee trees, however, the predators bred in the vetiver away from the spraying and crossed over to the coffee to control the pests. (Coffee pests are not attracted to vetiver grass.) With the vetiver, he has reduced his spraying program considerably.

In another instance, I was given access to a greenhouse in which potted vetiver plants had been neglected for two years. Despite the summer heat, the winter cold, and the humidity, I saw absolutely no sign of fungus or any other disease; the plants were clean and so was the inside of the greenhouse—a remarkable phenomenon, considering that any normal plant would have died from neglect and the inside of the greenhouse would have been covered in fungus. A similar observation comes from government phytosanitary officers at the U.S. Department of Agriculture (USDA), where plant pathologists examined a collection of clonal vetiver germ plasm that had arrived from five continents and eight different countries (and had surely been in many more since leaving India perhaps centuries before). After intensive testing for insects, fungi, bacteria, viruses, and everything else on their checklists, they cleared them all for unconditional release in the United States because they found absolutely no sign of any infestation or disease (Dafforn, personal communication). This is unheard of in vegetatively propagated plants, which never go through the "cleansing" stage of setting seed, and which are usually cesspools for all the maladies known to agriculture.

Researchers must take heed, however; this extraordinary ability to stay "pure" in the face of the constant pest and plague pressures found in nature cries out for explanation. Initial plantings of vetiver in a new area often attract a host of pests in the first year. These appear to do very little damage, apart from causing concern. Once the plants are established, the pests seem to leave them alone, having discovered that this "new plant" in the area is incompatible with their needs. If this sterling quality of vetiver could be understood, perhaps it would unlock secrets for achieving the same resistance in other valuable crops.

By now it is clear that using vegetative hedges has shown great results in controlling erosion in field agriculture, as well as in civil engineering, landscape stabilization, rehabilitation, and the reestablishment of native vegetation. And even though vetiver has long been grown in every imaginable tropical habitat, it has also proven remarkably free of the ailments that normally afflict plants when they are grown as monocultures.

Another early concern, of course, was the potential of invasiveness; but we quickly learned that there were types of vetiver that had been used for centuries without being a nuisance to humans or the environment. This "traditional knowledge" (in this case shared by farmers *and* scientists) has now been validated by modern molecular biology (see Chapter 3). Just as rice and cane have wild ancestors that are "weedy" (that is to say, they can regenerate by seed on open, fertile soil), so too does vetiver; it has been thriving happily for eons in the intermittent marshes of the Ganges plain, as noted above.

As we learned more about the plant, this concern diminished considerably. It became clear the vetiver used in erosion control is the essential-oil vetiver from southern India, where it seems to be known only in cultivation. It is now also clear that most vetivers outside southern Asia are these low-fertility, essential-oil types that are never invasive and are unlikely to become pests. This domesticated form of vetiver has long been grown as a field crop for its oil, which is used in perfumes. For this reason, the grass has been carried from place to place for centuries. It is now pantropical, growing in nearly 100 countries. In the extensive experience with the plant and in the literature that exists about the plant, experts do not consider vetiver to be a weed.

One conjectural ancestor of these cultivated essential-oil vetivers is the seedy vetiver from northern India and adjacent areas across the Ganges plain. This plant is not widely disseminated, but it has been introduced to southern India and a few other places. Morphologically, the two types are quite dissimilar; the northern India phenotype is lax, weak stemmed, and shallow rooted (and thus unsuitable for forming hedges). These traits hold true regardless of where the plant is grown.

The oils of the two types of plants vary chemically, rotate polarized light in opposite directions, smell different, and are treated separately in commerce. Technically, the northern Indian oil is "*Khus* oil," the southern Indian oil is "oil of vetiver."

The two types of plants also seem to differ in flower structure, although there are not yet enough botanical vouchers to be sure. So far, the differences fall within specific limits of the taxonomy, so at the current time, the two are considered the same species (see Chapter 3). The northern India vetiver is fully fertile, as are other species of the genus. As a convenience, taxonomists have long lumped unassignable cultivated plants with nearby relatives. Since the eighteenth century, the time of Carl Linnaeus, the Father of Taxonomy, it has been proposed that the wild northern India vetiver and the essential-oil southern India vetiver could be separate species, but this has not been separately examined in vetiver. Recent DNA results indicate there may be transitional types, but as of now, nearly all vetivers that have been fingerprinted can be handily assigned to either the northern India or southern India group (Dafforn, personal communication).

Initial DNA fingerprinting (RAPDs—Random Amplified Polymorphic DNA) of many genotypes has shown northern India seedy material to be quite heterozygous (have different genes) and genetically quite distinct from the southern India materials. By comparison, the "nonflowering" clones are unusually homozygous among themselves. Most are virtually identical by any genetic standard (as well as quite distinct from the seedy types of vetiver from northern India). Homozygosity such as this over a broad geographical area seems to indicate a long history of clonal propagation without sexual reproduction. None of these accessions has field-seeded over several hundred combined years of cumulative field observation.

A strong correlation seems to exist between oil yield from the roots and what is termed *nonflowering* in the Indian literature (incidentally, *nonflowering* is a misnomer; inflorescences occasionally occur in all cultivars). It seems that the most desirable plants for propagation and further introduction have also tended to be the most infertile. This selection pressure may explain why viable seeds (caryopses) are scarcely reported from elite cultivars, a common characteristic of plants domesticated for purposes other than seed production, such as potato and sugarcane (a close relative of vetiver). The sterility seems total in many vetiver genotypes (the possible result of various factors, such as pollen sterility and embryo abortion) but, of course, cannot be absolutely proven.

Many locations (for example, India, Nigeria, the United States, the Caribbean, and Fiji) have now been found with very old vetiver hedges. None show signs of spreading, either nearby or far downslope; they persist but have not naturalized. Watchfulness is, of course, called for so when agriculturists select germ plasm for erosion control, they should always monitor fertility case by case. One especially reassuring result from DNA fingerprinting, however, has been that in every case where growers have specified their samples as “nonseedy,” the DNA results have confirmed a clustering with the “nonfertile” types (Adams et al. 1997). This has given users added confidence that their vetiver is nonfertile if it does not produce viable seed after flowering the first time. Vetiver is not a fooler like so many plants that, for example, can flower (often irregularly) for years before throwing viable seed.

Yet in the 1950s, when vetiver grass was established as the best means for controlling erosion in the Fiji cane fields, the greatest uncertainty hanging over the whole system was “how long would it last?” How long would it be before the hedges died out and all the effective conservation and terracing would be lost? Because there was no apparent answer to this quandary, the vetiver technology was hard to “sell.”

In 1985, the vetiver hedges had been doing an excellent job in Fiji for 30 years, but the question still remained—“What will happen after 30 years?” No man-made conservation system that I knew of had lasted 30 years without massive maintenance costs or rebuilding, but technologists still had little confidence in a plant that could control erosion better than a machine could.

It was not until the watershed projects that I undertook with the World Bank in India that we found the answer to vetiver’s longevity. In the state of Karnataka, in a small farming area known as Gundalpet, farmers had been using vetiver hedges for more than 200 years as boundary markers for their farms. These boundaries had proven so permanent, never moving from where they were planted, that the Lands and Survey Department of the Karnataka state government had accepted them as benchmarks for land disputes in the area.

This breakthrough was sufficient for the World Bank to accept the system as a safe means of conservation it could support—a conservation system well within the means of the poorest peasant farmer. Once they had a supply of the planting material and the knowledge of how to use it correctly, the subsistence farmers needed no government support. The planting of vetiver grass was an economic and sustainable conservation system capable of covering a whole country.

In India, the various state government agricultural departments set up nurseries everywhere, laying out demonstrations of the conservation hedges in appropriate areas well within the public view. They held field days and distributed planting material to interested farmers. For once, the farmers were more than interested; they were “liberating” the planting material from government nurseries.

Through the World Bank and with the cooperation of various state government agricultural departments, I set up nurseries throughout India, laid out demonstrations of the conservation hedges in appropriate areas well within the public view, held field days, and distributed planting material to interested farmers. And the farmers were more than interested; they were eager to “liberate” the vetiver plants from government nurseries.

Now, only 15 years later, thousands of people are working with vetiver hedges in every clime in almost every tropical country, and the knowledge base is exploding, still without signs of potential vetiver pestiferousness. I could never have imagined, sweating with my multispecies field trials in 1950s Fiji, how my “dream” of a natural solution for soil conservation would spring to life in *only* 50 short years.

Soil Conservation versus Moisture Conservation

Despite India’s massive soil conservation drive and the millions of rupees spent constructing banks, waterways, and the like on and through farmers’ fields, the constructed system of soil conservation accepted worldwide, without question, was not accepted by the Indian farmers for the following reasons:

- The constructed system of soil conservation requires the farmers in a given watershed to cooperate with each other or the design will not work. Banks and waterways are set up regardless of farm boundaries to conduct the runoff away from the catchment as fast and safely as possible. Farmers did not like the idea of other farmers’ runoff being channeled through their farms.
- The construction of the conservation banks took out of production a strip of land 5 meters wide. In many cases, for small farmers, such construction meant losing 10 percent of their productive land.
- The government constructed the banks with heavy equipment or large labor gangs. When the banks breached (which they did often because of poor layout), the farmers did not have the power, money, or labor to repair them, so the system broke down.
- The farmers could not see the value of such a system; consequently, nowhere in India did the farmers carry out any maintenance.
- The government would undertake a large area for soil conservation and construct the banks and waterways; but because of the failures caused by rainstorms or poor design requiring massive maintenance and rebuilding, they could never finish one area and move on to another. Therefore, with the constructed system, they would never achieve the countrywide control they needed.

From the farmers’ point of view, they were losing land to a system they could neither support nor maintain, a system that was bringing “foreign water” onto their farms and doing them “no good whatsoever.”

If farmers do not accept a new system or technology, they do so for a good reason. In the case of construction for soil conservation, they knew that this system was taking their natural runoff and diverting it before it had the chance to soak into the ground, thus denying their crops the essential moisture needed for production. They knew they were losing land to the system. And they knew they could not repair the system even if they wanted to, because they did not have the power, labor, or technology.

From the government's point of view, such construction was the only system of soil conservation known to the agricultural/engineering world. It was costing them a fortune every year because of having to continually return to the beginning to carry out maintenance, rebuilding, or redesign, meaning they would never be able to cover the whole country. This system was very technical, and it was not "user friendly." If engineers got the levels wrong, at best, it did not work; at worst, because it introduced concentrated "foreign" runoff, the banks burst and caused massive erosion events that would not have happened if the system had not been introduced in the first place.

From the country's point of view, this system of fast flushing contour banks and waterways was presenting great problems further down the catchment. Runoff was being delivered into the drainage network faster than nature ever intended it to be. This high-speed runoff was carrying massive amounts of silt that were threatening to clog the country's navigable rivers and harbors. But what could they do? This was the system of soil conservation being taught around the world; all the best universities and the best textbooks dealt only with this system—a system that worked in the temperate climates and that worked in areas where governments and farmers had money and equipment for maintaining the banks and other structures.

But even the best-maintained areas suffered from too much water being delivered to the drainage network too quickly—a possible reason for the massive Mississippi River floods in the United States in the mid-1990s. Today, millions of hectares of highly erodible lands are now in the USDA Conservation Reserve Program, with great swaths of native grasses planted on what were once farmers' fields.

When I, through the World Bank's watershed development projects, introduced the Vetiver System to farmers in India, we had to change the conservation message to one that interested the farmers. That message was one of "moisture conservation" for increased and sustainable yields; most farmers did not want to hear about "soil conservation." In India, soil conservation had cost the farmers dearly and was, in their eyes, useless. Unfortunately, at that time, soil conservation departments were not interested in moisture conservation, and they failed to understand that by giving priority to moisture conservation, soil conservation itself would be looked after automatically.

As part of the World Bank's watershed development projects, I laid out vetiver grass hedges on government research stations as demonstrations and on farms that farmers had volunteered for the purpose of demonstrating the Vetiver System. The state government agricultural departments and extension services held farmers' field days at the time of planting the slips, again after the hedges were established, and once more after heavy rains to show the silt and organic matter that had been trapped behind the hedge.

Extension workers told farmers that this system that uses hedges to conserve moisture could increase their yields by 10 percent, and that the only cost involved was initially obtaining the planting material. The workers taught the farmers to plant the slips as a single line, with seven slips to the meter, and with about three hedges on each farm: one at the top of the field to prevent the neighbor's runoff from damaging the crop, one in the middle of the farm to hold back erosion and moisture, and one at the bottom of the farm to hold back its own runoff.

The farmers saw the following immediate advantages of this system:

- The farmers do not have to cooperate with each other to protect their individual farms.
- The hedges do not convey runoff; they filter the soil out of it, slow it down, spread it out, and let it pass on down the slope at a safe speed, giving full opportunity for the moisture to soak into the ground, as it does naturally.
- The hedges occupy a strip only 50 centimeters wide or 1/10 that of the constructed banks and channels; therefore, the farmers lose little land.
- With the constructed system, farmyard manure, quite often the only form of fertilizer the subsistence farmers can afford, was washed down the waterways and lost. With the biological system, the manure was saved behind the hedges and given time to soak into the ground.
- The crops can be grown right up to the hedges without any loss of yield.

The farmers themselves noted these points about the Vetiver System. What they had not known and what they found out ultimately were the following additional advantages:

- The effect of moisture conservation behind the hedges was massive, to the point of “droughtproofing” farmers’ crops, especially just after crop germination.
- If crops in the district failed because of lack of soil moisture, it was usually because the farmers planted after the first rain; their seed germinated, but there was no further rain to support the growth for six weeks. Their young seedlings withered and died and the farmers lost the seed they planted. Where the farmers had planted vetiver hedges, their fields retained enough moisture to support the seedlings through the six weeks of “drought” and the farmers were able to harvest a good crop.
- In normal years, yield increases were in the order of up to 50 percent over the traditional system.
- A farmer did not have to plant the hedges on the absolute contour of the land, because they were not conveying water; they were filtering it. These straighter hedges made it much easier for the farmer to follow with his plow. The hedges were just planted across the slope, straight across rills and gullies, which silted up behind the hedges after a few rainfall events, leaving the land level; this self-leveling feature is one of the great boons of vetiver hedges. Over time the rills and gullies in the farmer’s field disappeared.
- A breach in a hedge is no catastrophe. Because the land behind a hedge is level, only “local” water flows through a breach. In engineered structures, the flow is concentrated “foreign” water; by definition, the breach always forms at the “lowest point” for the catchment above it, so all the torrents rush through, creating deep-cut channels and gullies. As noted above, a constructed “cure” is often worse than no cure at all.

It was this increase in yields, the obvious saving of farmyard manure, the droughtproofing of crops, and the filtering/retention of soil and preventing its loss that won the farmers over—and all this at virtually no cost. Maintenance in the first two seasons was limited to filling gaps and making sure the hedges became established; after that, maintenance became virtually nil.

Vetiver grass is the only plant we have found that will give these results on a sustainable basis in the tropics. It should be noted that in the past few years the Vetiver System for soil and water conservation has stagnated in India, primarily because of the failure of government departments to promote the technology, and also because of a failure to involve farmers directly in the decision-making process. This “failure” is not confined to India, and it is not surprising; constructed terraces, although they cost the farmer land and profit, bring enormous amounts of money (and prestige) on an ongoing basis into the local engineering and construction economies. There is no incentive for these professional communities to lose all this income to farmers with only dibble sticks and sprigs of vetiver in their hands.

Constructed Systems of Erosion Control

To give a better appreciation of why “farmers” in poor countries do not accept the mechanical system for their farms, I have compared the constructed system with the biological Vetiver System explained above. (Also, as noted above, it is rarely the farmer who really makes the “conservation” decisions about the farm.)

Constructed conservation works in the West are used mainly on arable land, because arable land justifies the expense. Constructed conservation works are not used on farmers’ non-arable areas or rocky hill slopes. Why? First, the cost is prohibitive. And second, it is impossible to construct contour banks through rocky land. Vetiver hedges, however, can be planted from rock to rock without any problem. Because such unprotected rocky slopes above farmland pose an enormous threat from uncontrolled runoff entering the arable land, they cannot be ignored.

With the constructed system, the farmer has three basic components of runoff control. First, at the top of his field is the storm water diversion drain constructed to intercept the storm runoff from higher ground onto the arable land that it protects. It is an open drain, usually in bare earth, and is surveyed to a gentle gradient. It is the first line of defense, and all the structures lower down will be designed on the assumption that it will effectively control all the runoff from outside the arable land. If it fails to do this, the water released will almost certainly breach the lower works.

Second, the runoff from the arable land is caught in similar but smaller drains spaced at regular intervals down the slope. Their channels are usually kept free of vegetation, and the excavated soil forms a bank on the downhill side. They are usually surveyed on a gentle gradient so that they will not silt up or erode their channel, but will lead the runoff safely away from the arable land. This runoff is the rainfed farmer’s essential source of soil moisture, and the constructed system is channeling it away from his land before he can use it or before it has had time to soak in.

Third, constructed banks discharge into a natural drainage outlet, if a suitable one exists in a convenient position. When such discharge is not possible, an artificial channel, or waterway, must be constructed. This broad, land-gobbling waterway also will be a shallow, open drain, but with good grass cover (not possible in developing countries), and it will run straight down the slope. It needs careful design to avoid the flow that causes erosion, as it has throughout Lesotho, South Africa (see discussion at the end of Chapter 6).

All three of the above components of the constructed system cost money and take up valuable land, and the waterway always poses a major erosion problem. These constructed components can be replaced with three simple vetiver hedges planted by the farmer across the slope of his land. Vegetative hedges do not channel water away from the land; they hold it back, spread it out, and give it a chance to soak into the ground where it is needed before the surplus runoff "oozes" through the hedge and moves on down the slope in a natural fashion to the next hedge. Constructed mechanical systems also require surveyors, construction equipment or labor gangs, and continual maintenance; and they often need reconstruction. The vetiver hedges, however, once they have been correctly planted and established need no further maintenance and incur no further expense.

If maintained, the constructed banks and waterways have a life span of 5 to 10 years at best, because they are made from the same erodible soil they are designed to protect. Then they need to be rebuilt at almost the same expense as the initial construction. The vetiver hedges will last for centuries with little maintenance or cost. It truly is a natural solution.

5. The Problem of Erosion or Degradation

Degradation here refers to the physical and biological processes that diminish the usefulness of land. Typical environmental effects are (1) accelerated soil erosion, leading to loss or degradation of vegetation; (2) over-exploitation of groundwater; (3) salinization of soils; and (4) waterlogging and the silting of rivers, harbors, and storage dams, reducing the area of irrigated land and causing deterioration of water supply and quality.

The world is facing a crisis of unprecedented proportions. The physical environment is deteriorating. Because of soil loss and runoff, the per capita production of food grains is falling and will continue to fall; likewise, productive land is being lost and will continue to be lost. This crisis is of special concern in island nations where the land area is small and productive areas are severely limited.

Population growth rates also are putting enormous pressure on the environment and are not being satisfactorily controlled. At the same time, international assistance to developing countries, in real terms, is sharply declining. The grim warning in these facts is unavoidable. Further delay, further temporizing with reform, further weakening of external support—in effect, further failure to recognize this crisis will condemn entire continents, and especially island nations, to human misery.

Despite endless meetings and symposia, the international community, apart from “talk,” has done little to address the threat, and most of the conferences do nothing to alleviate the global problem of erosion, which leads to poverty. A number of appropriate technologies are available, however, for stopping soil erosion that leads to land degradation, poor crop yields, and starvation. These technologies will improve land productivity. The most outstanding of these is the use of vegetative soil and moisture conservation hedges that are cheap, replicable, and sustainable. The Vetiver System is one of the few that can be defined most simply as a system that meets the needs of the present without compromising the ability of future generations to meet their own needs.

Soil Conservation

Soil conservation is not new. It has been generally accepted as an essential principle in all good farm management systems since the early 1930s, when in America, H. H. Bennett persuaded the U.S. government that it had a duty to help farmers cultivate their lands in such a way that their land did not deteriorate with use (Bennett 1939).

This principle had long been accepted in western Europe, where improved systems of farming were being actively developed in the seventeenth century. This principle was embodied in precepts such as the one I mentioned earlier: *When a man hands over his farm to his son, he* *should always aim to turn it over in a condition that is at least as good as when he inherited it from his father*.

The early, improved farming systems developed in western Europe were aimed at the conservation of soil fertility. Farmers did not pay much attention to soil erosion until the onset of the tractor. Because the rainfall pattern in the temperate climate of western Europe is not as intense as it is in the humid tropics, European farmers generally were unaware that many of their practices were conservative only because they rarely experienced high-intensity storms. The total annual rainfall in southeast England, for example, is 450 to 600 mm and is spread throughout the year. The same amount of rain can fall in two or three storms in the tropics and, uncontrolled, can run over and through unprotected soil, causing massive erosion.

This lack of experience with tropical weather—high-intensity rainstorms, flash flooding, slips, mudslides, and washouts—had very serious consequences when emigrant farmers, retired soldiers, engineers, colonial planners, and university lecturers moved to the tropics and were faced with the problems of developing land or instituting land-clearing policies. Consequently, because they brought farming methods that worked in temperate climates but not in the tropics, soil erosion became widespread and, in many cases, accepted as inevitable with the extreme conditions being experienced and no known methods of control.

The Process of Erosion

The primary cause of soil erosion is uncontrolled runoff, which initiates the movement of surface soil as a thin sheet. Sheet erosion starts the soil and water moving, leading to in an uncontrolled rush down the slope of the garden or field, resulting not only in the loss of water (runoff), which is a dwindling asset, but also in the loss or redistribution of soil away from its area of origin. If this soil loss exceeds 4 tons/ha, it will not be replaced naturally for centuries—if at all. (For natural soil formation, a “rule-of-thumb” estimate is about 2.5 mm/year.)

Too often, sheet erosion is overlooked, perhaps because it is not spectacular. In reality, it is the beginning of the total process that led to the earth’s “grand canyons” being formed. The runoff that initially moves over the soil as a sheet, in a short distance deepens and increases in velocity, breaking up into tiny streams or rills. These rills, as they progress down the slope, run into each other concentrating as their velocity and depth increase into gullies. As the gullies deepen, they cut back up the slope. Branch rills feed into them, ultimately creating a pattern over hectares or hundreds of hectares of land that, seen from the air or in an aerial photo, looks like the drawing of a tree, the trunk being the major gully at the bottom of the slope flaring back to the very fine branches, which are the minor gullies and rills, finally to the “leaves,” representing the initial sheet erosion. The whole tree represents the drainage network of a watershed or an eroded watershed. Ultimately, the gullies will cut back right to the top of the slope to the point at which the runoff loses its velocity.

Other forms of erosion that people can have little influence over are geologic erosion (the natural weathering of mountains and the landscape), volcanic lahars, and seacoast or meandering rivers that cut their way into the landscape. But landslides, mudslides, slips—the destruction of the “toe slope” or slope stability, brought about by land clearing—often are the result of people’s interfering with the earth's natural stability through poor road preparation, poor site development, or lack of understanding of what causes a slip.

According to a study conducted by the Central Soil and Water Conservation Research and Training Institute in Dehra Dun, India, 29 percent of the eroded soil is permanently lost to the sea, 10 percent is deposited in reservoirs as silt, and 61 percent is displaced from one location to another (Rambabu 1984).

The "permissible" limit of soil loss at which fertility and cropping can be sustained was stated as 4 tons/ha. The average annual loss of topsoil in India is 16 tons/ha. If India is to continue to feed the people of that country, this enormous loss of soil cannot continue.

The most urgent problem facing world food production in the future is the development of an ecologically sensitive conservation system that will not only prevent erosion but will also go a long way to conserving water by storing moisture in the soil and recharging the aquifers. The poor, subsistence farmers in developing countries must overcome agronomic limitations that are very different from those of developed countries.

Over the last 70 years, many studies have been made concerning the factors that cause soil loss and runoff. In my opinion, too much time has been spent measuring the problem, with too little time given to educating the farmers (or planners, or policymakers, or politicians) and making them aware that erosion is a major problem. We need to teach them how to recognize soil loss and runoff, how to prevent erosion before it starts or gets out of control, and ultimately, how to control it once erosion has taken hold of the land.

Over the past 60 years, after the impact of soil erosion had been recognized, methods of soil conservation have been developed and implemented. Most of the fundamental research in soil conservation has been done in developed countries, nearly all of which are in the temperate regions of the world. Most underdeveloped countries, and certainly the more impoverished ones in which population pressure has exacerbated soil erosion, are in tropical regions. So if a system of soil conservation is recommended for an underdeveloped country, the system must be adapted to the region and the local farmers' ability to implement it. The technology must be directed purposefully toward them.

In the tropics, shifting cultivation was primitive man's approach to the vagaries of tropical fertility, soils, and climate that affected his crop. The farmer disturbed the balance between vegetation and soil as little as possible by clearing only small patches out of the forest and by clearing incompletely. He sometimes interplanted a variety of crops to provide foliage protection through the growing season and to hedge against the capriciousness of the weather. Nonetheless, fertility under shifting cultivation declines rapidly, and after three seasons the land would be left to fallow. In some cases, the land could take 10 to 20 years to regain its fertility and some of its stability. In this way, shifting agriculture in the tropics kept farmers only one step ahead of complete disaster.

As long as the soil is covered with dense vegetation, nutrients can be captured and held in the plant and the soil's surface litter. After the land is cleared for cultivation, "fertility" is leached out and the soils can become more acid (pH falls). This concept seems difficult for temperate climate scientists to come to terms with because it does not happen in areas of low rainfall. When scientists encountered acid soils in the tropics, their immediate reaction was to apply lime to increase their pH. But liming tropical soils can be disastrous; in many cases, heavy metals are precipitated, limiting the crops these soils can support (especially in the case of pineapples).

Before population pressure changed the parameters, farmers under tropical rainfed conditions used a fallow as the basic method of restoring soil fertility. In a Zaire rainforest, for example, one year's cultivation requires three years of restorative fallow; three years of cultivation requires 25 years of fallow. In Zambia and Liberia, a period of 18 months of cultivation on the acid sands requires 24 years of fallow to provide enough ash from the burning that follows clearing to offset low fertility and provide a suitable environment for crop growth. During these periods of fallow, the land is nonproductive, and initially, it is not protected from erosion or from runoff that results from the extremes of tropical downpours.

In the tropics, farmers have learned that fire quickly releases the bases (fertility) tied up in woody plants, giving an instant but short-lived boost to their crop production. Fires also immediately show up edible plants that germinate in the ashes, another reason for burning. Yet these fires are a major problem, especially in Indonesia/Malaysia, because they create a smoke hazard, causing air pollution and dense smog in cities. The more lasting effect of such burning, however, is the bare ground they leave, which leads to erosion.

In temperate climates, organic matter contributes to the humus supply, but because of higher soil temperatures in the tropics, organic matter is short lived and has little effect as it is rapidly broken down and leached through the soil or out of the area as runoff. In the Fiji sugar industry, I carried out exhaustive trials to ascertain the beneficial effects of mulching. I ploughed two rows of cane trash into one, three rows into one, up to four rows into one row; I applied up to five tons of mill mud per acre. Within 3 months, the effects of mulching were gone, and the effort of applying these practices was found to be equivalent only to the extra yield achieved by applying 200 kilograms per hectare of super phosphate.

As population pressure on the land has increased, tropical farmers have had to shorten their fallow periods at the cost of declining yields and more erosion. The traditional systems of slash-and-burn agricultural production are no longer available or capable of supporting dense populations. Erosion is out of control, land is scarce, and temperate climate methods of protection do not sustain production under tropical conditions.

Accepting New Technologies

Over the past centuries, in the tropical regions of China and Southeast Asia, attempts at sustained development have largely depended on human intervention for soil conservation and stabilization—man-made interventions such as terraces. In various areas of development—agricultural production, road building, railway alignments, irrigation development, dam protection, river control, the dispersion of runoff from cities and airports, the stabilization of rubbish dumps and landfills—constructed methods of erosion control and drainage have been the only input. These constructed interventions have high installation and maintenance costs, and they have to be continually rebuilt. But they are the accepted technology, and so far, nothing else has replaced them—or nothing else has been accepted to complement them, let alone replace them.

Static conservation measures (such as concrete structures) cannot cope with the high-intensity, dynamic forces of tropical weather conditions. What then can be done? The fate of millions of people in the tropics depends on finding a solution to the erosion problem that goes hand-in-hand with the weather. Likewise, if erosion is not controlled as population densities increase, the sea will virtually inundate delta dwellers and tropical island nations that are further threatened by global warming. With fresh water lakes silted up, perennial rivers will be reduced to flash-flood drainage networks, creating massive water shortages because this increased, uncontrolled outflow will not recharge natural aquifers, and the increased silt of the runoff will eventually silt up harbors and render them useless. The increased runoff will create havoc with floods, the extent of which today's population has not yet seen.

Unlike construction technologies, vegetative methods of soil conservation are dynamic systems—they are alive and can adjust themselves to the environment. These methods are not a recent concept. More than 2,000 years ago, the Chinese used willows (*Salix* spp.) to stabilize the lower reaches of the Yellow River. Farmers in India, Nigeria, and the Philippines have used biological systems, including vetiver and other grasses, for embankment stabilization, wind breaks, boundary markers, and the like. The idea of using plants to protect the land is not new. Legend says that more than 5,000 years ago, a Sumerian king codified the protection of the vegetative cover used to safeguard irrigation works and water supply networks from being destroyed by erosion (Lowdermilk 1948).

Hundreds of years ago in England, people planted hedgerows as a form of fencing. Where these hedgerows crossed the slope at right angles they have formed terraces 2 to 3 meters high, showing their capability of trapping soil that was being conveyed as runoff from areas of cultivation behind the hedge and up the slope. These hedgerows were not intentionally planted as conservation measures, but because hedge maintenance is costly and modern farm machinery works more effectively on large land areas, many hedgerows were removed. The resulting erosion came as a shock to all concerned.

For the last 200 years in Gundalpet in the southern Indian state of Karnataka, farmers have had vetiver hedges as farm boundaries. Once again, where these hedges crossed the slope at right angles, they had formed natural terraces up to 2 meters high, and this on land with slopes of less than 2 percent. This collection of soil was the result of 200 years of vetiver hedges remaining in place, steadily filtering and trapping the silt from runoff as the result of cultivation.

A 3-meter-high terrace created behind a 30-year-old vetiver hedge in the cane lands of the Fiji islands, resulting from the cultivation and continual ratooning of cane on a 50 percent slope, testifies to the benefit of the Vetiver System. This land is now stable and crop yields are increasing (see Figure 16-3a in Chapter 16).

In 1988, in the United States (the first country to initiate a Soil Conservation Service), the senior soil conservationist, having observed the work that I initiated in India, made the following observations (Kemper et al. 1985):

An old conservation practice has the potential to be a valuable tool in our arsenal of erosion control technology—using narrow strips of stiff erect grass to trap sediment, build bioterraces, diffuse concentrated flows of runoff water, and protect downwind soils and crops from wind erosion. This erosion control practice is not new to the United States, but it has seldom been used in recent years. It has been far more extensively applied in tropical countries.

A technology that was often recommended, but that was inapplicable to subsistence farmers in the tropics, was to leave crop residues where they fell on the surface. The objective of this form of conservation tillage was that, if more than 50 percent of the surface is covered by residue, inter-rill or sheet erosion is greatly reduced for most runoff events. During intense rainfall episodes in the tropics, however, runoff may concentrate and develop sufficient force to move soil, crop residues, and farmyard manure (FYM), forming rills and incipient gullies, and transporting these precious residues out of the area as waste.

The most effective management practice that the Soil Conservation Service developed in the United States for retaining maximum crop residue on the surface and maintaining the maximum cohesion in the soil to resist concentrated flow is *no-till*. Under no-till, however, any rills or small gullies that have developed are not smoothed out by cultivation. On highly erodible land, these incipient gullies can result in damage to equipment crossing them and lead to further, deeper gullying from runoff channeling down them.

Tropical farmers in less-developed countries do not share this luxury because their crop residues are essential for fodder or fuel, or they have to be burned off to allow for replowing with their light equipment. Practices such as no-till cultivation are more often out of the question because the subsistence farmers do not have the equipment (sprayers and seed drills), the power source, or the money. These farmers need an alternative system that they can afford to implement and use on a sustainable basis.

The United States spends millions of dollars annually in its efforts to transfer technology to developing countries to help them do a better job of conserving their soil and water resources and of improving their food production. One of the major impediments to acceptance of new ideas is the resistance of individuals who have invested in the status quo—in this case, constructive methods of soil conservation. Experience shows that decision-makers are more likely to adopt a practice when they have participated in the development of at least part of the underlying theory.

How Grass Hedges Work

Vetiver grass hedges have the morphological and physiological characteristics that are ideal for the vegetative method of soil and water conservation. The plant has stiff, erect stems and a fast-growing, extensive root system (up to 3 meters penetration in 12 months, in the tropics). When the plant is buried by sediment, new shoots and roots will grow readily from its culms. Vetiver grass is a plant that will last as a hedge for more than 200 years. No man-made soil conservation interventions could possibly last that long and still function.

Vetiver is tolerant of extremes of temperature (-10º to + 48º in Australia), soil moisture, and soil acidity and alkalinity (pH from 3.3 to 10.5) (Dalton, Smith, and Truong 1996). The plant adapts to adverse soil conditions, such as aluminum and manganese toxicities, as well as to high soil salinity and sodicity. Vetiver hedges not only survive fires, but they seem to thrive on being burnt; the hedge immediately regrows, thus preventing erosion.

The Vetiver System of conservation could be called the *flow through* system in contrast to the conventional diversion system used in constructed contour banks. Potential benefits of grass hedges include their ability to (1) filter runoff; (2) trap sediment, which fills rills, gullies, and associated depressions behind the hedges; (3) disperse concentrated flows; and (4) reduce the amount of runoff by temporarily ponding some of the water, thus increasing water intake opportunity time to refill aquifers and natural leveling of the terrace being formed behind the hedge. Infiltration rates are increased in areas of sediment accumulation because the coarser sediment is the first precipitated from decelerating runoff.

First-hand evidence of the long-term benefits of grass hedges healing incipient gullies, dispersing concentrated flows, and developing flatter “benches” is now available. Today in Southeast Asia, China, India, Africa, and Central and South America, use of the vetiver hedge technology is conserving hundreds of thousands of hectares of land. Even so, many potential users know nothing about this technology because of a major failure in government policies. Lack of communication with users and a failure by some research scientists and institutions to properly exploit the potential of this extraordinary grass is holding back conservation and land rehabilitation.

Although technical solutions have been known and practiced for the past 70 years, it has been only within the past 15 years that technical solutions, which can be applied successfully and sustainably given the existing social and economic constraints of the lesser-developed countries in the tropics, have been developed with any impact.

In most agricultural science textbooks, designs for land and water management require surveyors, engineers, and considerable use of heavy equipment. Because these requirements are out of the reach of most farmers in the humid tropics, their production potential remains impeded.

The following recorded evaluation (circa 1990) depicts a typical soil conservation system in India, which generally reflects the status quo. Exceptions exist, but they are rare.

Tungabhadra River Valley Project. Evaluation by the Monitoring and Evaluation (M&E) Unit of the Department of Agriculture (DOA), Karnataka State, India, is as follows:

- The Valley Project area has 1,000 mm of rainfall annually.
- 90,125 hectare contour bunded over 12 years 1975–1987 at a cost of Rs33.6 million (Rs20 to US$1).

- Of the existing bunds (soil conservation banks) at the time of the survey, 50 percent were intact; the remainder were either damaged or partly ploughed out.
- 69 percent of the farmers had ploughed out their bunds.
- Most existing bunds had been reduced in size by 20 to 40 percent; 30 percent were aged out.
- Damage to the bunds was caused by breaching, because they could not withstand storms [**Author's note:** they had been underdesigned]; 15 percent of waste weirs remained undamaged; the bunds were not maintained mainly because of financial reasons, but also because farmers saw little economic value in their use.
- The bunds and interbund leveling of the fields showed no significant crop yield improvements over unbunded and unleveled interbunds because of little moisture conservation.
- The difference in levels of any new technology uptake between bunded and non-bunded areas was negligible; likewise, there was no difference in crop yields.
- 52 person-days per hectare were used for bund construction, equivalent to approximately Rs520 per hectare.

This report on a typical soil conservation project implemented with the full support of the government conservation department shows the temporary nature of the constructed system of soil conservation. Though implemented with due care and attention by the authorities, the farmers gave it no support.

The government cannot afford to keep returning to the same areas and reconstructing projects that have collapsed through neglect. Continual maintenance using heavy earth-moving equipment or labor gangs is the life-blood of the constructed system.

This need to return and reconstruct is the reason the constructed system of soil conservation, if only in financial terms, can never cover a whole country. The manpower and equipment needs would be enormous.

Vetiver hedges, on the other hand, once established, are permanent. The planted area never needs to be revisited. The technicians, if they are necessary, can move on to a new area, eventually covering the whole country.

The production of food in poor, tropical countries is already too low to achieve an adequate level of nutrition. Subsistence farmers applying FYM, often the only form of fertilizer they can afford, face the dilemma of losing it to runoff or benefiting from their efforts, if the rains are not too severe, by slightly improved yields. With vetiver hedges holding the FYM in place and giving them the ability of storing enough moisture to fully use their benefits, their yields increase above anything they have experienced in the past. The moisture conservation effects of the Vetiver System are one of its greatest bonuses.

6. Rainfed Agriculture

With the global perspective in today's world, export success is one major route to economic progress for developing countries. But as producers face rising environmental expectations that reflect the growing recognition that current patterns of consumption are not environmentally sustainable, conditions for success are changing. Profound changes in the ways in which goods and services are produced, traded, and consumed will be required, both to reduce the burden on the global environment and to ensure that a growing population has the resources to meet its future needs (Robins and Roberts 1997).

This belief in changes is the philosophy of the Vetiver System for the tropics, or of "hedge technology" globally. Implemented correctly, the Vetiver System is the most environmentally attuned system of land stabilization so far introduced into the human arsenal of defense against the ravages of land degradation in the tropics. It is ecologically sensitive to the point that when vetiver (*Vetiveria zizanioides*) hedges are used to stabilize mine dumps, landfills, road cuttings, erosion scalds, etc., the end product is complete colonization by the local indigenous species of trees and shrubs that, before the introduction of the Vetiver System, which provides the necessary protection, could not possibly germinate or survive in such hostile conditions. No other system of conservation tried so far has the same natural outcome.

Rainfed agriculture, in which the farmer depends on the whims of the weather to get a crop, is the focus of this chapter. Vetiver grass hedge technology enhances the environment for agricultural production by helping to retain and store moisture and nutrients in the soil. This technology benefits not only the large-scale farmer, but more importantly, because of its low cost, can benefit the small subsistence farmer as well. Soil moisture is especially essential for the germination and survival of young plants. Where subsistence farmers are concerned, their hard work in making and broadcasting farmyard manure (FYM), often their only source of fertilizer, is wasted when the first rains "float" this dry, light material off their fields and into the drainage network. Vetiver hedges hold this vital nutrient on the field by slowing down the runoff and letting it soak into the ground for the benefit of the germinating crop. The Vetiver System does not stop in situ soil erosion caused by raindrop action on the soil. What it does is eventually change the slope of the field; it spreads out rainfall runoff behind the hedge and reduces runoff velocity, all of which helps reduce the erosive forces of surface water runoff.

Developed countries' methods of conserving moisture or rainfall in the rainfed areas, together with some of the new technologies that have been recommended for soil conservation and stabilization, to a large extent do not work in the tropics, especially with subsistence farmers.

Many conservation practices have been introduced into the tropics, but few of them have been accepted. Examples are as follows:

- **Fallowing Land.** Fallowing land to conserve moisture is pointless when nothing is done to hold and spread the rainfall that the land receives. Land leveling to spread rainfall "evenly," as practiced in some parts of India with inadequate equipment and labor, is a waste of money; farmers on their own cannot level land to the extent needed. Land leveling has had an impact on reducing soil loss and improving moisture loss on the Loess Plateau in northwest China, however, where hundreds of thousands of hectares of very steep land have been leveled, with significant yield increases.
- **Wet Fallowing.** Farmers in rainfed areas cannot afford to leave the land idle to "wet" fallow. It has been demonstrated that vetiver hedges conserve more moisture for a standing crop than wasteful fallow periods do when nothing is produced.
- **Using Crop Residues.** Few subsistence farmers can hold over crop residues; they need the residues for fodder or fuel, or they need them for compost (FYM). If they do not need them, they do not have the power to plow crop residues into the soil and generally need to burn them off before plowing. Many farmers in Latin America and Africa practice no-till farming and green manuring.
- **Alley Cropping.** Not all alley cropping works, for several reasons. (1) The trees (which sometimes are actually shrubs or other alley liners) compete with the crops being grown. (2) Aligning the alleys with the slope and the shade is often incompatible with the conditions of growth or the slope of the land. (3) The trees or shrubs in the alleys generally do not conserve moisture or soil. (4) The trees or shrubs are generally difficult to manage and are costly in labor use.
- **Water Harvesting.** Water harvesting is generally too costly for the land needed as a collector and for the construction of the diversion banks and irrigation system. It is impractical in areas where the amount of available land is limited.

With the world's population rapidly expanding and the pressure from this growth being applied to land use, there is little effort that focuses on the prevention of runoff and soil loss. The system of soil conservation that was intended for rich, developed countries in temperate climate regions and then recommended globally was designed to run "excess" water off the land as rapidly and safely as possible. This system deprives the subsistence farmer (in this case, the farmer who depends on rainfall for the success of his crops) in the tropics of the essential storage of soil moisture. The constructed system of soil conservation together with other misguided systems of cultivation, which in some countries became law, made it very difficult for these farmers to ever attain the full benefit of their soils or rainfall on a sustainable basis under rainfed conditions.

Rainfed Agriculture versus Irrigated Agriculture

It is an interesting fact of history that in most of the arid zones of the world—in the Near East, India, North Africa, and Central America—very advanced agricultural civilizations developed, flourished, and eventually disappeared. Usually they disappeared because farmers did not conserve soil and water, or because they used irrigation schemes that lacked a drainage component, which resulted in salinization of the alluvial areas.

Back in history, ample land was available for exploitation; today, such land does not exist. And to date, throughout much of the world, the focus on increasing production of the land has been on irrigated agriculture.

Since 1950, the amount of irrigated land increased from about 94 million hectares to about 200 million hectares. During the 1980s, however, the rate of irrigation development dropped markedly and in the 1990s was less than 1 percent per year. This decrease is possibly due to several factors. (1) Few good dam sites are left, and a strong environmental lobby opposes building any more irrigation dams. (2) River water used for irrigation comes under the legal stress of riparian rights (a country's right to access and use water on land that borders on or includes a stream, river, or lake) and can lead to legal conflict. (3) Irrigation schemes that were allowed to develop without a drainage network are now subject to major in situ salinization problems, outside the schemes and sometimes miles away, further down the drainage network. (4) Dams are silting up and losing their capacity because their catchment areas were not protected against erosion. (5) Groundwater for irrigation is being depleted faster than it is being recharged. Added to all these factors is the increased demand for clean water from burgeoning cities.

The world's population is growing at the rate of 1.7 percent annually and in parts of Africa as much as 4 percent. Irrigated land accounts for up to 18 percent of the cultivated land, but produces 33 percent of the food. The cost of irrigation and drainage in the 1990s averaged around US$10,000/hectare but could be as high as US$25,000/hectare in the drier parts of Africa. Can irrigated agriculture continue to expand and produce a significant proportion of the world's food supplies? It appears certain that the additional food production needed in future years must come from the approximately 80 percent of cultivated land that is rainfed.

During the past 50 years, dryland farming has come under more use, abuse, and neglect, but not much has changed. The methods of moisture conservation that were developed for temperate climates and then imposed on the tropical areas have shown little effect on conservation or production. The large areas of land that must be farmed to meet the current and future needs of the world increasingly occur in high-risk areas that have limited or erratic rainfall. These lands are also highly subject to water and wind erosion. Therefore, it is essential that in the tropics the Vetiver System, now proven effective, be spread and used as quickly and widely as possible to stabilize these lands and retain the essential moisture and nutrients needed to produce food crops on a sustainable basis.

Relatively small areas of former desert now under irrigation, such as the Imperial Valley in California and the Jordan Valley in Jordan and Israel, produce a large variety of crops with record yields. Today, water is not a limiting factor; but if the catchment areas of these schemes and others like them are not properly managed for soil and water conservation, they too will be returned to desert.

The central problem of sustained land use in the rainfed areas has always been to find and maintain a balance between human requirements and the productive capability of the land. This goal has rarely been achieved because an effective system of moisture conservation has not been developed, put into practice, or maintained through the years. Using the best crop seeds of the highest yielding varieties, preparing the best seedbeds, planting in a timely fashion, and fertilizing are all wasted if sufficient moisture is not available to sustain crop growth.

Throughout history people, by overuse, have consistently reduced the productive capacity of the rainfed lands. Originally, a large proportion of the more or less scanty vegetative cover consisted of palatable and nutritious grasses and shrubs. Overgrazing, selective grazing, and burning caused an overall reduction of this plant cover, resulting in the large-scale replacement of useful plants by unpalatable “fire climax” species. Overcultivation has reduced cover and intensified erosion by wind and rain, starting a process that frequently is irreversible. Gullies cut through alluvial valleys increase water runoff with a higher silt load, leaving little time for soakage to recharge natural aquifers; as a result, storage reservoirs fill with silt. So, where do we stand? The situation is worse today than it ever has been. Politicians and planners seem not to have received the message about this problem and its future implications.

Rainfed areas that are under the greatest threat are those of the tropical island nations. The denudation of these islands will lead to disaster—no sustainable crop production, silted harbors, perennial river systems becoming seasonal, groundwater disappearing, and the destruction of the coral reefs (in most cases, barrier reefs are their only protection from the ocean) from the effects of soil loss and runoff. Worse still, these islands will face the distinct possibility of not having enough water to sustain their increasing population needs.

Throughout the developing world, drought has been blamed for crop failures when drought is not always the culprit. Instead, the scenario may be like this: The rainfed farmer plants his seed when he considers that the “rains” have started. Although sufficient rain may have fallen to germinate the seed, it is not sufficient enough to sustain its growth. And sometimes, because the follow-up rains may be one month to six weeks late, the young plants wilt and die. In many cases, the farmer has no more seed in reserve and consequently loses his crop for that season. Ultimately, adequate rain may fall, but for the farmer, the rain will have been badly distributed or it may have come too late. Or sometimes, adequate rain may have fallen, but because of poor cultivation practices, 60 percent of the rain may have been lost to runoff.

Alternatively, look at the scenario from another aspect of a farmer who inherited his farm in a 1,000 mm rainfall area: Because of increasing population pressure on the land and overcultivation, his effective rainfall, with 60 percent runoff, is now only 400 mm. Given the choice, he would never have farmed in such an area. Under these conditions, “drought” is declared and aid agencies are mobilized. But because these agencies provide food aid and do not replenish the farmers’ seed supplies, they become dependent on aid again the following year.

For the most part, these problems can be avoided by using the Vetiver System to conserve moisture in situ. Once established, vetiver hedges interrupt the natural flow of runoff and spread it out behind the hedge, slowing it down and reducing its erosive power. This deceleration backs up the runoff water behind the hedge for many meters while it filters through the dense base of the hedge, after which it carries on down the slope in a natural fashion wetting the whole area. It also deposits its silt load behind the hedge, which initiates natural terracing and prevents soil loss.

The important point here is that after the rainfall, the runoff water is not diverted sideways—it oozes through the hedge over its entire length and at a speed that allows it time to soak into the ground. By the time the runoff has oozed through the first hedge and starts to reach erosive velocity it is intercepted by the second hedge. This pattern continues down the slope, giving the whole area the full benefit of the rain that has fallen.

The hedges themselves can be extended for kilometers around the slopes because they do not convey runoff; they filter it, temporarily holding it back until it passes through and then on down the slope.

Constructed conservation measures impinge on the whole structure of the watershed, the drainage network, the natural aquifers, the infrastructural network, and the farming system. The constructed banks also are limited in their dimensions and length, because they can carry only so much water before it has to be disposed of or they will overflow. One kilometer would be the maximum safe length of a constructed diversion bank before it would have to be emptied into a waterway or natural drainage outlet, concentrating water where nature never intended it to be.

For the constructed system to work to design, every landholder in the watershed has to cooperate, because the banks, like pipes, must be capable of conveying the water around the slope to the point of disposal.

To enable these banks to convey runoff at the correct speed, so that they do not silt up or erode their channel, the design criteria for banks must follow the contour exactly, making it very difficult for the farmer to follow the banks with his plow since some of the curves are extremely sharp.

This contortion of the farmers' blocks (fields) makes the system unacceptable and explains only one of the reasons that third world farmers do not maintain these banks. Other reasons for lack of maintenance are (1) the amount of land the banks and channels take out of production, (2) the fact that the banks cannot be crossed with farm implements, (3) the unacceptable amount of foreign water the bank's channels track across a farmer's field from his neighbor's runoff, and (4) the ponding and bogging the banks cause in the black cotton soils (vertisols). Such ponding causes the failure of vast areas of the cotton crop, for example, which cannot tolerate bad drainage. After water is delivered to the drainage network, it is full of silt and threatens all downstream infrastructure. Contour banks deliver too much water too fast to the drainage outlet and often cause serious flooding.

On the average farm, the constructed bank takes a strip of land 5 meters wide out of production. Every kilometer of bank is equivalent to one-half hectare of land lost. With the vetiver hedges properly maintained, 1 kilometer of hedge results in a loss of only 1/20th of a hectare.

When vetiver hedges are used as the means of soil and moisture conservation in any given area, the farmer does not need to seek the cooperation of his neighbor because the hedges do not convey the runoff in any direction but merely filter it on its way down the slope. This nondirectional conveyance of water means that the hedges do not have to be laid out on the contour and can in fact be applied as a straight line across the slope, crossing gullies at right angles to the flow. Once the hedges are well established, these gullies will be filled with silt and will begin to form a terrace in line with the hedge.

The farmers appreciate the benefits of the Vetiver System because they can “peg out” the lines themselves. They need no engineering levels, though A-frame levels are useful and effective and can be made by the farmers; they only need an average point of equal elevation on either side of the field to peg out a line. The hedge lines being straight or gently curved are easy to follow with the plow. The hedges can be mowed and crossed with farm machinery, or they can be laid out with an overlapping gap that will not allow any erosion but will allow passage of people and animals diagonally through the hedge line. The hedges can be planted wherever they are most effective or convenient to the farmer. Whereas, to enable the constructed banks to convey the runoff to their targeted outlet, they must be laid out in a set pattern with the correct fall, regardless of infrastructure.

Subsistence farmers in the Zaka District of Zimbabwe, for example, expressed the advantages of the Vetiver System in the following statements: “less labor compared to mechanical contouring”; “improved moisture conditions leading to yield increases”; “no erosion in the fields; “land is released for cultivation as a vetiver hedge occupies less space compared to mechanical contouring”; “availability of thatching grass from vetiver”; and “snakes are repelled by vetiver grass” (Dreyer 1997).

The statement of “no erosion in the fields” refers to sheet and even rill erosion, which are common phenomena in the fields conserved with standard contour banks. Rill erosion occurs mainly where the constructed banks are too far apart.

Some people who are new to the Vetiver System have a misconception that the silt accumulation along the back of the hedges should be moved back up the slope where it came from. This replacement is totally unnecessary and a great burden on labor. The silt accumulation forms perfectly stable terraces over time. Once vetiver hedges are established, the farmer sees for the first time the amount of soil loss he is experiencing under his normal climatic and cultivation conditions. Without the hedges, he and his descendants would have continued cultivating the land until there was no soil left. Moving the silt back up the slope would be a waste of time and money because it would be washed straight back down the slope with the next rains.

Stabilization of Ocean Islands

Thousands of ocean islands in the tropics, most which are relatively small, are the only home their inhabitants have. They depend on these islands for their very existence, yet little is being done to stop them from being swallowed up by the sea or turned into tiny maritime deserts.

Nearly all these islands depend on rainfed agriculture, because very few have sufficient water for irrigation schemes. The soil that is eroded from these small land masses is not just relocated somewhere else on the island where it can be stabilized or used again; usually it is washed out to sea and is irretrievable. In the process of reaching the sea, it destroys the coral barrier reefs that protect the island from the fury of the ocean.

When population pressure was low, these islands had a stable environment. Coconuts, yams, and products of the sea were the staple diet, supplemented by fruit and vegetables that islanders could grow in the area. Timber for building and grass for thatch were in sufficient supply to sustain the fairly static population.

In the last half of the twentieth century, with improved medical care and a massive decrease in infant mortality, population pressure has reached a point at which all the available land has been cultivated; the timber is gone; the grasslands have been overgrazed; and in many cases, goats have been brought in, originally as a source of meat, but have now greatly added to the denudation of the grasslands, thus increasing the runoff from the cultivated lands.

Tourism has become the main income earner for many of these islands. Tourism depends on infrastructure to get the tourists to their destination and then house them in hotels. But this industry imposes more problems than it solves. Tourists use vast amounts of food and water. Food can be flown or shipped in, but the need for more water poses a major problem of supply.

Many islands have limited water supplies that depend on recharging the aquifers for sustained use. The natural bush and grassland that spread the rainfall, held it in the undergrowth, and gave it time to be absorbed have largely been destroyed or are in the process of being destroyed, or have been turned into mowed lawns or concrete. Once this absorbent mass has lost its effectiveness, aquifers are no longer recharged and perennial rivers or streams dry up and become seasonal, flowing only during heavy storms. Damming these flows to conserve water could be a short-term solution, but the silt load these flows carry from the overcultivated fields will mean that the dams will be short lived. Damming rivers also usually inundates the best patches of alluvial land, which these islands cannot afford to lose. The islanders may temporarily gain water, but they lose production capacity in the process; and when the dam inevitably silts up, they have lost both.

Soil and water must not be allowed to leave these islands as waste. The soil has taken thousands of years to form and is a precious commodity that cannot be replaced. Water is replenished year round as rainfall, but it can be lost as runoff. To recharge the natural aquifers, this runoff must be retained, preferably in situ. Retaining the runoff also retains the soil.

In an island configuration, it should not be difficult to plan a system of vetiver hedges capable of retaining the rainfall, spreading it out and holding it long enough on the slopes to recharge the natural aquifers. This input would require a series of well-placed, well-maintained hedges starting at the top of the catchment area and finishing at the high tide contour on the sea front. Vetiver hedges will grow in all these locations.

These hedges need not interfere with the road network, the farming system, the towns, or the airports, but they would greatly enhance their sustainability by preventing erosion; preventing landslides and slips; handling the excess runoff from newly sealed surfaces such as roads, airports, and hotel areas; preventing fresh water from reaching the reefs, let alone destroying them; and preventing silt from ruining the harbors.

A proposal for saving the ocean islands could include the following steps: (1) Select a series of small islands for demonstration purposes; (2) allocate money from an 'AID' agency to employ non-governmental organizations (NGOs) or vetiver specialists to establish vetiver nurseries; (3) develop a planned approach for stabilizing the island's watersheds, from the highest point to the sea; (4) educate the people about how the system will work for them; (5) train gangs to plant the hedges and look after them until they have become established, which takes about three seasons; (6) train and fund extension workers for the continual maintenance of the system for the future benefit of all the inhabitants; and (7) in the schools, teach about the importance of the system to the island's existence.

Such a project could take three to four years; but once the system is well established and working properly, these islands would become examples of what could be done to hold or even reverse the damage being done to these precious little dots in the ocean that now are being completely neglected.

A Need to Rewrite the Book on Conservation?

The *Field Data Book* lists six land use classes that are based on forms of land use to bring land to, or maintain it in, its most productive state (Soil Conservation Authority 1969). (Classification is according to the known potential of the land under average management.)

These six land use classes are as follows:

1. Land suitable for cropping without need for erosion control measures;

2. Land suitable for cropping but in need of erosion control measures—
   (a) Needs no constructed works but requires broad rotations (such as pasture for at least three years out of five) or special cultivation practices (such as stubble mulching);
   (b) Needs the use of contour principle; namely, contour cultivation alone or together with closed banks or graded banks and waterways;

3. Land suitable for grazing without the need for erosion control measures;

4. Land suitable for grazing but in need of erosion control measures—
   (a) Can be plowed for pasture improvement and can be contour banked, furrowed, or ripped;
   (b) Cannot be plowed but can be surface worked for pasture improvement and can be contour furrowed or ripped;

5. Land suitable for strictly controlled grazing where no constructed erosion control measures can be undertaken and vegetative cover must be carefully maintained; and

6. Land not suitable for agricultural production because of roughness, stoniness, wetness, dryness, infertility, or extreme erosion hazard.

Those who use and promote vetiver grass technology consider that there is no such thing as "flat" land. We believe that all land needs erosion control, from the top of the mountain to the riverbank or the coastline. In the past, some conservationists have made the mistake of allocating land to classes that need no erosion control. In the tropics, no land falls into this category.

All land erodes, no matter how flat it is. Once rills develop into incipient gullies, these gullies cut up from the bottom of the slope to the top. If we can prevent gullies and rills, then we can bring erosion under control.

Those of us who use the Vetiver System consider that no squares or right angles exist in nature; therefore, when considering the protection of land from erosion, we consider the whole watershed as a unit and not some portion of the watershed that has been squared off to form a project area. Too many aid projects start as a square on a map regardless of topography. Unless a project can control a watershed or branch watershed (microwatershed), development is meaningless.

Many misguided systems of conservation cultivation exist in rainfed areas; for example, the ridge and furrow system, which is law in Malawi. To build the ridges and furrows, using hand hoes, was an enormous burden on the farmer and his family. The system made absolutely no sense because it was seldom addressed to the contour of the land. The seed was planted on top of the ridge, out of touch with the soil moisture, except under extremely wet conditions. The furrows ran the rainfall out of the area, conserving no moisture for future development of the crop. The system depended on substantial rainfall throughout the crop's life; if the rainfall failed, the crop failed.

In some countries, land is leveled to make it absorb more rainfall and prevent runoff. This practice also is misguided. People cannot level land mechanically and keep it level. Land is a dynamic entity; once it has been leveled, it settles, it heaves, and it moves. Even water poured on a smooth table top, will run off at some point; it will not form an even cover a few millimeters thick over the whole table.

If a vetiver hedge is planted over relatively level ground so that it holds back runoff water and spreads it out, wherever there is a depression behind that hedge, the leveling effect of the water will fill it with silt. When the soil moves again after the rains, it will be re-leveled by the next spread of runoff. So the natural hedge is the best way to naturally level land, to keep it level, and to spread the benefits of runoff. The hedge does this job better than a person could ever do it and continues to do it as long as a viable hedge is in place. And, as an extra benefit, the continuation of the job costs nothing.

The result of this natural leveling is obvious in the cropping areas of Gundalpet, Karnataka State, India, where farmers have used vetiver hedges as boundary fences for more than 100 years. The rainfed crops look so even in growth that one could be excused for thinking they were irrigated.

In the above six land classes, much reliance is placed upon natural vegetative cover, or land that can be contour ripped; but these are only temporary measures of control. Contour ripping lasts for just one or two episodes of rain, then the "inter-rip" runoff fills the ripped lines with silt, and they are no longer effective. If there is a fire or drought, the vegetative cover is destroyed and there is nothing to control the runoff when the drought breaks, usually with a massive thunderstorm. Runoff under these conditions can reach 80 to 90 percent of the rainfall and cause extensive, permanent damage. Vetiver hedges thrive on being burned; regrowth is immediately initiated from moisture and nutrients stored in the massive root system, regardless of the existing weather conditions.

In the conservation classification of land, nothing is recommended for the sixth land use class, which is placed in the "too-hard basket" because it is too difficult to handle. It is too stony, too rough, or too dry to do anything with; so it is allowed to carry on eroding and impacting on better lands below it. The Vetiver System does not ignore these bad lands. They are just as important to protect in the context of the watershed as the best lands. These lands are the areas where the farmers can plant their fuel wood and timber trees behind the vetiver hedges. They can easily be treated with properly planned, planted, and maintained vetiver hedges. Thus, the whole watershed can be protected with the Vetiver System. No section of it is too hard to handle. Vetiver hedges can be established through the worst, most marginal areas, as is evidenced by its success in stabilizing the mine dumps in South Africa.

In extremely rocky land, because a contour line cannot be pegged out due to lack of continuity, it is impossible to construct conservation banks and heavy equipment cannot be operated. But vetiver hedges can be planted from one rock face to another and still be effective filters that prevent erosion.

Vetiver hedges do not transport runoff water to the drainage outlet, so there is no need for waterways. Waterways have been the bane of the constructed soil conservation system since its inception.

When there has been no natural area for disposal of runoff from diversion banks or overflowing contour banks it has been necessary to construct a grassed waterway. Unfortunately, these channels nearly always have run straight down the slope to the nearest section of the drainage network. Obviously, the biggest problem with "grassed waterways" has been keeping a cover on them and stopping them from eroding; this scheme has not always worked, especially in the third world.

A classic example of waterway failure comes from Lesotho in Southern Africa. In many areas, the herringbone pattern of diversion banks leads into the main waterway, which forms the backbone of the constructed system of soil conservation. In most cases, these waterways, running straight down the slope, have eroded into deep gullies; and these incisions have now made it impossible for farmers to cross from one side of their fields to the other. These waterway gullies are now beyond repair and will continue to deepen and destroy the surrounding countryside. Lesotho is one of the best examples of a country whose erosion is out of control, despite (or because of) the gallant efforts of the United Nations soil conservation projects that have been carried out in the past, but that have failed. The country has now been left to its own demise. It is also unfortunate that Lesotho is too elevated and too cold for vetiver grass to grow there without a lot of effort and good management. Sadly, the country stands as a testimony to the failure of the constructed system of soil conservation being “swept under the carpet” and no longer discussed.

In some countries where constructed soil conservation banks are used, a major mistake has been made when introducing the Vetiver System. They have planted the vetiver hedges along the top of the existing banks, thus preserving the bank and channel system and preventing the banks from eroding. This error perpetuates the wrong system. Where banks exist, vetiver hedges should be planted up the slope, above them, not following their contorted contour line, but evened out to a smooth curve in the farmer’s field. Once the hedges are working, the contour banks should be leveled and the area they occupied used for cultivation. In the tropics, vetiver hedges should replace contour banks; they should never protect them.

In 1986, the soil conservation book for the tropics was rewritten and has become my most successful publication and the most widely distributed handbook. Called *Vetiver Grass: The Hedge against Erosion*, this practical field guide has reached its fourth edition, and more than 200,000 copies have been circulated in English, Spanish, and Portuguese. In addition, various agencies have translated many thousands of copies into other languages, including among others, Chichewa (Malawi), French, Gujarati, Hindi, KiSwahili, Malagasy, Mandarin, Nepali, Pidgin, Swazi, and Zulu. It appears in a modified form in this book as Chapter 7.

7. Vetiver Grass: The Hedge against Erosion

In the late 1980s, I wrote a handbook to benefit extension workers in India who were using vetiver grass (*Vetiveria zizanioides*) technology for the first time. This chapter is a modified version of that book, *Extension Worker's Handbook*, first published in India as *Vetiver Grass: A Method of Vegetative Soil and Moisture Conservation* in 1987 by the World Bank and later published as *Vetiver Grass: The Hedge against Erosion.* The handbook, now in its fourth edition, has been edited and reprinted in many languages.

In the handbook I explain in simple terms what erosion is, how to recognize it, and how to apply the Vetiver System to help prevent it. I also introduce the concept of contour cultivation and moisture conservation, both practices essential to successful farming in rainfed areas and an essential part of the Vetiver System.

Sheet Erosion

Sheet erosion is initially the most damaging form of erosion, mainly because it often is not recognized and therefore is seldom treated. Triggered by rainfall, sheet erosion accounts for the loss of billions of tons of soil every year. As raindrops pound the ground, particles of soil are knocked loose and then carried away by the runoff. This runoff further strips unprotected areas of their valuable topsoil and becomes the muddy water that ends up in drains, streams, and rivers. Sheet erosion leads to more striking forms of erosion—rills and gullies, for example, the focus of most conservation efforts to date.

Figure 7-1a. Sheet erosion leaves visible marks

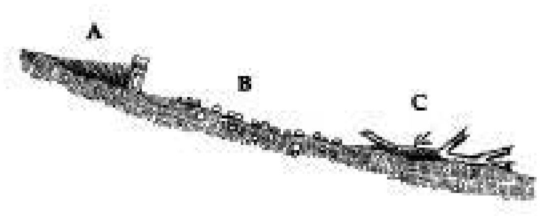


Figure 7-1b. The land shows signs of sheet erosion

Although not as spectacular as rills and gullies, sheet erosion does leave visible marks, as shown in Figure 7-1a: soil collecting behind obstructions on a slope (such as the brick in example A), stones left behind by the runoff because they were too heavy to be carried away (B), or molded mounds of soil and other debris trapped under branches, twigs, or even clumps of straw (C). The reality of sheet erosion's marks appears in the photo, Figure 7-1b.

Figure 7-2a. Sheet erosion exposes tree roots.

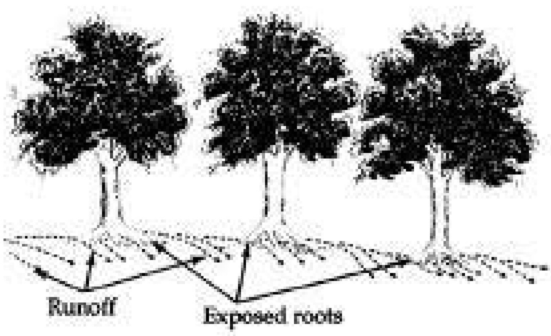


Figure 7-2b. Loss of soil exposes roots.

The effects of sheet erosion are more readily apparent in forest areas that are devoid of ground cover, and in fields or wastelands with a few standing trees, where the loss of soil exposes the roots of the trees. (See Figure 7-2a and the photo in Figure 7-2b.) Water can then easily pass beneath the trunks of the trees and among their roots. After all the soil that supported them and gave them life is washed away, the trees will be washed out of the ground as well.

Trees by themselves do not prevent soil loss caused by sheet erosion; forests do, with their thick litter and low-growing vegetation. In areas where forest cover is not possible or practicable, vegetative barriers can be used to stop the loss of soil. Fibrous-rooted shrubs and grasses planted as hedges along the contour of the land slow the runoff, spread the water about, weaken its erosive power, and cause it to deposit its load of valuable soil behind the hedgerows. As a result, the runoff proceeds gently down the slope, and if the hedges have been planted at the correct

Figure 7-3b. Sheet erosion results in loss of topsoil.

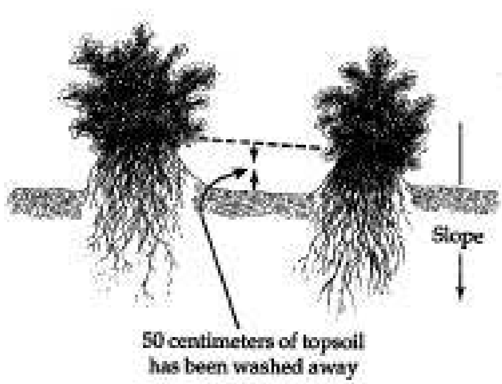


Figure 7-3a. Sheet erosion washes away topsoil.

vertical interval (discussed later and illustrated in Figure 7-23), it proceeds without further erosive effect.

The amount of soil lost through sheet erosion is alarming. Figure 7-3a, which depicts two surviving plants whose roots prevent sheet erosion, shows how the amount can be measured. In this case a layer of soil 50 centimeters deep—as measured by the distance between the top of the plant mounds and the present soil surface—has been lost across the entire area of the field since the plants became established. The photo in Figure 7-3b shows the vulnerability of the exposed roots after the soil has washed away.

Rainfed Farming

The traditional way of farming in rainfed areas, no matter how flat the land may seem, is along the slope, or up and down the hill. (See Figure 7-4a and the photo in Figure 7-4b.) This system encourages runoff and soil loss and thus makes sheet erosion worse. Often more than 50 percent of the rainfall is lost as runoff and thereby is denied to the crops; and the steeper the slope, the faster and more erosive the runoff. Rainfall is less effective because the water is not given a chance to soak in. By plowing along the slope, the farmer in Figure 7-4a is unknowingly encouraging the rainfall to leave his field.

Figure 7-4a. Traditional farming in rainfed areas requires planting along the slope or up and down the hill.

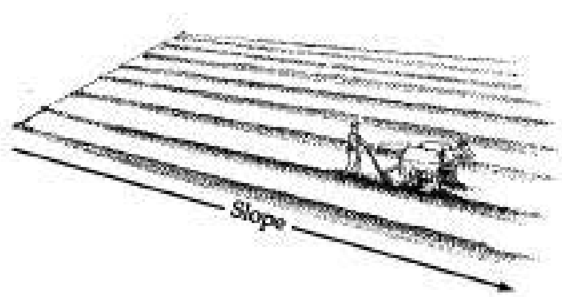


Figure 7-4a. Traditional farming in rainfed areas requires planting along the slope or up and down the hill.

Figure 7-5a and the photo in Figure 7-5 b illustrate the method advocated in this handbook—the use of vegetative contour hedges to prevent erosion and conserve natural moisture in the soil. Once established, such hedges need no maintenance and will protect the land from erosion for years as they build up natural terraces. In contrast to the planting furrows in Figure 7-4a, those at

A in Figure 7-5a follow the contour of the land as laid out by the vegetative hedges at B in the illustration. Constructed earthen embankments, or contour bunds, have slowed erosion throughout the world since the 1930s. But this constructed method of soil conservation creates an unnatural system of drainage and, from my experience in the field, I no longer consider it appropriate for smallholders.

Figure 7-5a. Farming with vegetative contour hedges prevents erosion and conserves natural moisture in the soil.

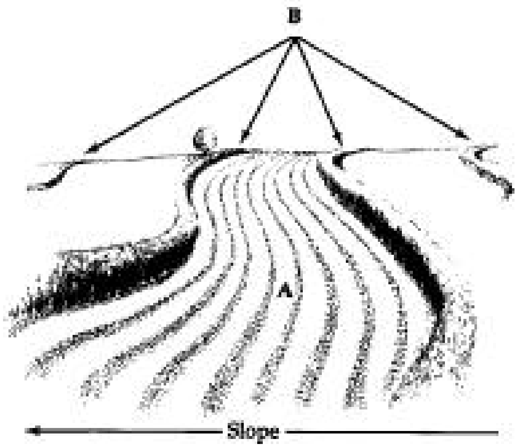


Figure 7-5b. Farmers who use vegetative contour hedges, which require little or no maintenance, will protect their land from erosion for many years.

The embankment in Figure 7-6a was constructed with topsoil taken from point A, which was thereby transformed into a channel to convey the runoff sideways.

Figure 7-6a. With the constructed method of soil conservation, the farmer loses a 5-meter-wide strip of land over the entire length of the bank.

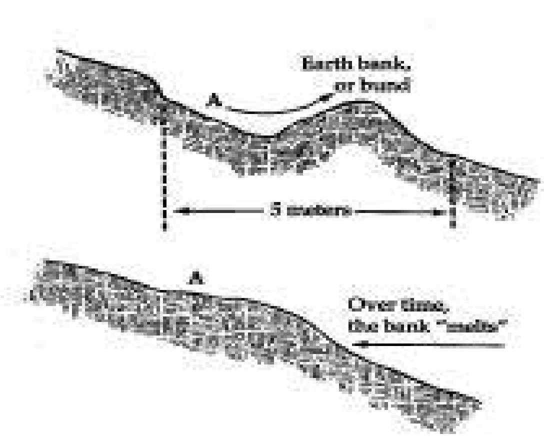


Figure 7-6b. With the constructed method of soil conservation, conservation efforts failed on India's black cotton soil.

But the bank is made of the same soil it is supposed to protect, and because its construction makes the slope steeper, over time the bank will erode and "melt" away. Then it will have to be replaced—at great cost to the farmer. Moreover, to collect sufficient soil to make the bank and channel shown in Figure 7-6a, a 5-meter-wide strip of land must be taken out of production over the entire length of the bank. This represents a loss of 1 hectare of productive farmland for every

20 hectares of land treated with embankments or bunds. The photo in Figure 7-6b clearly shows a typical failure of the constructed system of conservation in self-mulching vertisols in India.

Figure 7-7. With the constructed system, land is drained in an unnatural way, leaving some areas too dry and others too wet.

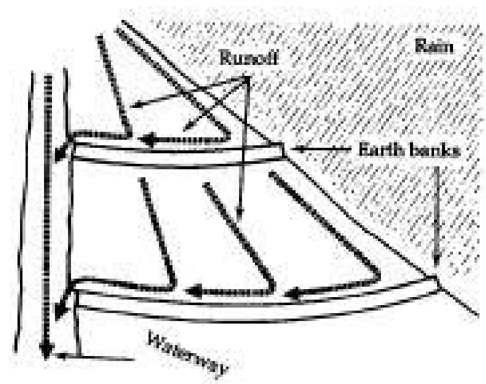


Figure 7-7 shows the unnatural way the land is drained by the constructed system. All of the runoff is channeled sideways and dumped into a constructed but unproductive waterway that no smallholder would want running through his or her farm. This system makes the areas below the banks too dry and the channel areas too wet for optimum crop production.

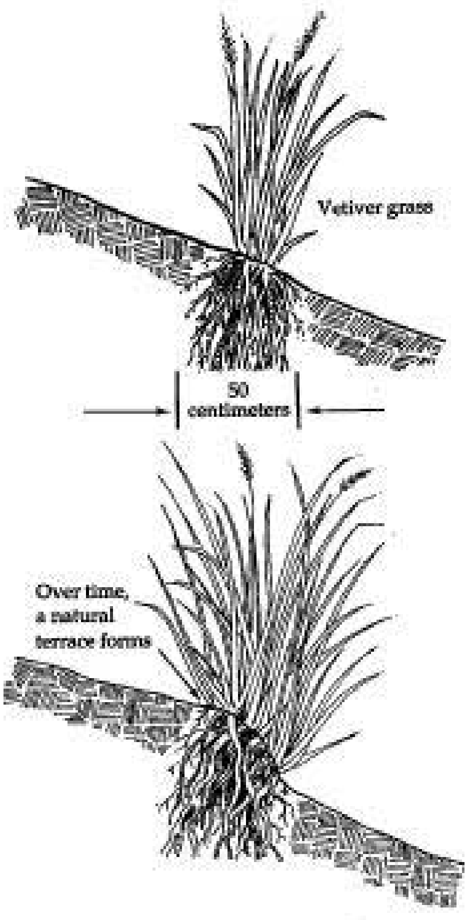
In contrast, the vegetative method of soil and moisture conservation uses nature to protect itself. In the system demonstrated in this handbook with vetiver grass, only a 50-centimeter strip—or one-tenth of the land occupied by earthen embankments or bunds—is taken out of production. (See Figure 7-8a.) Because the grass root divisions, or slips as they are called, are planted in a single plowed furrow, little soil is disturbed. And whereas earth banks have to be made with bulldozers or by hired labor, the vegetative system requires no special tools or labor beyond that which a farmer would already have.

The bottom illustration in Figure 7-8a shows what happens over time in the vegetative system: the runoff drops its load of soil behind the vetiver hedge, the grass tillers up through this silt, and a natural terrace is created. The terrace becomes a permanent feature of the landscape, a protective barrier that will remain effective for decades, even centuries. The photo in Figure 7-8b shows how the terrace builds up over time.

The photo in Figure 7-9a shows not only the failure of a constructed bank in India but also the failure of the cotton crop the bank was designed to protect. Before this bank's failure, the entire

Figure 7-8a. The vegetative system of soil and moisture conservation uses nature to protect the soil.

Figure 7-8b. Soil build up naturally behind this vetiver hedgerow. This photo is a cross section of a hedge and soil profile. Note the original soil surface is shown as the dark humic layer.



area was flooded by the constructed system's trapping of too much water. Because cotton cannot tolerate poor drainage, the crop failed completely.

The photo in Figure 7-9b was taken on the same day in a different location of the same field as in Figure 7-9a. In this situation the cotton crop thrived, protected by a single vetiver hedge that spread the runoff out and gave the water a chance to soak into the ground over the whole area protected by the hedge, thus producing an excellent crop of cotton.

With the vegetative system, when the runoff reaches the hedges, it slows down, spreads out, drops its silt load, and oozes through the hedgerows, a large portion of the water soaking into the land along the way. (See Figure 7-10.) No soil is lost, and there is no loss of water through the concentration of runoff in particular areas. The system requires no engineering—the farmers can do the whole job themselves.

Figure 7-9a. Not only has the constructed bank failed, but the cotton crop that the bank was constructed to protect has also failed. Before this bank's failure, the constructed system trapped too much water, flooding the entire area. Because cotton cannot tolerate poor drainage, the crop failed completely.

Figure 7-9b. Believe it or not, this field is part of the same one shown in Figure 7-9a, but here the cotton crop, protected by a single vetiver hedge, has thrived. The hedge spread out the runoff, giving it a chance to soak into the ground, which resulted in an abundant crop of cotton. (This photo was taken on the same day on the same field as was Figure 7-9a.)

Figure 7-10a. With the vegetative system of soil and moisture conservation, drainage benefits the crop. Runoff slows down, spreads out, drops its silt load, and oozes through the hedgerows, enabling a large portion of the water to soak into the land along the way.

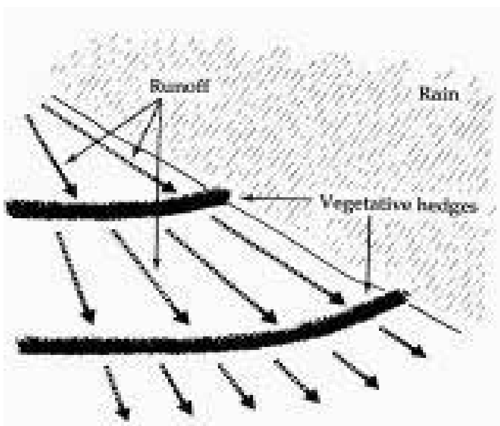


Figure 7-10b. When the runoff drops its silt load, it builds up behind the hedge, creating a natural terrace. The height of the terrace in demonstrated here by the line of farmers; the one on the right appears taller because he is standing on the terrace.

Near Mysore in the southern Indian state of Karnataka (in the villages and hamlets of Gundalpet and Nanjangud, for example), farmers have been maintaining vetiver hedges as boundary markers around their farms for more than 100 years. To keep the hedges narrow, the farmers simply plow around the edges of the hedgerows whenever they plow the rest of the field for cropping. The hedges are in perfect condition and provide permanent protection against erosion.

Vegetative Contour Hedges

Figure 7-11a presents a cross-sectional view of a vetiver contour hedge at work. The leaves and stems of the vetiver plant slow the silt-loaded runoff at A and cause it to deposit the silt behind the plant at B while the water continues down the slope at C at a much slower pace. The plant's spongy root system, pictured at D, binds the soil beneath the plant to a depth of up to 3 meters. By forming a dense underground curtain that follows the contour of the land, the roots prevent rilling, gullying, and tunneling. The photo in Figure 7-11b shows how the soil from the runoff has been trapped above the original topsoil behind the vetiver hedge.

Figure 7-11a. This cross-sectional view of vetiver shows a vegetative contour hedge at work.

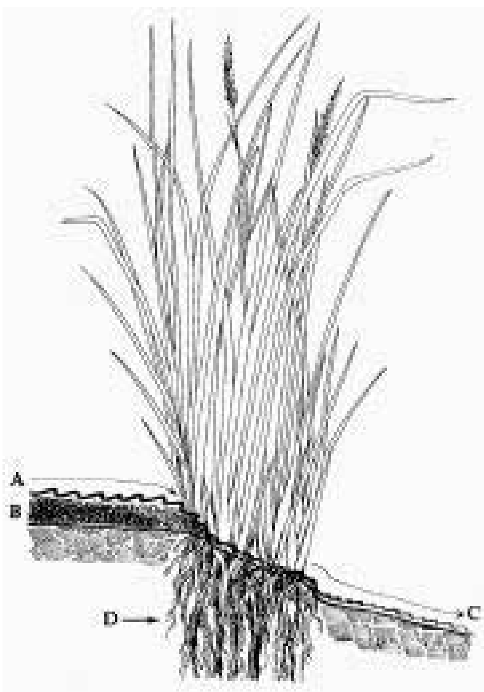


Figure 7-11b. This cross-sectional view of a two-year-old vetiver hedge shows how about 60 cm of soil has been trapped above the original dark band of topsoil.

The strong aromatic oil contained in vetiver makes the grass unpalatable to rodents and other pests, and many Indian farmers report that it also keeps rats from nesting in the area. Because the dense root system repels rhizomes of grasses such as *Cynodon dactylon*, the hedgerows prevent such grasses from entering the farm field and becoming a weed. Another benefit of planting the hedgerows, according to the farmers near Mysore, is that the plant's sharp, stiff leaves keep away snakes.

Figure 7-12a.With the vegetative system, the hedge grows continuously, leaving no gaps for runoff to flood the crop.

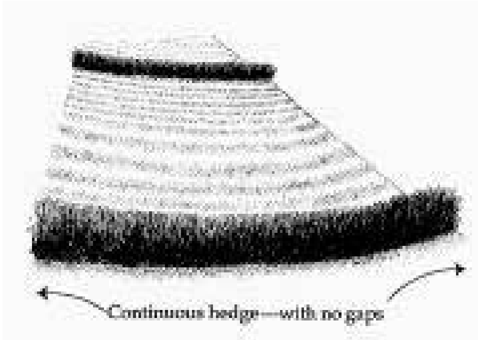


Figure 7-12b. A vegetative system in Panama conserves soil and moisture, protecting the crop.

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Figure 7-12c. In Costa Rica, a vetiver hedge hugs the contour of the land, conserving soil and moisture and protecting the crop

To be effective as a method of soil conservation, the vegetative system must form a hedge, as shown in Figure 7-12a and in the photos in Figures 7-12b and 7-12c. Although under certain circumstances thick hedges can be formed in one year, it generally takes two to three growing seasons to establish a hedge dense enough to withstand torrential rains and protect the soil. During the first two seasons, and sometimes the third, the vetiver plants need protection, and any gaps in their line have to be filled. (During the first two seasons it should also be easy to see the silt being trapped behind the plants as they are establishing, a phenomenon that extension workers should try to point out when explaining the system to farmers.) Although the earth banks used in the constructed method of soil conservation are effective immediately, they break down over time and frequently burst open in heavy rainstorms. Once a vegetative hedge has been established, it will neither wear out nor require further maintenance, other than periodic trimming. The photos in Figures 7-12b and 7-12c provide a good example of this use of the Vetiver System.

Trimming the hedges to a height of 30 to 50 centimeters prevents them from seeding and makes them thicken up, thereby increasing their effectiveness in filtering runoff. In several villages and hamlets near Mysore, the farmers trim their hedges every 2 weeks throughout the year and feed the young palatable leaves (which are out of reach to the rodents) to their livestock, often chopping them up and mixing them with other fodder. They are thus ensured a year-round supply of stock fodder regardless of rainfall.

Following the Contour

Many fieldworkers—and even research workers—lack a clear understanding of what is meant by the *contour*. Figure 7-13a illustrates a common misconception: that a furrow plowed along the main slope follows the contour. This is incorrect.

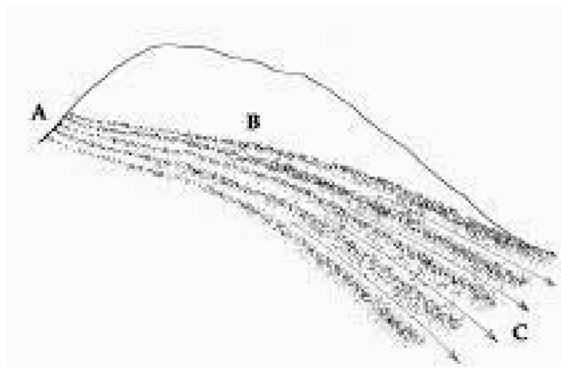


Figure 7-13a. With this false contour of the land, the furrows follow the main slope straight down instead of curving around the hill. This contour will not conserve soil or moisture.

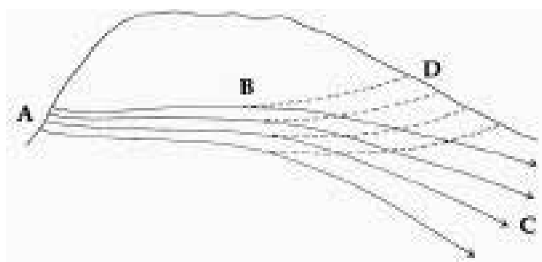


Figure 7-13b. With this true contour of the land, the furrows embrace all slopes and maintain equal elevation all the way. This contour will conserve soil and moisture.

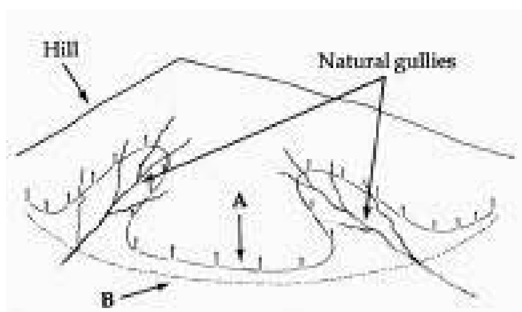


Figure 7-13c. Earth banks, which must convey the runoff to a waterway off to the side of they field, must be constructed on the exact contour (marked with pegs at A), often making it difficult for the farmer to follow when plowing. With vegetative hedges, however, the contour can be averaged into a smooth curve (line B).

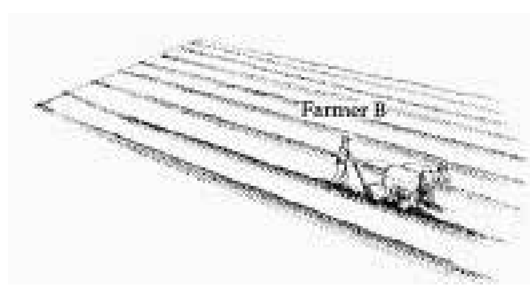
A true contour embraces all slopes, major or minor; it is a line of equal elevation around a hill. The furrows in Figure 7-13a, which starting from point A, follow the main slope straight down to point C, instead of curving around the hill; they are not on the contour and therefore will neither conserve moisture nor prevent erosion. The true contour, pictured in Figure 7-13b, runs from A to B to D and continues around the hill, maintaining equal elevation all the way.

Because constructed earth banks that conventionally are used to control erosion must convey the runoff to a waterway off to the side of the field, they have to be constructed on the exact contour As shown in Figure 7-13c, such a line (marked with pegs at A) can be difficult for the farmer to follow when plowing.
The vetiver hedges, however, do not have to be exactly on the contour to provide effective soil and moisture conservation since their purpose is to reduce the velocity of the water as it passes through them and not to channel the water elsewhere. After the contour line has been pegged in (see Figure 7-18a), the extension worker can smooth it out to make it easier for the farmer to follow. In Figure 7-13c hedges and plow furrows (crop lines) need only follow line B. The silt filtered from the runoff will build up behind the hedges and eventually form a natural terrace. Because the hedges run across the slope, the ends of each hedgerow should be turned up the slope to prevent runoff from spilling around the sides; this will encourage natural terraces to form more readily and prevent erosion at the ends of the hedgerows, especially in steep lands.

In Figures 7-14a and 7-14b we see two farmers, A and B. Both are good farmers, but farmer A in Figure 7-14a is a wise farmer; he has protected his land against soil loss by planting vetiver hedges on the contour, and he is using the hedgerows as guidelines to plow and plant on the contour.

Figure 7-14a. On a protected farm, vegetative hedges planted on the contour protect this land against soil loss. The hedgerows serve as guidelines for plowing and planting on the contour, creating furrows that will hold rainfall and store extra moisture in the soil in anticipation of long periods of dry weather.

Figure 7-14b. On an unprotected farm, plowed furrows that run straight up and down the slope encourage the rainfall to run off the farm, taking soil and farmyard manure for the ride and moving so quickly that no water is soaked into the soil as a protection against dry spells.



The furrows created in this fashion will hold rainfall and store extra moisture in the soil, thus allowing crops to withstand long periods of dry weather. What farmer A is doing costs no more than what farmer B in Figure 7-14b is doing. All that is involved is a change in land management.

Farmer B is a good farmer, but he is not farming wisely; he is not thinking. By plowing just straight up and down the slope, even a very gentle slope, he is encouraging the rainfall to run off his farm, taking his farmyard manure (FYM) and an irreplaceable layer of topsoil along for the ride. The rainwater runs off so quickly it does not have a chance to soak into the soil, and thus his crops have no protection against dry spells.

Figure 7-15a. When rain falls on the protected farm, the vegetative hedges and the contour furrows protect the soil from running off the land.

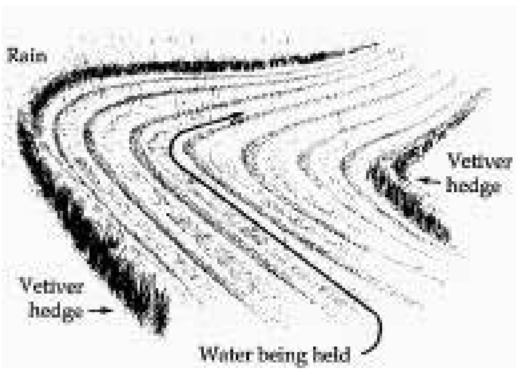
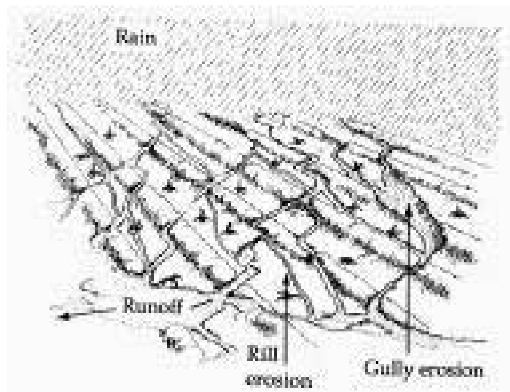


Figure 7-15b. When rain falls on the unprotected farm, the water runs off at great speed, taking the topsoil and fertilizers with it and eroding the soil as it moves along.



Figures 7-15a and 7-15b illustrate what happens when the two farming systems are exposed to heavy rainfall. Farmer A's field is protected by the vegetative hedges, and there is no loss of soil (Figure 7-15a). The contour furrows store all the rainwater they can hold. Any surplus rainfall runs off, but the vetiver hedges control the flow—slowing it down, spreading the water about—and cause the silt to be deposited. As a result, the runoff is conducted down the slope in a safe, nonerosive manner.

On Farmer B's unprotected land, the rainfall runs off at great speed, taking along his fertilizers and topsoil. The uncontrolled ride down the slope causes unnecessary and damaging erosion (Figure 7-15b). Because the runoff races by so quickly, no moisture is stored. Rainfall is only 40 to 50 percent effective, and farmer B is always complaining about droughts. Ultimately he will have to abandon his farm because there will be no soil left in which to grow crops. Farmer A will never have this problem; his yields will increase over the years.

The photos in Figures 7-15c and 7-15d show the importance of land management for moisture conservation in rainfed areas. Unlike irrigated farming, in which farmers have complete control over their crops' water needs, rainfed farming is totally limited by the amount of rain that falls in the area for the success or failure of the crops. By plowing and planting on the average contour, rainfed farmers have a better chance of holding the rain that falls in the field and in the actual crop rows, which means that the whole field benefits. In heavy storms, when the crop rows cannot hold the rainfall, the vetiver hedges prevent any damage from erosion by spreading the runoff out and giving it time to soak into the ground.

Figure 7-15c. Because rainfed farmers are limited to the amount of rain that falls in their area for the success of their crops, they must plow and plant on the average contour to hold the rain that falls in the field and in the actual crop rows. The farmers also need vetiver hedges to prevent an abundance of rainfall from eroding the soil by spreading the runoff and giving it time to soak into the ground.

Figure 7-15d. When farmers do not plow and plant on the average contour, heavy rainfalls wash away the topsoil and farmyard fertilizers. Without vetiver hedges to spread the runoff, giving it time to soak into the soil, an abundance of rainfall erodes the soil.

Thanks to his vetiver contour hedges, farmer A obtains an excellent crop. (See Figure 7-16a.) Because the soil has retained ample moisture from earlier rains, his crop is benefiting from the warm sunshine, all the grains are filling, and the crop stand shows even growth. Farmer A will reap a high yield.

Figure 7-16a. On the farm with a protective vetiver grass contour hedge, farmer A obtains an abundant crop.

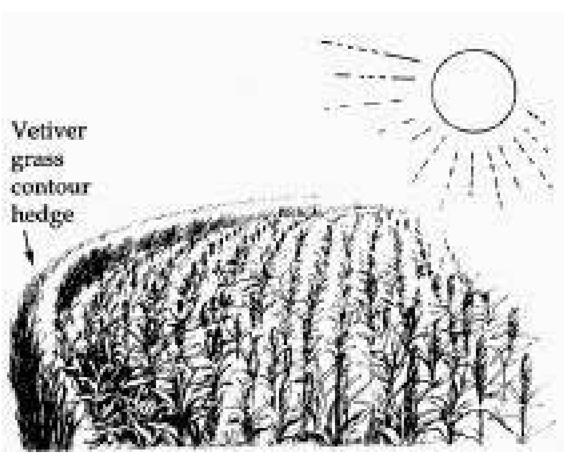
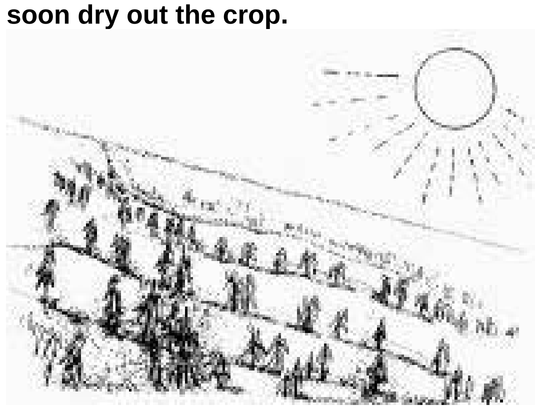


Figure 7-16. On the unprotected farm, farmer B's failing crop grows only in pockets where some moisture was trapped; but the sun will soon dry out the crop.



In contrast, farmer B has a disappointing harvest. (See Figure 7-16b.) His crop has all but failed, and what little remains—growing in pockets where some moisture was trapped—is being dried out by the sun. Only a small percentage of the grain will fill, and the resulting crop is uneven. Farmer B can expect a low yield. Yet he planted the same crop as farmer A, used the same fertilizer, planted at the same time, and received the same amounts of rainfall and sunshine. Unlike his neighbor, however, farmer B lost most of his fertilizer, 60 percent of his rainfall, and

Figure 7-17a. On a protected farm in Ethiopia, a vetiver hedgerow protects a crop of maize.

Figure 7-17b. On a protected farm in China, vetiver hedgerows are overwintering, protecting jojoba seedlings from soil and wind erosion.

a layer of soil, possibly a centimeter thick, from his farm—all because he did not plow on the contour and use vegetative hedges to protect against erosion and help his cropland retain moisture from the rain. If he had taken the advice of his extension service and plowed and planted on the contour, farmer B could have obtained the same high yields as farmer A. The photos in Figures 7-17a and 7-17b attest to the success of crops that are protected by vetiver hedges.

Figure 7-18a. Farmer B and his extension worker peg out contour lines along the old furrow.

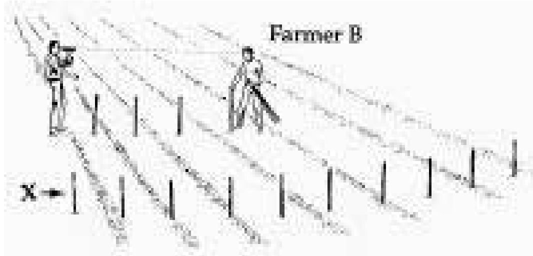


Figure 7-18b. Farmer B plants on the contour.

Figure 7-18c. An extension worker in Papua New Guinea pegs out vetiver hedges on the contour.

Having learned his lesson, farmer B contacts his extension worker, and together they mark, or peg out, contour lines across the old furrows. (See Figure 7-18a.) This simple process requires virtually no engineering skills—only the use of a small hand-held level. The extension worker stands at the edge of the field and, sighting through the level, has farmer B move up or down the slope until the two people are standing level, at which point the farmer marks the spot with a peg. In Figure 7-18a, the contour line (X) has already been pegged out, and the farmer has but to follow the line of pegs with his plow (as shown in Figure 7-18b) to create the furrow in which to plant the slips of vetiver grass that will eventually form a contour hedge. This is all that has to be done to establish the vegetative system of soil and moisture conservation. The photo in Figure 7-18c shows an extension worker and farmers working together to peg out vetiver hedges on the contour.

Like any long-lived plant, however, the vetiver hedge system normally takes two to three seasons to become fully effective. You cannot plant a mango tree today and expect to pick mangoes next month, but it is possible to get some immediate effect from the system by using dead furrows as a preliminary step until such time as the vetiver grass can be established.

The preliminary stage of establishing the vegetative system is depicted in Figure 7-19a. While waiting for vetiver planting material to be produced in the nursery, the farmer laid out the contours, prepared seedbeds following the contour furrows, and every 5 or 6 meters double plowed a dead furrow. The two dead furrows in the figure have been planted on the contour to pigeon peas and intercropped with six rows of groundnuts. The shape of each seedbed is show beneath the crop illustration: DF marks the deeper dead furrow, PP the row of pigeon peas it supports. Eventually, vetiver grass will be planted in some of the dead furrows, but in the interim these furrows themselves will provide a bit of protection against runoff. Planting the vetiver grass will stabilize the whole system, as shown in Figure 7-19b, where a vetiver hedge has taken the place of one of the dead furrows.

Figure 7-19a. The initial setup of vetiver hedges uses dead furrows (DF) to support the pigeon peas (PP).

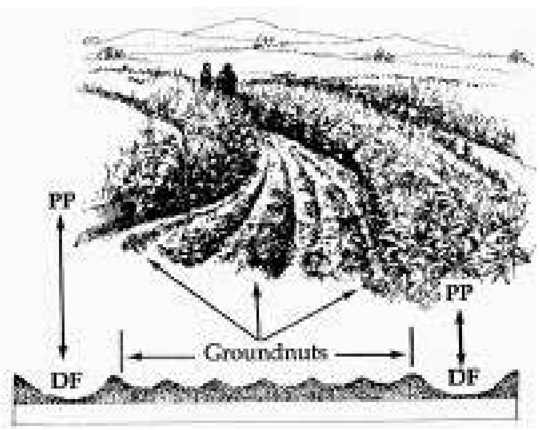
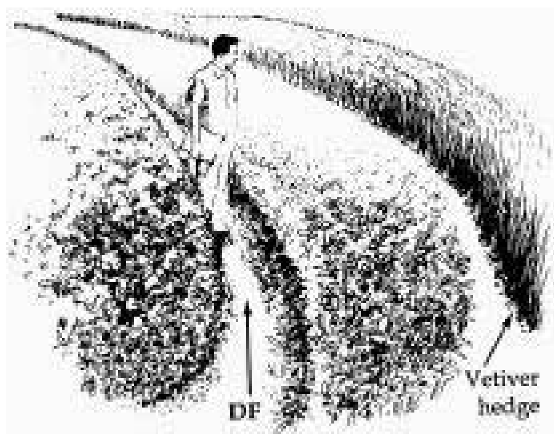


Figure 7-19b. To stabilize the system, the farmer has planted a vetiver hedge in one of the dead furrows.



Establishing Vetiver Hedges

To establish a vetiver hedge, follow the step-by-step instructions that appear on the next few pages, along with tips on handling the planting material, advice about the best time to plant, and information about what to expect after the grass is planted.

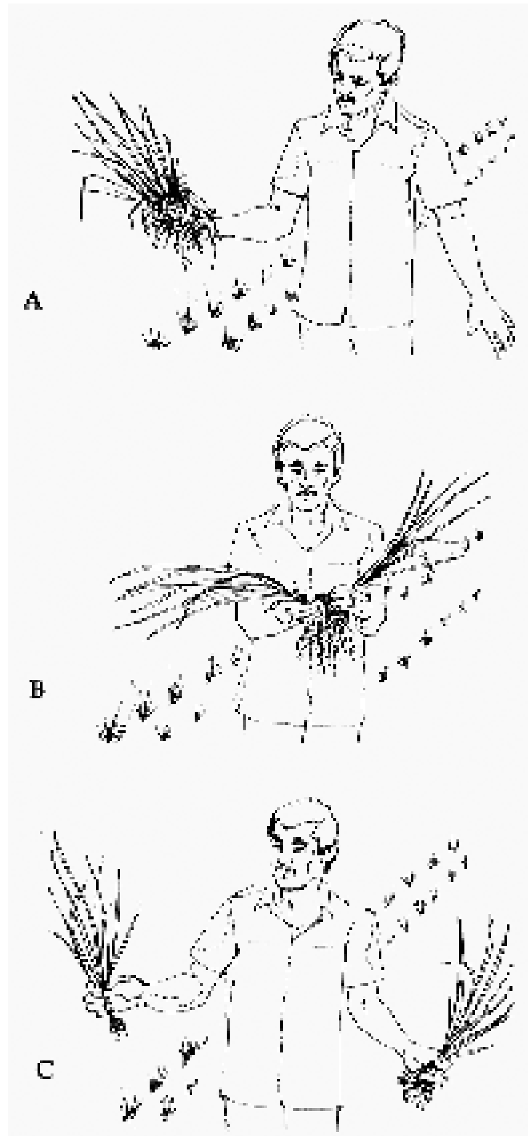


Figure 7-20a. The farmer digs out a clump of vetiver grass from the nursery (A), tears a handful of grass and roots (the slip) from the clump (B), and prepares to plant the slip in the field (C).

Figure 7-20b. Women prepare vetiver slips for hedge planting.

The first step for establishing a vetiver hedge is obtaining the planting material, usually from a vetiver nursery. If vetiver grass is unknown in your area, check with the nearby botanical gardens. Ask them to look up *Vetiveria zizanioides*. If it has been collected, the herbarium sheet will show what the plant looks like, note where the specimen was found, and provide the local name of the plant. Vetiver is found throughout the tropics and has been grown successfully as far north as 42° latitude. Vetiver nurseries are easy to establish. Inlets to small dams or water holding tanks make the best nursery sites, because water en route to the dam or tank irrigates the vetiver grass, which in turn removes silt from the water. Large gullies protected with vetiver grass also make good informal nurseries. For best results in establishing a vetiver nursery, the vetiver root divisions, or slips, should be planted in a double or triple line to form parallel hedges across the streambed. The hedgerows should be about 30 to 40 centimeters apart.

Figure 7-21a. To prepare the vetiver for planting, the farmer holds the slip on a block of wood and uses a knife to trim the roots.

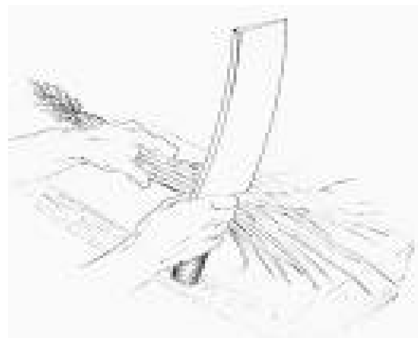


Figure 7-21b. The trimmed vetiver slip is ready for planting.

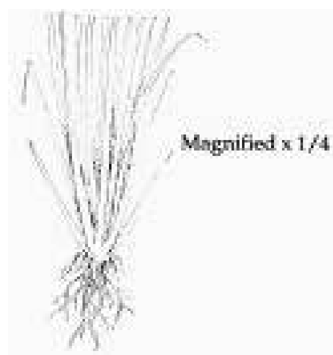


Figure 7-21c. The farmer plants the vetiver slips 10-15 centimeters apart.

Figure 7-21d. In Mexico, a farmer has correctly spaced planting slips in a vetiver hedgerow.

To remove a clump of vetiver grass from the nursery, as shown in illustration A, Figure 7-20a, dig it out with a spade or fork. The root system is too massive and strong for the grass to be pulled out by hand. Next, tear a handful of the grass, roots and all, from the clump (B). The resulting piece, the slip, is what will be planted in the field (C). In the photo in Figure 7-20b, women in India prepare vetiver clumps for transport to the fields by separating them into planting slips, trimming the slips, and bundling them. Before transporting the slips from the nursery to the field, cut the tops off about 15 to 20 centimeters above the base, and the roots 10 centimeters below the base. Cutting will improve the slips' chances of survival after planting by reducing the transpiration level and thereby preventing them from drying out. As shown in Figure 7-21a, all that is needed to prepare the slips for planting is a block of wood and a knife—a cane knife, machete, cutlass, or panga will do. The finished planting piece is shown in Figure 7-21b.

Although vetiver grass can be planted from single tillers (when planting material is scarce), this practice is not recommended for grass to be planted in the field, because it takes too long to form a hedge. Fertilizing the slips with di-ammonium phosphate (DAP) encourages fast tillering and is helpful both in the nursery and in the field. To do this in the field, simply dibble DAP into the planting furrow before planting the slips.

Always plant the slips at the beginning of the wet season to ensure that they get full benefit of the rains. Planting vetiver slips is similar to planting rice seedlings. Make a hole in the furrow that was plowed to mark the contour. Push the slip into the hole, taking care not to bend the roots upward. Then firm the slip in the soil. Then 10 to 15 centimeters from the slip, along the same contour furrow, plant the next slip, and so on. (See Figure 7-21c and the photo in Figure 7-21d.)

Only a single row of slips need be planted. If planted correctly, the slips can withstand up to one month of dry weather. Some slips may die, however, and leave gaps in the hedge line. If possible, fill these gaps by planting new slips. In some instances it may be possible to use the live flower stems, or culms, of neighboring plants—simply bend the culms over to the gap and bury them. The live stems will produce roots and leaves at the nodes.

Of course for this or any vegetative system to work, the plant must form a hedge; otherwise, the system cannot act as a barrier against soil loss. Planting the slips too far apart (see Figure 7-22a) would render the system almost useless because it would take too long for the slips to grow together to form a hedge. The photo in Figure 7-22b shows a hedge in China that was planted in the wrong way. Even though the farmer had the extension workers' handbook showing the correct method for achieving a hedge with vetiver and had advice in the field, he planted the slips too far apart. This method of planting will never work as a method of soil conservation, and the farmer will eventually abandon the system—not because the system does not work, but because the farmer did not lay it out according the instructions.

Moreover, without the extra support of a hedge to hold the soil, fertilizer, and moisture against the vetiver grass, the plants would not be able to survive the worst droughts. Even in arid areas that receive less than 200 millimeters of rain a year, an effective vetiver contour hedge could ensure its own viability. The combined effect of contour cultivation and the hedge's performance in slowing and spreading the runoff is to increase infiltration of water into the soil. Thus the hedge can help itself to what might be the equivalent of half again as much rainfall.

Figure 7-22a. If the farmer plants the slips too far apart, it will take too long for the hedgerow to grow.

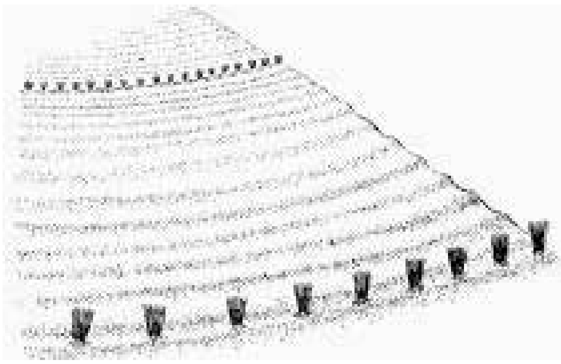


Figure 7-22b. In China, a farmer incorrectly spaced the planting slips and the vetiver hedgerow never grew.

For the system to provide maximum protection against erosion, the hedgerows should be spaced apart at the proper vertical interval (VI). The VI is the vertical distance from one hedgerow to the next one down the slope. The actual distance measured along the ground, called the surface run, depends on the steepness of the slope. With a vertical interval of 2 meters, for example, the hedges on a 5 percent slope would be about 40 meters apart, whereas those on a 2 percent slope would be about 100 meters apart. As shown in Figure 7-23, the surface run between hedgerows planted on a 57 percent slope with a VI of 2 meters is about 4 meters. For a more comprehensive look at the relationships among slope, surface run, and vertical interval, see Table 7-2 at the end of this chapter. In practice, a VI of 2 meters has generally been found to be adequate.

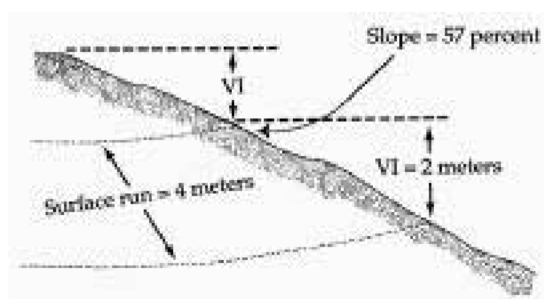


Figure 7-23. The surface run between hedgerows planted on a 57 percent slope with a vertical interval of 2 meters is about 4 meters.

After the hedges have been established in the farm field, the only care they will need is annual trimming to a height of about 30 to 50 centimeters to encourage tillering and prevent shading of the food crops. When plowing for cropping, plowing along the edges of the hedgerows will remove any tillers that encroach upon the field and will thus prevent the hedges from getting too wide.

Moisture Conservation

Although measures to retain natural moisture in the soil are essential to all rainfed-farming systems, the art of in situ moisture conservation, as it is called, is rarely practiced and not widely understood. There is no such thing as flat land; water runs off all land. No matter how flat it may seem, all land must be contoured if it is rainfed. Earth shaping, land leveling, and similar techniques are required in irrigated areas only; rainfed areas must be contoured. Figure 7-24 shows what happens when land is planted on the “flat” without the benefit of contour furrows.

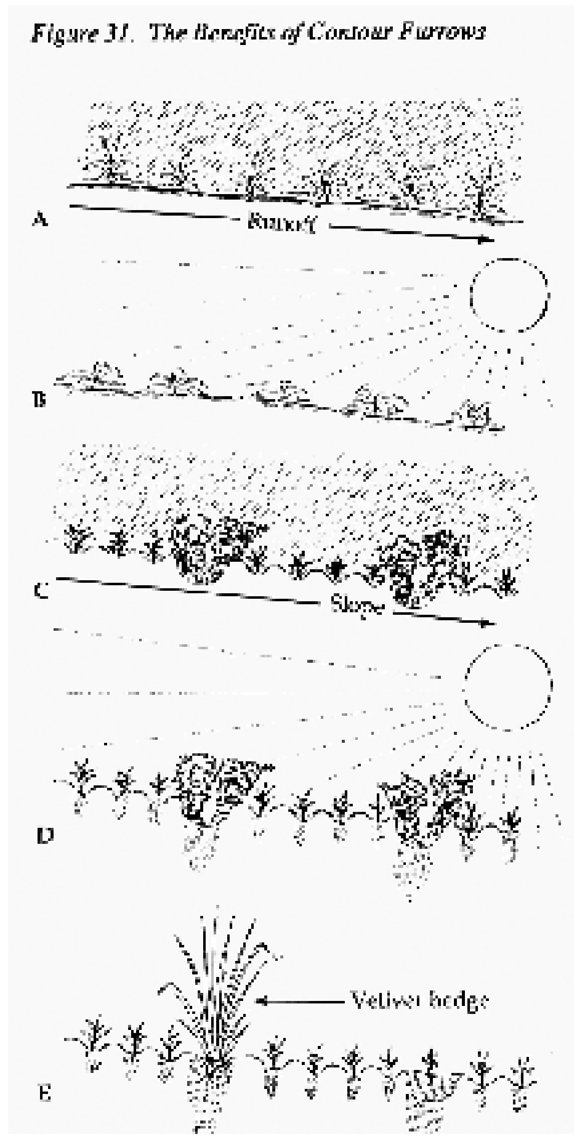


Figure 7-24. When land is planted on the flat, rain runs straight off the field (A), resulting in land with no stored moisture and plants that wilt and die in the sun (B). When land is planted on the contour, while waiting for the time to plant vetiver, dead furrows take up the surplus runoff (C), resulting in a natural system of water storage and plants that enjoy both the moisture and the sun (D). When vetiver grass is planted in one of the dead furrows, it stabilizes the natural system (E).

In view A, the rain runs straight off the field. View B shows the results: because no moisture has been stored, the plants wilt and die in the sun. View C shows the same area planted to contour furrows, with a pair of dead furrows taking up the surplus runoff until the vetiver can be planted. Rain caught and held in each furrow’s micro-catchment has the chance to soak in. Each furrow can hold 50 millimeters of rainfall, so in most storms there is no runoff. Thanks to this natural system of water storage, the plants can benefit from the sunshine, as shown in view D. In view E, one of the dead furrows has been planted to vetiver grass to stabilize the system.

A vetiver grass hedge is the key to the in situ moisture conservation system. Once established, it serves as a guideline for plowing and planting on the contour, and in times of heavy storms it prevents erosion from destroying the farmer's field. The beauty of the plant is that, once it has established, the hedge is permanent.

Figure 7-25a. This is what a system of vetiver hedges planted over a large area would look like. Unlike a constructed system, the Vetiver System requires no waterways and does not have to spill into a drainage network.

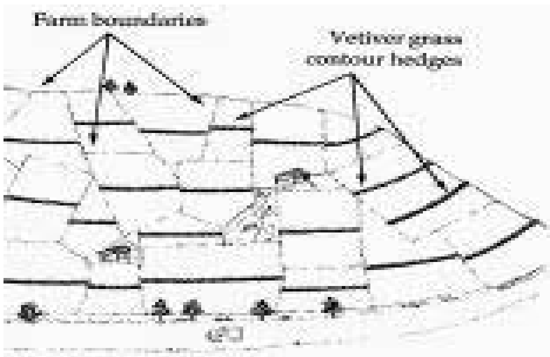


Figure 7-25b. The Vetiver System enables the farmer to plant vetiver the full length of his field since the hedges do not convey runoff.

Figure 7-25a is a diagrammatic representation of what a vetiver grass system would look like in a smallholder farming area. The Vetiver System fits perfectly into the individual farm system, where no waterways or earthworks exist. Most farmers have one line of vetiver roughly in the middle of their fields, no matter what the shape; long fields may need two lines to stabilize them. Although each field has its own line or lines of vetiver, the entire hillside is protected against erosion because each line protects the ones farther down the slope. Under this system, once the hedges are established, no further protective work is needed, and maintenance is minimal. The farmers each have their own supply of vetiver planting material. Should a gully start to form anywhere, the farmer obtains cuts slips of vetiver from an existing hedge and plants it across the incipient gully to prevent its spread—permanently and at no cost except for the farmer's own labor.

The photo in Figure 7-25b shows vetiver hedges planted over a large area. Unlike a constructed system, the Vetiver System requires no waterways, and runoff does not have to spill into any drainage network. Because they do not convey runoff, the hedges can be as long as any given farmer's field. The hedges spread out the runoff, providing moisture conservation over the entire area. At the same time, the hedges filter out the silt, enabling the excess runoff to flow harmlessly down the slope.

Why Vetiver Grass Is the Ideal Plant for the Vegetative System of Soil and Moisture Conservation

Although many grasses and trees have been tried over the years as measures to prevent erosion, to date only vetiver grass has stood the test of time. As made clear by the following list of its characteristics—derived from observations of *V. zizanioides* throughout the world—this truly remarkable plant is ideally suited for the vegetative system of soil and moisture conservation. No other grass is known to rival its hardiness or diversity.

V. zizanioides—

- When planted correctly, will quickly form a dense, permanent hedge.
- Has a strong fibrous root system that penetrates and binds the soil to a depth of up to 3 meters and can withstand the effects of tunneling and cracking.
- Is perennial and requires minimal maintenance.
- Is practically sterile; because it produces no stolons or rhizomes, it will not become a weed.
- Has a crown that is below the surface, which protects the plant against fire and overgrazing.
- Has sharp leaves and aromatic roots that repel rodents, snakes, and similar pests.
- Has leaves and roots that have demonstrated a resistance to most diseases.
- Once established, is generally unpalatable to livestock. The young leaves, however, are palatable and can be used for fodder. (In Karnataka, India, a cultivar of *V. zizanioides* selected by farmers has softer leaves and is more palatable to livestock. This cultivar is also denser, less woody, and more resistant to drought than some of the other available cultivars.)
- Is both a xerophyte and a hydrophyte, and once established, vetiver grass can withstand drought, flood, and long periods of waterlogging.
- Will not compete with the crop plants it is used to protect, and in fact, vetiver grass hedges have been shown to have no negative effect on—and may in fact boost—the yield of neighboring food crops.
- Is suspected to have associated nitrogen-fixing mycorrhiza, which would explain its green growth throughout the year.
- Is cheap and easy to establish as a hedge and to maintain—as well as to remove if it is no longer wanted.
- Will grow in all types of soil, regardless of fertility, pH, or salinity, including sands, shales, gravels, and even soils with aluminum toxicity.
- Will grow in a wide range of climates and is known to grow in areas with average annual rainfall between 200 and 6,000 millimeters and with temperatures ranging from -9º to +50º Centigrade.

- Is a climax plant; therefore, even when drought, flood, pests, disease, fire, or other adversity destroy all surrounding plants, the vetiver will remain to protect the ground from the onslaught of the next rains.

Other Practical Uses for Vetiver Grass

Apart from its success as a system of soil and moisture conservation, vetiver grass has proved effective for a variety of other purposes.

Stabilizing terrain and structures. One of the most important uses of vetiver grass is stabilizing the terrain and structures such as dams, canals, and roadways. Figure 7-26, for example, shows how vetiver can be used to stabilize a typical paddy field that relies on earth banks to keep irrigation water at the correct level. These banks (top illustration) can be worn down by the action of wind-churned water (lap erosion) and the activities of rats, crabs, and other hole-burrowing pests. The subsequent large-scale erosion, not to mention the loss of expensive and in some cases irreplaceable irrigation water, could lead to loss of the crop.

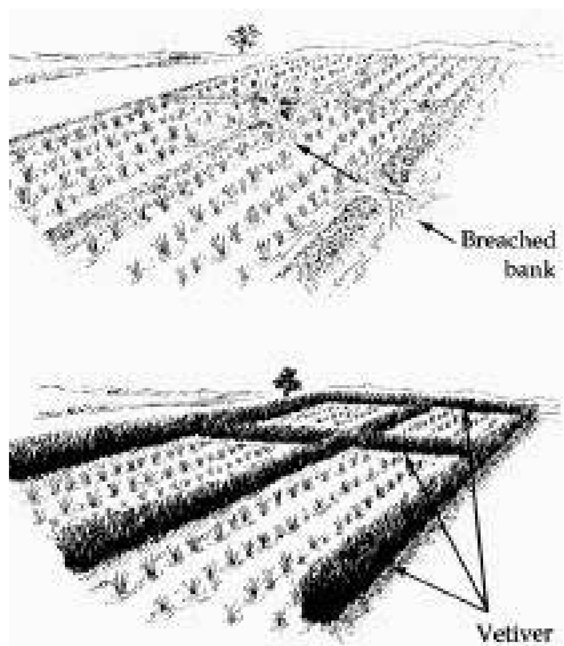


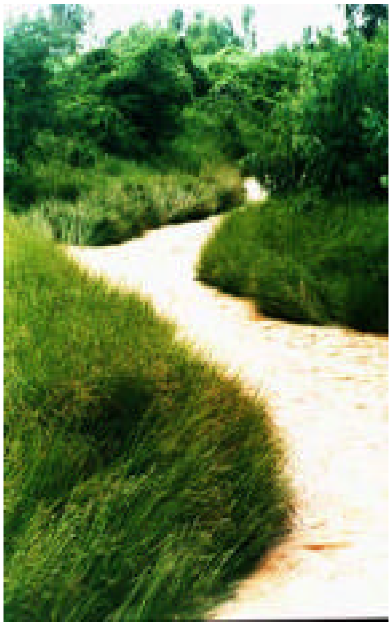
Figure 7-26. Vetiver can be used to stabilize a paddy field.

Vetiver can be planted on top of the paddy banks to stabilize them (bottom illustration). Vetiver grows well under these conditions and does not suffer from the occasional inundation of water. In addition, vetiver roots contain an essential oil that repels rodents. Furthermore, because its roots grow straight down and not out into the crop, the grass has no negative effect on the rice or its yield. Each year the vetiver can be cut back to ground level to prevent shading of the crop.

In another example, vetiver can be used to maintain river levees by preventing them from being eroded back into the fields. (See Figure 7-27a and the photo in Figure 7-27b.) It can also be used on river flats to prevent silt from entering the watercourse from the runoff of surrounding fields.

Figure 7-27a. Vetiver protects riverbanks by preventing river levees from being eroded back into the fields.

Figure 7-27b. In Zimbabwe, vetiver protects a riverbank.



Establishing tree crops. Vetiver's stabilizing influence is especially useful in steep and rolling country, where the distribution of moisture cannot be controlled. Unsuitable for the cultivation of cereal or other annual crops, such areas, when stabilized by vetiver grass, can be successfully planted to perennial tree crops on the contour. Most attempts to grow tree crops on steep hillsides are abandoned because the resulting poor, uneven stands are not worth the cost of maintenance.

Figure 7-28a. A vetiver grass hedge nurtures a fruit tree on a hill.

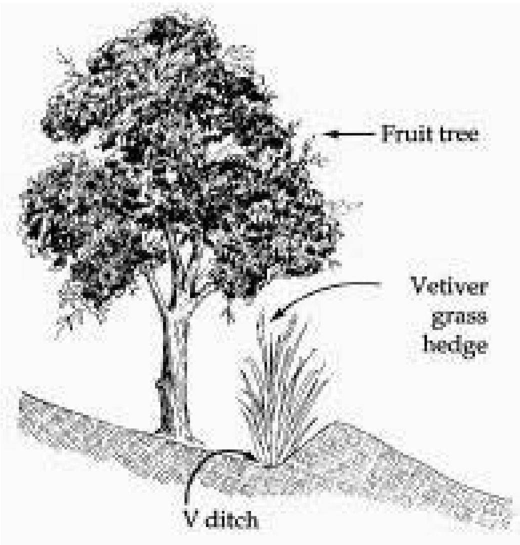


Figure 7-28b. In Costa Rica, a vetiver hedge nurtures young coffee plants.

Figures 7-28a and 7-29a show a method of establishing tree crops on such hills using contour vetiver hedges. First the contours of the hill are pegged out. Next, by hand or with a bulldozer and ripper unit, the farmer digs shallow V ditches along the contour lines. A row of trees is planted close to the edge of each ditch, and vetiver grass is planted in the ditches.

Figure 7-29a. Vetiver hedges stabilize tree crops.

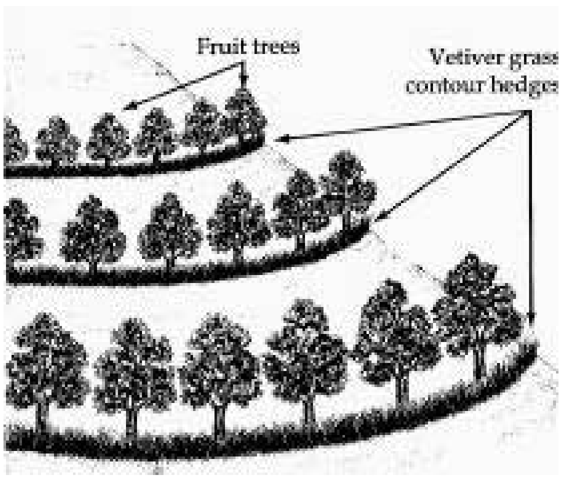


Figure 7-29b. In Malaysia, vetiver hedgerows protect young rubber trees on steep, stony slopes.

Under this arrangement of planting, the runoff between one row of trees and the next one down the slope collects in the vetiver-lined ditches (there is usually sufficient drainage on the slopes to preclude the possibility of waterlogging). Thanks to the effects of such water harvesting, the rows of trees do not have to be planted as close together as the trees within a row. Initially, the V ditch will provide a measure of runoff control, thereby increasing the soil's moisture content, and both the vetiver and the planted trees will benefit. By the time the ditch "melts" away after a couple of years, the vetiver hedge will be established and performing its function of increasing the infiltration of runoff, halting the loss of soil and soil nutrients, and creating a natural terrace.

Because the collection of runoff in the contour ditches has the effect of doubling or tripling the amount of effective rainfall, fruit trees planted by this method need no irrigation in the first three years of establishment. The vetiver grass lines stabilize the whole system. The photos in Figures 7-28b and 7-29b show the success of such systems.

Mulching. After the vetiver hedges are properly established, the farmer can cut down the vetiver grass to ground level when the dry season sets in and use its leaves as mulch at the base of the fruit trees to help retain stored moisture. (See Figure 7-30a and the photo in Figure 7-30b.) The advantage of using vetiver for this purpose is that its leaves harbor few insects and last well as mulch. Vetiver hedges also protect the young trees in the hot summer months by providing some indirect shade; in the colder winter months the hedges act as windbreaks.

Establishing forests. Forest trees should be planted by the same method as when establishing tree crops—on the contour and, if possible, in V ditches bordered by vetiver hedges to stabilize them. Where this has been done, the results have been spectacular: more than 90 percent of the seedlings planted by this method survived the 1987 drought in Andhra Pradesh, India, whereas 70 percent of the other seedlings died.

Figure 7-30a. Mulch cut from vetiver hedges holds moisture for the fruit trees, repels insects, prevents fungal disease, and outlasts other mulches.

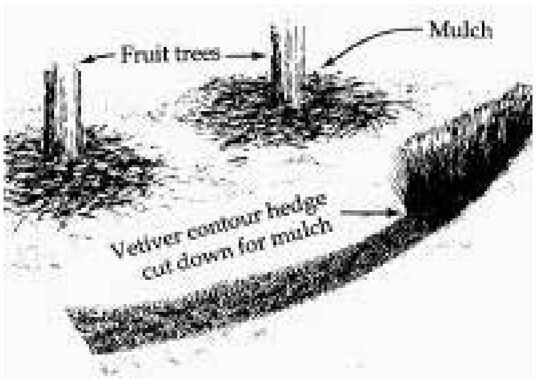


Figure 7-30b. On a coffee plantation, vetiver mulch controls pests and improves moisture availability, which is essential for high production.

Stabilizing masonry walls for hill farming. In the Indian Himalayan highlands, where farming is carried out on terraces, vetiver grass is now being used to stabilize the masonry risers that have been erected over the centuries. The walls pictured in the photo in Figure 7-31a need all the support they can get to withstand the seas whipped up by typhoons, and during tropical storms, to withstand the massive damage caused by runoff from associated torrential rain pouring over the walls, and even through the walls, from the catchment above. The hedges in the photograph have withstood the rigors of a typhoon that destroyed other walls in the area that were not protected by vetiver hedges.

Without some form of vegetative support, these ancient structures require continual maintenance. If one riser washes out during a heavy storm, other terraces farther down the slope often suffer considerable damage because of the domino effect. Figure 7-31b, which depicts a typical terrace system in the hills, shows the type of damage frequently sustained. To allow for drainage between the stones, the masonry risers are not bound together with mortar. If the walls were solid, instead of just a small section falling out, the whole wall might collapse and trigger a landslide that could destroy the entire farm. Although these terraces have done an excellent job through the years, they do exact a toll in the form of crop losses, and they require a lot of hard work in repairs.

When we explained the Vetiver System of stabilization to the hill farmers, they wanted to plant as many areas as possible. In a World Bank project begun in 1986, vetiver grass was planted along the edge of the terraces during the rainy season in the hope that its strong root system would reinforce the masonry risers. It worked perfectly.

Figure 7-31c shows what the vetiver grass-protected terraces should look like once established. The grass is planted only at the extreme edge of each terrace so the hedges do not impede the

Figure 7-31a. In the Himalayan highlands terraces are frequently washed out by concentrated flows of run-off water.

Figure 7-31b. A terrace system in the hills can easily be washed out during the rainy season.

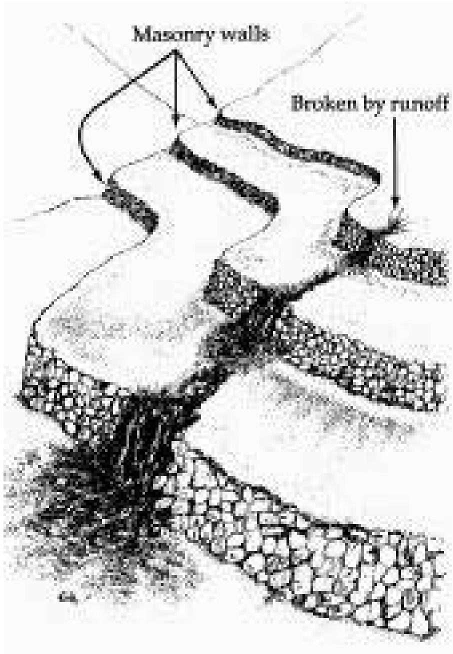


Figure 7-31c. Vetiver grass, planted on the extreme edge of each terrace, stabilizes the terraces without interfering with the essential drainage between the stones.

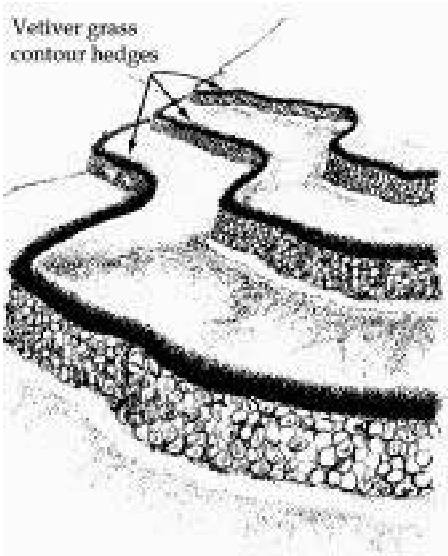
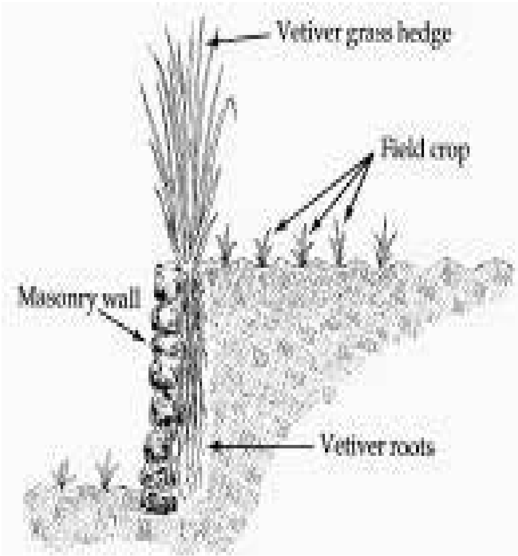


Figure 7-31d. The vetiver root system stabilizes the entire rock face of the vulnerable masonry risers.



essential drainage between the stones. According to the farmers, what causes most of the damage during heavy storms is the cascading of water down the slopes and over the top of the masonry terraces, especially if the water has a chance to concentrate into a stream. Once established, the vetiver hedges should take most of the erosive power out of this runoff as well as protect the edge of the terrace.

As shown in the close-up in Figure 7-31d, the masonry risers are vulnerable because they are simply stones stacked on top of each other and are usually 2 to 3 meters high. Because its strong root system can easily penetrate to the bottom of the risers, vetiver grass can be used to protect the entire rock face.

In another project in the Himalayan highlands, in areas with no masonry terraces to halt massive sheet erosion, vetiver grass contour lines are being established to determine whether the natural terraces that build up behind the hedges will form a base of stable land for the production of fuel wood and fodder crops. In China, in the provinces of Jiangxi and Fujian, vetiver grass hedges are now being used to protect the edges of citrus and tea terraces.

Protecting roads. Vetiver grass is also used to protect road cuttings, as shown in Figure 7-32a. People in St. Vincent in the Caribbean use it to line the outer edge of the tracks to their houses. The grass has exhibited a remarkable ability to grow in practically any soil. In Andhra Pradesh, India, for example, it was observed growing at the Medicinal and Aromatic Research Station at the top of a bare hill. Even though the soils on that hill are skeletal—granite boulders had to be In the West Indies, the plant has been used extensively for stabilizing roadsides and has completely prevented erosion for years. bulldozed to make a plot for the grass—and are deprived of most of the benefits from rainfall (since they are located at the very top of the hill), and at the time supported no other form of growth, the vetiver grass showed no signs of stress. A plant that can thrive under these extreme conditions should be able to do an excellent job of stabilization almost anywhere.

Figure 7-32a. Vetiver hedges stabilize roadsides.

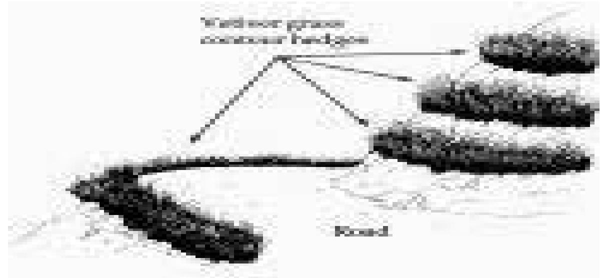


Figure 7-32b. In Malaysia, vetiver hedgerows stabilize country roads for minimal cost and maintenance.

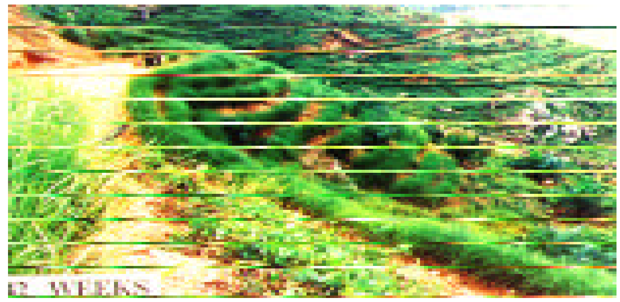
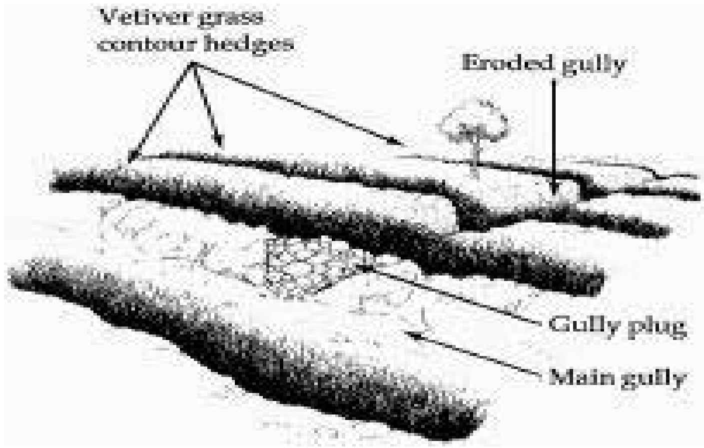


Figure 7-32c. In Malaysia, vetiver hedgerows stabilize high-cost highways.

The photos in Figures 7-32b and 7-32c show how vetiver grasses have been used in Malaysia to protect roads. In Figure 7-32b, the hedgerows stabilize the slopes of country roads. Once the hedges are established, the roads are fully stabilized and do not slip. The cost to establish the hedges is minimal, and the maintenance is even less. The same Vetiver System is used to stabilize high-cost highways, as shown in Figure 7-32c.

Stabilizing wasteland development. The use of vetiver grass in wasteland development has recently been tested, and vetiver has proved effective as the initial stabilizing plant. In the Sahel region of Africa (in the state of Kano, Nigeria) and in Bharatpur in central India, under the extreme conditions of constant fire and drought, *V. nigritana* and *V. zizanioides*, respectively, have survived as the climax vegetation for hundreds of years. When planted as contour hedges in wasteland areas—the first stage in stabilizing such areas—*V. zizanioides* reaps the benefits of any surplus runoff and harvests organic matter as it filters the runoff water through its hedges. Because the foothills of the Indian Himalayas are very young geologically, they are highly erodible; planting vetiver contour hedges around these slopes and then across the short erosion valleys will stabilize these areas. A masonry plug at the end of the system allows silt to build up and give the grass a basis of establishment. (See Figure 7-33.)

Figure 7-33. Vetiver hedges stabilize wasteland areas.



The same would apply to normal gullies as shown in Figure 7-34a. Once established, the grass would fill and terrace the gullies with silt. In an upland area of Fiji, as shown in Figure 7-34b, a gully was stabilized with vetiver grass some 30 years before the photo was taken. In the photo, the gully is fully stable and the hedges remain where they were originally planted.

Figure 7-34a. Vetiver hedges stabilize gullies.

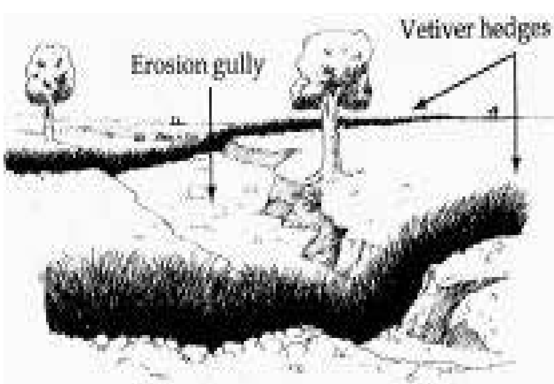


Figure 7-34b. In this upland area of Fiji, some 30 years before this photo was taken, this gully was stabilized with vetiver hedgerows, which still remain where they were originally planted.

Stabilizing riverbanks and canal walls. Using vetiver grass to stabilize riverbanks and canal walls is another recommended practice. In an experiment in Tanzania, on the road to Dodoma, a road engineer used vetiver grass to protect the wing wall of a bridge on one side of the river and constructed the usual concrete wing wall on the other side. Some30 to 40 years later, the concrete wall had already collapsed into the river, and the bank it was protecting was eroded. On the other side, the vetiver grass was still holding the bank in perfect shape. Figure 7-35a shows how vetiver grass can be used to protect the river approaches to a bridge. The success of the Vetiver System is evident in the photo in Figure 7-35b, where newly planted vetiver hedges protect the approaches to a small bridge in El Salvador. During the floods of Hurricane Mitch in 1998, this bridge did not wash out.

Figure 7-35a. Vetiver hedges protect the river approaches to bridges.

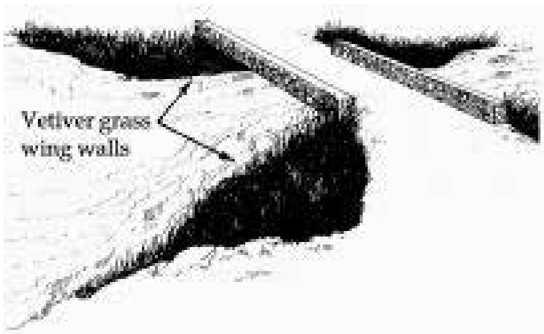


Figure 7-35b. In El Salvador, newly planted vetiver hedgerows protect the approaches to a small bridge.

Figure 7-36a shows how vetiver grass can be used to protect the banks of a major irrigation canal. In Bangladesh, as seen in the photo in Figure 7-36b, the canal has been stabilized with vetiver hedgerows for decades, and the plants do not invade the river or the fields behind the rows.

Figure 7-36a. Vetiver hedges protect irrigation canals.

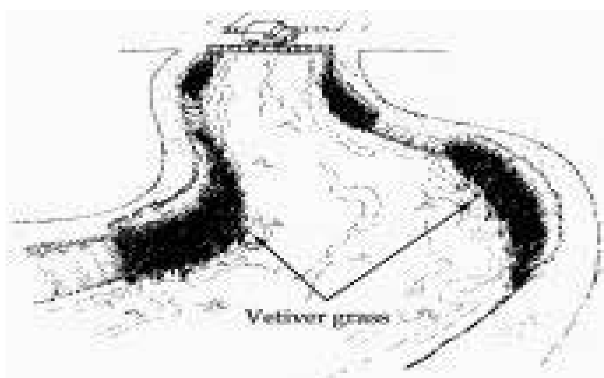


Figure 7-36b. In Bangladesh, vetiver hedgerows have stabilized this canal for decades.

The contour irrigation aqueducts that lead back from the main canal around the foothills to the upper reaches of a command area suffer from siltation and erosion as they wind their way around the slopes. The typical problem is depicted in the top illustration in Figure 7-37a: the concrete conduit is undercut by erosion at point A and fills with silt at point B. To overcome this problem, vetiver grass should be planted parallel to the upper and lower sides of the concrete conduit. As shown in the bottom illustration, the upper hedge will prevent silt from entering the canal, while the lower two hedges will prevent erosion and thereby keep the concrete structure from being undermined by rills or gullies.

Figure 7-37a. Vetiver hedges protect irrigation channels.

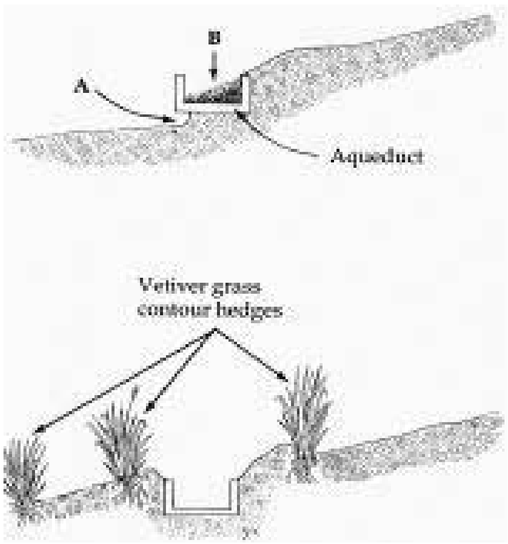


Figure 7-37b. On a sugar farm in Zimbabwe, a vetiver hedgerow protects an irrigation channel (behind the hedge), while other rows protect the drain.

On a sugarcane farm in Zimbabwe, as seen in the photo in Figure 7-37b, the left side top vetiver hedge is protecting an irrigation channel from silting up behind the hedge, while the other rows protect the drain from erosion and silting and help maintain its shape.

Protecting dams. A similar approach can be taken to protect dams. Small dams are silting up at an alarming rate throughout the world. Once they become filled with silt, they are of no further use—and in many cases there is no other site suitable for a new dam. If vetiver grass is planted around the sides of the dam, as shown in the top illustration in Figure 7-38a, the silt carried by runoff from the surrounding hills will be trapped before it reaches the dam. Vetiver hedges planted across the inlets (A) of small dams on intermittent streams will protect the dams from siltation. In time, these hedges will form stable terraces that can be used for cropping or tree planting. In the bottom illustration, vetiver has been planted on the walls of a dam to protect them from being worn down by rill erosion, a problem afflicting many unprotected earth dams around the world. To make it easier to spot seepage along the toe, or very bottom of dam walls and canal banks, vetiver should not be planted in those areas.

The photo in Figure 7-38b shows a small farm reservoir in India around which the farmer planted vetiver grass to protect the reservoir from wave action (lap erosion). The photo in Figure 7-38c shows a dam wall in Zimbabwe on which vetiver provides complete protection and stabilization.

Figure 7-38a. Vetiver hedges protect dams.

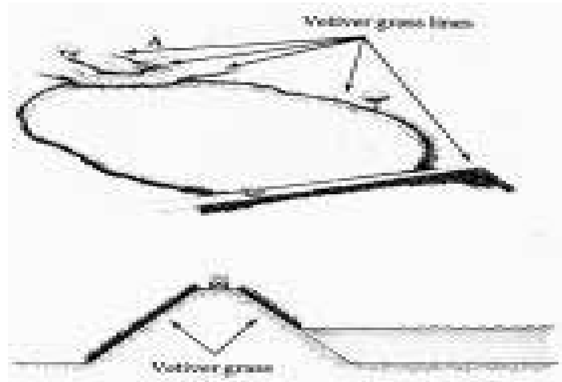


Figure 7-38b. Vetiver grass planted around the shore of a small farm reservoir protects the reservoir from wave action.

Figure 7-38c. In Zimbabwe, vetiver planted on the wall of a dam provides complete protection and stabilization.

Common applications. The versatile vetiver plant has numerous common applications as well. It makes good bedding for livestock, because it soaks up the urine and stays dry longer. Ultimately, it makes good compost. In countries with strong winds, vetiver grass hedges make good windbreaks to protect young fruit and timber trees. The grass when green also serves as a firebreak. Vetiver is used as mulch for tree crops and as thatch for roofs of houses, sheds, and shelters. (See the photo in Figure 7-39.) The grass is woven into baskets, and the leaf midribs and flower stems make excellent brooms.

Figure 7-39. In Zimbabwe, vetiver grass thatch is popular. With good thatching techniques, vetiver thatch will last for many years.

Management Tips

In the preface of the first edition of the handbook, we asked users to give us their views and share their experiences. Below are some of the responses we received.

General observations

- Well-grown vetiver hedges result in less runoff and improved groundwater supplies. Dry-season stream flow improves under the hedge system of in situ moisture conservation.
- In most instances on slopes of up to 5 percent, about 10 centimeters of silt is deposited behind the hedges annually.
- In addition to its use for soil and moisture conservation, vetiver is being used for fodder, thatch, mulch, livestock bedding, windbreaks, roadside protection, and brooms.
- Where hillside crop drainage is required—as in the case of tobacco ridges on a graded slope—vetiver hedges act as an excellent buffer against erosion if placed on the contour at fixed intervals on the hillside.
- Most vetiver plant roots grow straight down for at least 3 meters. Other roots will grow out into the field for up to 50 centimeters, but they do not significantly affect crop growth—probably because of the high moisture content of the soil associated with the hedge.
- Vetiver hedges take about three years to be fully effective under low rainfall conditions. If vetiver slips are planted 10 to 15 centimeters apart, the hedge will form more quickly. Even where gaps exist, interplant erosion does not seem to be a problem because the roots join together in the first year to form a subsurface barrier.
- Where vetiver is planted along the edge of terraces, forward-sloping terraces are better than backward-sloping terraces because less runoff is removed by the terrace back channels. Also because one can dispense with the back channel—and also in some instances the front channel, where constructed—more land will be available for cropping. The ultimate objective should be to dispense with terracing, where possible, through the use of vetiver hedges, so that the topsoil can remain relatively undisturbed.
- Vetiver has been observed growing under conditions ranging from 200 to 6,000 millimeters of rainfall annually and at 2,600 meters above sea level. It survives snow and frost (in tropical mountain areas) and grows on most types of soil. It obviously grows better where the soil is moist and fertile, but even under adverse conditions it grows extremely well compared with other grasses.
- In many countries vetiver has been infected with brown spot. The disease does not seem to have an adverse effect on its growth, however. A few instances of black rust have been observed but are not significant. In India the rust seems to be vetiver-specific and does not cross-infect other plants. In China stem borers have attacked vetiver, but in most cases the borer dies once it gets in the stem. Farmers generally are unconcerned and tend to respond by selecting plants that are more pest and disease resistant.
- Some early results from India, on both alfisols and vertisols, indicate that rainfall runoff was reduced from 40 percent to 15 percent (compared with the control), and silt loss was reduced from 25 tons per hectare to 6 tons per hectare (all for 2-year-old hedges on 2 percent slopes). The time to wilting in one demonstration on alfisols increased from 7 days to 20 when in situ moisture conservation measures were applied.
- An interesting technique observed in China was the plaiting, or interlacing, of vetiver leaves and stems from separate, neighboring plants to create a temporary barrier until the full hedge could be established.

- The cost of vetiver hedges depends on the availability and cost of planting material. In India the initial cost of hedge establishment is estimated at US$8 per 100 meters of hedge, US$6 of which goes for planting materials and other inputs. Once the live material, in the form of a hedge, is on the farm, the cost to produce new hedges is relatively low—it may be as little as US$2 per 100 meters. Under such conditions the economic rate of return is more than 100 percent. Where the slopes are less than 5 percent and the hedges are spaced about 40 meters apart, 250 meters of hedge is required per hectare at a cost of between US$5 and US$20. (See Table 7-3 at the end of this chapter.)

Selecting planting material

- In Karnataka, India, to date six cultivars have been identified. One cultivar selected over the years by farmers exhibits superior characteristics for hedge formation; fodder; and insect, disease, and drought resistance.
- When selecting material, choose plants that exhibit resistance to pests and diseases and that tiller well.
- Where winters are cold, select material that is more tolerant of cold temperatures.

Establishing nurseries

- Vetiver planted densely in large gullies can be used for replanting elsewhere. Gullies make good informal nurseries because often they are permanently moist and have conditions good for growth.
- Stem and root cuttings grown under plastic may be a cheap way of vegetative propagation.
- For optimum tillering, nurseries should be fertilized (150 kilograms per hectare of nitrogen) and irrigated (especially in very dry areas).
- Nursery plants should be cut back to about 30 to 50 centimeters to encourage tillering.
- The best nurseries seem to be in loamy sands to sandy-clay soils where the drainage is good and where it is easy to dig up the plants for transplanting. We have seen excellent nurseries (when well watered) in sandy areas near perennial rivers.

Field Planting

- As long as the vetiver is planted when the ground is wet, it can survive a long period of drought after planting.
- On very small farms and fields where land is scarce and where farmers are reluctant to plant across their fields, vetiver should be planted on the field boundaries.
- On non-arable lands that are heavily eroded, vetiver should be planted first in the gullies and around the gully heads. The material from the gullies can then be used for planting across the slopes in subsequent years.

- Gap filling is essential and should be done at the beginning of the wet season. The possibility of “layering” live stems across the gaps should be tried as a gap-filling measure.
- To encourage tillering and hedge thickening, the grass should be cut back to 30 to 50 centimeters after the first year. Cutting in the first year does not seem to have any incremental impact on tillering.
- Termite infestation (attacking dead material) can be controlled by applying 1 kilogram of benzene hexachloride (BHC) for every 150 meters of hedge line.
- Once the vetiver has established (one month after planting), plowing a small furrow immediately behind the vetiver hedge line helps to capture runoff and results in better growth of the plant.

Table 7-1. Slope, Surface Run, and Vertical Interval

Slope					Surface run[a]
Degrees	Percent	Gradient			(meters)
1	1.7	1	in	57.3	57.3
2	3.5	1	in	28.6	28.7
3	5.3	1	in	19.1	19.1
4	7.0	1	in	14.3	14.3
5	8.8	1	in	11.4	11.5
6	10.5	1	in	9.5	9.6
7	12.3	1	in	8.1	8.2
8	14.0	1	in	7.1	7.2
9	16.0	1	in	6.3	6.4
10	17.6	1	in	5.7	5.8
11	19.4	1	in	5.1	5.2
12	21.3	1	in	4.7	4.8
13	23.1	1	in	4.3	4.5
14	25.0	1	in	4.0	4.1
15	27.0	1	in	3.7	4.0
16	28.7	1	in	3.5	3.6
17	30.6	1	in	3.3	3.4
18	32.5	1	in	3.1	3.2
19	34.4	1	in	3.0	3.1
20	36.4	1	in	2.8	3.0
21	38.4	1	in	2.6	2.8
22	40.4	1	in	2.5	2.7
23	42.5	1	in	2.4	2.6
24	44.5	1	in	2.3	2.5
25	46.6	1	in	2.1	2.4
26	48.8	1	in	2.0	2.3
27	51.0	1	in	2.0	2.2
28	53.2	1	in	1.9	2.1
29	55.4	1	in	1.8	2.1
30	57.7	1	in	1.7	2.0
31	60.1	1	in	1.7	2.0
32	62.5	1	in	1.6	1.9
33	65.0	1	in	1.5	1.8
34	67.5	1	in	1.5	1.8
35	70.0	1	in	1.4	1.7

36	72.7	1	in	1.4	1.7
37	75.4	1	in	1.3	1.7
38	78.1	1	in	1.3	1.6
39	80.1	1	in	1.2	1.6
40	84.0	1	in	1.2	1.6
41	87.0	1	in	1.2	1.5
42	90.0	1	in	1.1	1.5
43	93.3	1	in	1.1	1.5
44	96.6	1	in	1.0	1.4
45	100.0	1	in	1.0	1.4

a. The figures for the surface run are based on a vertical interval (VI) of 1 meter. To use this table, multiply the surface run by the VI; for example, with a VI of 2 meters on a 70 percent slope, the surface distance between vegetative barriers = 2 x 1.7 = 3.4 meters.

Table 7-2. Cost of Land Treatment with Contour Hedges of Vetiver Grass by Slope Classification and Cost of Labor

(U.S. dollars per hectare)

Slope	Daily cost of labor					
(percent)	*$0.50*	*$1.00*	*$1.50*	*$2.00*	*$2.50*	*$3.00*
0–1	2.43	3.44	4.45	5.46	6.47	7.48
1–2	7.29	10.32	13.35	16.38	19.40	22.43
2–5	17.02	24.08	31.15	38.21	45.28	52.34
5–10	36.46	51.60	66.74	81.88	97.02	112.17
10–15	60.77	86.00	111.24	136.47	161.71	186.94
15–20	85.08	120.40	155.73	191.06	226.39	261.72
20–30	121.54	172.01	222.48	272.95	323.42	373.89
30–40	170.15	240.81	311.47	382.12	452.78	523.44
40–50	218.77	309.61	400.46	491.30	582.15	672.99
50–60	267.38	378.41	489.45	600.48	711.51	822.55
60–70	316.00	447.22	578.44	709.66	840.88	972.10
70–80	364.61	516.02	667.43	818.84	970.25	1,121.66
80–90	413.22	584.82	756.42	928.02	1,099.61	1,271.21
90–100	461.84	653.62	845.41	1,037.19	1,228.98	1,420.77

Note: Figures are based on a vertical interval of 2 meters.

8. Fifteen Years of Bioengineering in the Wet Tropics From A (*Acacia auriculiformis*) to V (*Vetiveria zizanioides*)

by Diti Hengchaovanich

About the Guest Author: *The author of this chapter, Diti Hengchaovanich, graduated in civil engineering from Chulalongkorn University, Bangkok, in 1967, and in 1969, received a master of engineering degree in geotechnical engineering from the Asian Institute of Technology (AIT). For 15 years he had been responsible for the remedial works on some 200 failed slopes in mountainous terrains with extremely erodible soils in regions prone to high and very intense rainfall in the humid tropics. He rigorously undertook civil engineering solutions, in combination with major bioengineering measures, which have proven to be effective both functionally and economically. Diti Hengchaovanich has written technical papers and shared his experiences at several international conferences. He also serves as a specialist consultant locally and internationally for slope stabilization and erosion control projects.—JG.*

The Problem

The Wet Tropics, or that part of them that is included in the Southeast Asian equatorial monsoon belt, is the region with the most intense and frequent rainfall incidences in the world. The annual precipitation is in excess of 2,000 millimeters per annum, rising to 6,000 millimeters in some exceptionally wet years. Highway and infrastructure projects constructed or founded on residual soils derived from the weathering of parent rock minerals are renowned for their rainfall-induced erosion problems, shallow mass movement or "slipping," and deep-seated instability problems (landslides) caused in the main by the removal of natural vegetation. Compounding the problem, some of these projects are located in mountainous or steep topography, where runoff is more rapid, accentuating the erosion and the destabilizing processes.

Vegetation (dead or alive) for erosion control and slope stabilization has been used since ancient times, usually based on past experience, observation, or empirical methods. The resurgence of the practice of using vegetation for erosion control in a more scientific and methodical manner began in the 1930s in Europe. Over the last decade, the practice has become more popular because of recent research into vetiver grass (*Vetiveria zizanioides*) stabilization systems, heightened awareness of the environmental issues leading to the availability of knowledge, and parameters lending credence to the designs.

In the Wet Tropics, "grassing" (including leguminous cover crops) by sodding/turfing or hydroseeding, together with planting of shrubs and trees, has been used for decades for slope protection with varying degrees of success. Grass or leguminous cover crops may be relatively good for slope protection, but because of their loose growth pattern and shallow roots, they may be ineffective for intense rainfall areas with highly erodible soils; hence, the use of trees with their deeper, stronger root networks to address the shallow mass movement problems. Many tropical tree species, however, have shallow root systems or inappropriate taproots that have little effect on soil stabilization. In some cases, the very weight of the trees can cause landslides in areas where the “toe slopes” have been destroyed by road construction.

The problem with using trees for stabilization is the interim period (2 to 3 years) before the establishment of the trees (even with fast-growing species such as *Acacia auriculiformis* or *A. mangium*) when the bare ground is still vulnerable to the forces of nature.

Vetiver (*V. zizanioides*), a plant classified as a grass, is unique in its ability to rapidly establish and stabilize soils with its deep, intense root system; therefore, over the last 5 years of experience with its use in the field, it has been suggested as a better means of stabilizing slips and landslides. The concept of using plants for erosion control is well accepted because they are effective, environmentally friendly, and aesthetically pleasing. Using plants, however, especially using their roots for reinforcing soils in the shallow movement zones (similar to the constructive method of “soil nailing/soil doweling”), has started to gain some ground because of research done by my colleagues and me.

The use of “dead vegetation” such as bamboo as a reinforcing element (akin to geogrids) to address the deep-seated instability problems of soils has recently been tried with initial success and is described later in this chapter.

Vegetation for Erosion Control and Slope Stabilization

Although the terms *erosion* and *stability problems* are fairly distinct, common usage tends to overlap because the problems are interactive. *Erosion* is the natural process whereby external agents such as wind or water remove soil particles. But it is erosion that leads to the *instability* of large areas of the watershed.

In the Wet Tropics, erosion is accentuated by heavy rainfall resulting in excessive runoff, which is responsible for the rills and gullies. Over time, these rills and gullies deepen and cause slopes to “over-steepen,” thus reducing their stability. Deep-seated problems can arise from this lack of stability, depending on the slope geometry, inherent soil strength, and ground or “pore” water characteristics. These are basically geotechnical/geological problems that have to be addressed by proper studies and analyses.

With a variety of computer programs now available for evaluating the stability of slopes or for determining their “factors of safety” against sliding or failures, such evaluations have become less tedious or laborious. But shallow-seated problems that lie in the 60 to 250 centimeters (cm) depth range do not lend themselves for such accurate computation with the available software. These depth zones present a chronic problem in the Wet Tropics with heavy rainfall and inherent highly erodible slope materials. It is now believed these problems of slope stability can be dealt with very effectively by the bioengineering measures described below.

Background. Over the millennia, nature has “designed” vegetation as a means for blanketing and stabilizing the soil surface. In the Wet Tropics, this vegetative blanket has evolved from rainforests comprising a complex multistrata canopy, with plants ranging from big trees to shrubs, creepers, and undergrowth to leaf litter, covering the organic humus-rich topsoils. In its natural state, the rainforest offers excellent overall protection. In light of the current awareness of environmental issues, the preferred option for addressing the above problems of erosion would be to go back to the solutions that nature had already provided before human intervention. Unfortunately, this option is no longer a possibility.

Control of surface movement by use of grasses and leguminous cover crops. The use of grasses and leguminous covers is fairly common in civil engineering or infrastructural works. In fact, it is stipulated in most standard specifications. The methods usually employed are seeding (manual or hydroseeding) and turfing/sodding. On occasions, geotextile mats (made from vegetative materials such as jute, coconut coir, or paddy straw) may be incorporated to render interim surface protection and serve as mulch before and after biodegradation.

Turfing is carried out using broad-leafed carpet grass (*Axonopus compressus*) because it is the most readily available. It is a relatively shade-tolerant grass that thrives in residual soils under high rainfall. In the highlands, the use of Guatemala grass (*Tripsacum andersonii*) has been noted with limited success because the grass is a vigorous colonizer, and elephant grass (*Pennisetum purpureum*) has been employed on a few projects and found to be fairly successful but short lived. Both of these species, however, are tall growing and soil specific; neither can be ranked as turf grasses. Turfing is traditionally the best method because it gives instant coverage, but turfing material is not always available because of heavy demand, lack of good nurseries, and labor shortages. As a result, it has been overtaken by hydroseeding on projects requiring mass production.

Hydroseeding is a relatively novel method for planting grass and legume seeds in Southeast Asia, although it has been used in America since before World War II. Basically, it is a method of embedding seeds onto the face of the slope by a slurry, jetted from a pump-equipped, truck-mounted mixing tank. The slurry normally comprises water, grass and/or legume seeds, fertilizer, fibrous mulch (paper), and tackifier (sticker). Hydroseeding technique is ideally suited for slopes with little or no access; steep slopes (especially cut slopes) more than 35 degrees, where normal turfing would be either difficult or impossible; or rocky or gravelly slopes with cracks and crevices, and being totally devoid of topsoils. It is a fast and efficient operation with 0.5 hectare being covered in an hour’s spraying. In the Wet Tropics, residual soils are rather acidic or sodic. Hence a soil ameliorant such as lime or gypsum may need to be applied to correct the pH and facilitate growth. Use of this additive increases the cost and inconvenience of this practice.

The most common grasses used for hydroseeding are signal grass *(Brachiaria decumbens)*; narrow-leafed carpet grass (*Axonopus affinis*); grasses imported from Australia, such as Bermuda grass (*Cynodon dactylon*) and Guinea/Hamil grass (*Panicum maximum*); and Ruzi grass (*Brachiaria ruziziensis*) produced in Thailand. Legume seeds commonly used are Centro (*Centrosema pubescens*), Calopo (*Calopogonium mucunoides*), and Puero (*Pueraria javanica*), all of which are widely used in the plantation sector as ground cover and a nurse crop for young rubber trees. In plantations throughout the tropics, they have been known for years as “covers.” One major problem the hydroseeding specialist faces is the purity and germination of the seed being used and the adaptability of the seed to the ecosystem in which it is to be used.

Because hydroseeding and turfing are successful in areas where the soil is not highly erodible (that is, it has some cohesion) and where they are not practiced in the midst of a heavy monsoon period, soil type and timing limit this method of erosion control.

Likewise, because grasses and legumes require time for growth and establishment before any benefit is obtained, the intervening period often necessitates the use of expensive synthetic or natural fabric to blanket the bare slopes. These geofabrics are marketed under trade names such as geojute (soil saver), fibromat, and geocoir to reflect their main components. These geofabrics act as mulch with the following functions: to absorb raindrop impact; to help conserve moisture; to hold seed and soil firmly in place; and to serve as minicheck dams, trapping seeds and soil particles and reducing water runoff. The biodegradable types also will add humus for establishing grass stands in 2 to 3 years when they disintegrate. ***[Book author's note:** All these interventions add greatly to the necessary labor inputs, the timeliness of the operation, and the total cost.—JG]*

***[Book author's note:** I think that hydroseeding is never a real success. Slips often occur because the plants used are too shallow rooted to stabilize steep cuttings, are often exotic and unsuited to the conditions, or are too specific in their soil requirements for sustained growth.—JG]*

Mitigation of shallow-seated instabilities (slips) by shrub and tree planting. Although grass can provide some slope protection when soil/climatic conditions are not extreme, its roots do not extend deeply enough into the soil (probably about 20 to 40 cm) to provide the grip and anchorage needed to prevent surface slip in the event of heavy, prolonged rainstorms. The residual soils in the Wet Tropics with their intrinsic lack of cohesion, when subject to fines (particles less than 0.2 millimeters in diameter) being washed out of the profile by rainwater, will see the collapse of the soil's structure and thus liquefaction or soil flow, leading to slipping.

On many highways, one often can see random patches of stone pitching and gunite (shotcrete/cement spray), which are conventional ways of rectifying work carried out for the shallow-seated or shallow mass movement problems. It is not unusual to see a repeat of these works in the form of costly repairs if the real root cause of the problems are not identified and solved initially.

In some cases, reconstruction is carried out by the earthwork method. Engineers have observed that if some timber stakes are hammered into the ground through the collapsed area, they will help hold up (or nail) the weak spot. The soil nail/doweling concept was not well known in 1985. Thus, we conceived of the idea of "wicker work" terracing, which could be considered as a modified form of contour wattle staking on the slope (Gray and Leiser 1982).

Basically, the technique involves the staking of timber posts, 30 x 75 millimeters x 1.5 meters long, into slopes along the contour with a vertical interval of 5 meters. The stakes, driven at 600 millimeters center-to-center spacing, are woven in between by means of bamboo cuttings obtained from adjacent hills. Fast-growing shrubs and trees are grown behind the stakes. The aim is to create hedgerows with the aid of stakes to minimize and block eroded sediments and to hold the slope up, pending the establishment of the shrubs and trees. Some 12 years later, on a visit to one of these staked areas, it was found that the site had turned into a mini-jungle because trees had already colonized the place. There was no trace of any slope failure or collapse to be seen. ***[Book author's note:** The cost of this practice is high.—JG]*

Later, Wright and Upadhyaya, at the Agricultural Research Service of the U.S. Department of Agriculture (USDA), discovered a unique fungal protein, which may be the primary glue (nicknamed "superglue") that holds soils together (Wright and Upadhyaya 1998). This protein is named *glomalin*, for Glomales, the scientific name for the group of common root-dwelling fungi that secrete the protein through hair-like filaments called hypha.

I have used various shrubs and trees on a number of highway slopes, including Mexican lilac (*Gliricidia sepium*), wild tapioca (*Glochidion wallichianum*), yellow wattle or acacia (*A. auriculiformis*), *A. mangium*, and *Eucalyptus camaldulensis*, together with some trials of *Leucaena leucocephala* on low land and *Anthocephalus chinensis* and *Duabanga grandiflora* for rocky slopes.

Mexican lilac is a leguminous plant normally used on cocoa plantations as a shade-provider, while wild tapioca grows in Malay villages. These plants are easy to grow simply by inserting cuttings into side slopes. They thrive on infertile, compacted material of the embankment. Because of its slender growth pattern, Mexican lilac does not uproot in strong winds, nor does it block sunlight to the grass or undergrowth. Wild tapioca, on the other hand, is a bushy shrub with a canopy capable of limiting raindrop impaction. It can grow on poor soils and withstand drought. Mexican lilac and wild tapioca are used together at a 3-meter vertical interval (VI) contour, spaced approximately 3 meters apart.

Root excavation conducted on these two plants revealed that Mexican lilac extended 5 meters along the slope inclines, and wild tapioca extended about 7 meters. Because wild boars, which are abundant in the locality, also like to feed on the wild tapioca, causing damage to the roots, we have eliminated this combination of plants from further trial.

We first used yellow wattle on roadside shoulders, toes, and platform areas, but it tends to shed a lot of leaves, which can be dangerous on the road surface. We then changed the species for this use to *A. mangium*, which grows fairly fast and sheds no leaves. Its seedlings can be produced easily in bulk at site nurseries. One of the drawbacks of *A. mangium* is that its branches are rather brittle and prone to snap in the event of strong winds. Hill stated that it produced substantial stem-flow, possibly even hundreds of liters a day during rain, resulting in local scouring (Hill, personal communication). Work by Zhao in China seems to suggest that at high rainfall intensities, drip from leaves is even more erosive than direct exposure to rain (Zhao 1996). This subject needs more research. Stem-flow from trees could be a major drawback to the whole philosophy of using trees to prevent erosion.

Even though acacia is fairly fast growing, it still takes at least 2 to 3 years for the trees to mature, establish, and become effective. Moreover, on steep slopes (transition zones between man-made and natural slopes), it is rather difficult to grow acacia.

We introduced vetiver grass (*V. zizanioides*) in 1994 as a trial to study its effectiveness in overcoming some of the deficiencies of the *Acacia* species.

Erosion control and slope stabilization with vetiver grass. In August 1993, with funding and support from the Public Works Department (PWD), Malaysia, we constructed four trial embankments to observe the field performance of vetiver hedges and to evaluate their potential use for engineering purposes.

Three months after planting, an exceptionally heavy monsoon hit Peninsula Malaysia, which caused numerous failures along major highways and hillside cuttings. We found, however, that slopes planted with vetiver grass hedges were not significantly affected, even after just 3 months from establishment. ***[Book author's note:** Vetiver grows exceedingly fast in the Wet Tropics.—JG]* In mid-April 1994, we conducted an excavation exercise to determine the rooting depth of vetiver (see Figure 16-21). We found that the massive root networks had reached a record depth of 3.6 meters after just 8 months of growth.

From these trial plantings we also observed that vetiver could grow rapidly to form a complete hedgerow able to trap runoff soil material. From the root depth monitoring exercise, it was evident that the roots managed to penetrate the harder stratum. They not only grew vertically, but some seemed to incline themselves, following the side slope profile. From the limited trials carried out, results appeared encouraging, indicating the tremendous potential of vetiver for slope protection and stabilization work.

In response to a number of engineers' calls for more parameters for a wide range of vegetation categories, so that they could plug into them in their computer designs, my colleague and I decided to carry out some experiments for that purpose.

One of the experiments involved a test on the gain in shear strength in soils by the presence of vetiver roots versus identical soils that were root free. By conducting large-scale direct shear tests at an embankment at varying depth levels, the increase in shear strength can be determined. In the process of evaluating a plant species as a component of slope stabilization, it is also important to determine the root tensile strength properties, because when a plant root penetrates across a potential shear surface in a soil profile, the distortion of the shear zone directly resists shear, while the normal component increases the confining pressure on the shear plane. The tensile strength of a root is defined as the ultimate root tensile force divided by the cross-section area of the unstressed root (without bark, because bark has weaker strength properties).

For determining root tensile strength, we sampled mature root specimens from 2-year-old vetiver plants grown on an embankment slope. We tested the specimens in fresh condition, limiting the time elapsed between the sampling and testing to 2 hours maximum. We connected the unbranched and straight root samples (about 15 to 20 centimeters long) vertically to a hanging balance via a wooden clamp at one end, while fixing the other end to a holder that we pulled down manually until the root failed. At failure, we monitored the maximum load.

The mean tensile strength of vetiver roots varies from 180 to 40 MPa (megapascals) for the range of root diameter 0.2~2.2 millimeters. The mean tensile strength is about 75 MPa at 0.7~0.8 millimeters root diameter, which is the most common diameter class for vetiver roots. This is approximately equivalent to 1/6th (one-sixth) of the ultimate tensile strength of mild steel.

Compared to many hardwood species, the average tensile strength of vetiver roots is very high. Even though some hardwood roots provide higher tensile strength values than the average tensile strength values of vetiver roots in the root diameter class of 0.7~0.8 mm, their average tensile strength values are lower since the average root diameter is much higher than that of vetiver roots. (See Table 8-1.)

Table 8-1. Tensile Strength of the Roots of Some Plants

Botanical name	Common name	Tensile strength (MPa)
Salix	Willow	9-36*
Populus	Poplar	5-38*
Alnus	Alder	4-74*
Pseudotsuga	Douglas fir	19-61
Acer sacharinum	Silver maple	15-30*
Tsuga heterophylia	Western hemlock	27*
Vaccinum	Huckleberry	16*
Hordeum vulgare	Barley	15-31*
	Grass, forbs	2-20*
	Moss	2-7kPa*
Vetiveria zizanioides	Vetiver grass	40-120 (Average 75**)

* After Wu (1995).
** After Hengchaovanich and Nilaweera (1996).

Moreover, because of its dense massive underground root system, it offers better shear strength increase per unit fiber concentration (that is, 6-19 kPa—kilopascals—per kilogram of root per m3 of soil) compared to 3.2~3.7 kPa per m3 of soil for tree roots. For a detailed account of these tests, see Hengchaovanich and Nilaweera (1996).

Concurrent with these tests, we also carried out some preliminary experiments to affirm the evapotranspiration and soil moisture depletion characteristics of vetiver. We anticipated that vetiver would be able to deplete moisture in the soil, thus lowering pore water pressure and thereby increasing suction under partially saturated conditions. Apart from the mechanical reinforcement by roots, this situation would have beneficial effects on slope stability from the geotechnical point of view.

With the above results, one can say that vetiver roots behave like “living” soil nails or soil dowels. (Soil nails or dowels are now being widely used, at great cost, as construction methods for steep slope stabilization processes.) The advantage of the living vetiver soil nails or dowels is the absence of problems associated with long-term corrosion of metallic nails. In fact, the effects of vetiver even improve with the passage of time.

While the dense underground root webs offer shear strength increase to soils, resulting in slope stability enhancement, the upper part of vetiver, or the stiff stems, act as a living barrier to trap silt in the erosion control process. Because of its rapid and vigorous growth rate in the humid tropics, vetiver can form a dense hedgerow, if planted in that pattern, in just 3 to 4 months and is capable of slowing down rainfall runoff, distributing it uniformly and filtering it, and trapping eroded sediments at the hedge face. As an extra benefit, the hedgerow adjusts itself in tandem with trapped silt on the up slope, thus ensuring that it will never be buried and die off. A number of studies have been conducted on the erosion control properties of vetiver that show its silt-trapping capabilities being 6 to 35 times greater than that of other grasses or plants. For more information, visit the Web site maintained by The Vetiver Network: www.vetiver.org.

Another salient feature of the vetiver grass root is its power of penetration. In research conducted by Chalothorn, vetiver was found to break through hardpans as thick as 15 centimeters, with the root extending down to 74 centimeters below ground level (Chalothorn et al. 1998). In other words, it is a “breakthrough through breaking through” (Chomchalow and Henle 1997).

On slopes underlain with weathered rock and boulders, the penetrating vetiver roots will provide anchorage by root tendon action. Coupled with soil superglue mentioned earlier, this vegetative method should go toward enhancing slope stability even further.

Use of bamboo strips as reinforcing elements for deep-seated instability. Long before the reinforced soil concept popularized by Henri Vidal became universally accepted, ancient people had already used vegetation (albeit dead material) to enhance slope stability (Vidal 1966; Yamanouchi 1986). For example, the Great Wall of China, where twigs of tamarisks were used; the ziggurats in Mesopotamia, where reeds were used; and the use of willows to stabilize earth dykes, by an engineer with the name of Pan, in China during the Ming Dynasty (Barker 1994). Even as recently as a few decades ago, according to an anecdotal account, tin miners in Malaysia always included grass straw in mine tailings for stabilization when constructing spoil bunds.

By incorporating tensile elements into the soil, which naturally lacks tensile strength, a new composite construction material is created whose mechanism of reinforcement is derived from the generation of frictional forces between the soil and the reinforcement (Ingold 1982).

Reinforced soil structures, constructed because of the need to steepen side slopes to overcome space restraint, are normally very costly. The high costs can be attributed to the cost of the reinforcing elements, either imported stainless steel or synthetic polymers. Costs can be substantially cut if local materials can be used in lieu of the imported ones. Bamboo, for example, is an abundantly available, replenishable material that was used to substitute steel because of acute shortages during World War II. Even today in Thailand, many low-cost village road slabs are still built using bamboo matting instead of steel mesh.

Bamboo as a material possesses a very high strength to weight ratio, with its tensile strength of 265~388 MPa nearing that of mild steel at 480 MPa (Abang Abdullah and Abang Abdulrahim 1984). One of the chief drawbacks in using bamboo as an engineering material is its absence of long-term durability (if not properly treated by chemicals or completely encased in concrete, it is prone to attacks by fungi, insects, and the like) and its variability because of nonhomogeneity and anisotropy, being a naturally occurring and not manufactured material.

Using proven preservative techniques applied to timber piles that have been long lasting (> 50 years—Low, personal communication) and when designing reinforced embankments using bamboo, generous allowance is made in the calculations when applying the tensile forces that the bamboo strips will be expected to withstand (to account for variability). Steep embankments using bamboo reinforcement, à la geogrid, can be calculated, designed, and constructed.

Six steep, bamboo-reinforced embankments, with side slopes varying from 1:1.2 to 1:0.85 (v:h), have been formed successfully and, for more than 2 years, have been open to service on an expressway in Malaysia, with excellent performance at considerably lower costs than the conventional reinforced walls. For slope protection, vetiver and geojute laid in between hedgerows and creeping legume such as *Arachis pintoi* and *A. glabrata* are planted, which ensures a good outer armor for the reinforced soil block.

Discussions and Conclusions

Once a slope is well designed geotechnically with appropriate factors of safety, it becomes necessary that slope protection be properly implemented to ensure long-term stability, especially for those high rainfall areas faced with highly erodible soil materials, such as those in the Wet Tropics.

Two approaches whereby long-term stability can be implemented are (1) the conventional “hard” or “inert” approach favored by the conservative engineers: using shotcrete/gunited surface, stone pitching (mortared riprap), or wire mattresses (gabions), which are very costly; or (2) the “soft’’ or “green” approach, which besides being much less expensive, is aesthetically pleasing and environmentally friendly.

For the green, or bioengineering, solution, an engineer must be judicious in selecting which measure to employ to suit one’s need based on climate, soil types, and budgetary constraints. For example, during fairly dry weather conditions, with the soil being relatively hard and cohesive and assuming a nursery with good turf is available in the vicinity, it may suffice just to have turfing as slope protection, with decorative shrubs thrown in for landscaping or beautification purposes, budget permitting.

Or in extreme conditions, on steep slopes where soils are highly erodible, the rainfall is copious, and time is of the essence (a constructed slope can collapse in no time), vetiver planting should be seriously considered. On the other hand, if deep-seated stability is required of an embankment, then an inexpensive reinforced soil wall using treated bamboo as a reinforcing element could be recommended.

In using a bioengineering approach, one must remember that it is a hybrid or cross-disciplinary approach and that one is dealing with living things that can wilt or perish. Therefore, we highly recommend that one consult with or seek the involvement of an agriculturist; otherwise, the scheme will fail for incorrect or improper implementation and will give bioengineering a bad name.

On the other hand, because the plant is being called upon to perform engineering functions that sometimes are quite extreme, it too has to be subjected to stringent specifications that can be enforced through good quality control procedures just like other engineering materials.

In addition, like all living things, plants need time to grow, mature, and establish before they can truly function. The plants also require some maintenance so that the functioning is sustainable. A good maintenance program that includes steps such as fertilizing, watering, and weeding, depending on the type of plants one is dealing with, is essential, especially for expensive road construction.

With good design during the planning stage, careful selection of quality planting materials that meet specifications, and correct planting and maintenance techniques, it can be confidently said that good results will be achieved with the full potential of the plants being exploited.

9. Environmental Protection and Land Rehabilitation

This chapter is based on a number of articles published and conference papers presented by Paul Truong, who is the leader of the Bio-Engineering and Land Rehabilitation Group of the Queensland Department of Natural Resources, Brisbane, Australia. During the past 12 years, he has conducted extensive research and development, as well as application, of the Vetiver System in erosion and sediment control, and in land rehabilitation in tropical and subtropical Australia, Asia, and Africa. His pioneering research on vetiver grass tolerance to adverse conditions and heavy metal toxicities has established the benchmark for Vetiver System applications in toxic wastes and mine rehabilitation, for which he has won several Vetiver Network awards.

Contamination of the environment by urban wastes and by-products of rural, industrial, and mining industries, particularly in the rapidly developed economies of developing countries, is a worldwide concern. Most of the toxins responsible for the contamination contain high levels of chemicals and heavy metals, which can affect flora, fauna, and humans living in the area of the contaminated sites, or downstream from them.

Rehabilitating Landfills and Contaminated Lands

Old landfills and industrial waste dumps, such as tanneries and electrolytic factories, usually are contaminated with heavy metals such as arsenic (As), cadmium (Cd), chromium (Cr), lead (Pb), mercury (Hg), and zinc (Zn). Because these heavy metals are highly toxic to humans, the movement of these metals through the landfill and off site must be controlled.

The Queensland Department of Natural Resources (QDNR) has used vetiver grass (*Vetiveria zizanioides*) hedges successfully for erosion and leachate control at an old landfill site near Brisbane. This landfill has caused great concern in the local community because contaminated materials and leachate from the landfill polluted adjacent ground and watercourses. Several attempts have been made in the last 20 years to rehabilitate the fill's side slopes (70 percent) with local vegetation, but those attempts have failed.

Paul Truong carried out rehabilitation work by planting vetiver rows on the side slopes for erosion control. For leachate control, he planted vetiver en masse at the toe of the slope where leachate appeared.

Although the landfill was contaminated, vetiver established easily and grew well with nitrogen (N) and phosphorous (P) applications at planting time. The slopes were completely stabilized within 12 months and local vegetation established naturally between the hedgerows. At the same time, leachate was reduced substantially during the wet season and was eliminated during the dry season. When the slope was stabilized, native trees and shrubs were planted to complete the rehabilitation work. When used in this application, vetiver acts as a nurse plant.

On the same principle, thick stands of vetiver have been used in Australia to soak up subsurface effluent drained from septic tanks and intensive animal operations such as piggeries, cattle feedlots, and dairy farms.

Rehabilitating Mining Wastes

Tailings and overburden resulting from mine processing often contain high levels of toxic substances, including heavy metals.

Truong used vetiver successfully to rehabilitate coal mine tailings in Queensland. The tailings substrate was saline, highly sodic, and high in heavy metals, but it was extremely low in N and P.

By adding mulch and fertilizers together, he observed the growth of vetiver increase by 20 tonnes per hectare, almost 10 times higher than other species growing in the area.

Old gold mine tailings are often extremely acidic (pH 2.5 to 3.5) and low in plant nutrients. Revegetation of these tailing sites is not only difficult, but it is expensive because the bare soil surface is highly erodible. Mine tailings are often the source of contaminants such arsenic, affecting the local environment both above the ground and under ground. Truong achieved good establishment of vetiver on this hostile substrate with appropriate applications of lime and fertilizer.

Purifying Polluted Water

Chinese research showed vetiver has the capacity of reducing soluble N by 74 percent after 5 weeks and soluble P by 99 percent after 3 weeks. These findings indicate that vetiver has a great potential for purifying eutrophic water. Nitrogen and phosphorus are the two main elements that pollute water. Research conducted in Thailand has shown that the Vetiver System could absorb a substantial amount of Cd, Hg, and Pb in wastewater.

Controlling algal growth. Throughout the world, algal growth in rivers and dams is a major concern. Soluble N and particularly P are usually considered to be the key elements causing water eutrophication leading to the blue-green algal growth of inland waterways and lakes. The removal of these elements by vegetation is the most cost-effective and environmentally acceptable method of controlling the algae.

Chinese researchers have shown that vetiver grass can remove dissolved nutrients and reduce algal growth within 2 days under experimental conditions. Therefore, the Vetiver System can be used as a very effective control of water infested with blue-green algae. The Chinese researchers also found that under such a rich source of available nutrients, vetiver produced an enormous biomass, from 177 to 354 tonnes per hectare dry matter in 6 months. This biomass is capable of removing large quantities of nitrogen and phosphorus in polluted water areas.

Controlling Pollution Caused by Effluent Disposal

Effluent from sewage and septic treatment plants is high in nutrients, and unless these contaminants are effectively removed or contained, they become a major source of impurities in the local environment. Truong has used vetiver effectively in reducing and containing effluent from a complex of septic tanks on a holiday camp in Queensland, Australia.

Managing intensive animal farms. Piggeries, dairy farms, and cattle feedlots produce effluent high in nutrients and are a major source of pollution of the local environment. In Australia, Truong has used the Vetiver System to trap coarse materials from these farms on dry land and also to remove N and P in effluent ponds. In fact, the Vetiver System is now the major component of the environmental management plan for a very large piggery (12,000 sows) in southern Queensland.

Rehabilitating Fruit Trees and Orchards

In low rainfall regions of Asia and Africa, which are exposed to the threat of severe erosion and, in many cases, are abandoned by farmers, vetiver hedges, when planted either in long rows or semicircles just down hill of fruit trees, have not only stabilized these areas but have brought them back into production with good yields of fruit and nuts. In 1995, using the same principle, P. K. Yoon established vetiver hedges successfully on an almond farm in Spain.

Stabilizing Infrastructure

The main causes of steep slope instability are uncontrolled runoff leading to surface erosion and structural weakness of the slope. While surface erosion often leads to rills and gullying, structural weakness will cause mass movement leading to mudslides or landslips (landslides).

Because of its deep and extensive root system, vetiver is highly successful at penetrating difficult soil profiles and pinning (or "nailing") soils to steep slopes. Thai researchers have excavated the roots to a depth of 6 meters straight down into the ground. Trials conducted by Diti Hengchaovanich showed that the mean tensile strength of vetiver roots is equivalent to approximately one-sixth that of mild steel. The results of these tests indicate that vetiver roots are as strong as, or even stronger than, the roots of many hardwood tree species that have been used by engineers and have proven positive for root reinforcement on steep slopes.

In a soil block shear test, Hengchaovanich also found that root penetration of a 2-year-old vetiver hedge with 15-centimeter plant spacing can increase the shear strength of the soil in an adjacent 50-centimeter-wide strip by 90 percent at 0.25 meter depth.

Malaysian road engineers also observed that vetiver can grow vertically on slopes steeper than 150 percent (100 percent slope 1:1 = 45° degrees). It is faster growing and its roots impart more reinforcement than any other plant, making it a better candidate for slope stabilization. Another less well-known characteristic that sets vetiver roots apart from other tree or grass roots is its power of penetration and the extreme density of its roots. The innate strength and vigor of the roots enable them to penetrate through difficult soil, hardpan, or rocky layers with weak spots. They have even managed to punch through asphaltic concrete pavement. Hengchaovanich et al.

have observed that vetiver roots basically behave like living soil nails or dowels of 2 to 3 meter depth commonly used in a "hard approach" to slope stabilization work.

In Spain, P. K. Yoon established vetiver successfully under drip irrigation at Lorca (39° N. Lat.) and El Chopillo (38° N. Lat.), where the temperatures range from -14°C in winter to 47°C in summer. Once established, vetiver has grown well without further irrigation and has effectively stabilized a 1.5:1 (65 percent) highway batter. Excavation showed that vetiver roots reached down to between 1.7 and 2.1 meters after only 9 months of growth. These results indicate that with initial irrigation vetiver can be established and continue to grow under these extreme temperatures, while moisture conserved from the winter rain proved adequate for active growth during the summer months.

In China, many examples show that vetiver's strong, fibrous root system penetrates and binds the earth to a depth of up to 3 meters and can withstand the effects of tunneling and cracking. Vetiver quickly forms a dense, permanent hedge and, therefore, is an excellent plant for road embankment stabilization. In fact, it is 90 percent cheaper using vetiver grass as a bioengineering technique for embankment stabilization than using conventional engineering methods. Because these costs are relative, similar savings can be expected in other parts of the world.

Rehabilitating Arid Land and Desert Areas

As explained before, when planted in a single row no less then seven "slips" to the meter, vetiver plants will form a hedge, or living porous barrier, which slows and spreads runoff water and traps sediment. As water flow is slowed down, its erosive power is reduced, and at the same time, the hedges allow more time for water to infiltrate to the soil, while eroded material is trapped. Therefore, an effective hedge will reduce soil erosion, conserve soil moisture, and trap sediment on site.

Vetiver can improve the rehabilitation of degraded arid lands and the reclamation or control of desertification in the following five ways.

1. Spreading and improving infiltration of runoff water. Revegetation of degraded arid land and desert fringes does not occur naturally, mainly because of (a) the loss of surface water, which occurs because of surface sealing impinging on water infiltration, and (b) the high rate of runoff, which occurs because of the exposure of subsoil or surface crusting resulting from overgrazing or wind erosion. The excessive runoff rapidly fills the drainage network and is lost from the area where it is needed most for the rehabilitation process.

Appropriately laid out vetiver hedges will slow and spread runoff water that is concentrated in depressions and gullies, filling them with silt and slowly leveling the land. Runoff will then have more time to infiltrate and move deeper to the subsurface profile, where it is less likely to be lost from surface evaporation, and to recharge aquifers.

Over time this trapped soil moisture will further improve the soil structure and provide a more favorable environment for revegetation either by introduced plants or by naturally germinating native plants.

2. Diverting and concentrating water. When planted with a slight fall (0.2 to 0.5 percent), vetiver hedges can become effective diversion structures for collecting and diverting water to protect critical areas such as gully heads or to concentrate runoff water to areas in which rehabilitation is a top priority or to a recharge catchment to improve the groundwater supply.

3. Trapping sediment. Silt fans formed from the trapped sediment, resulting from both water and wind erosion, are important sites for revegetation because (a) the soil is lighter in texture and is often more sandy, which gives it a higher rate of water infiltration so it is more efficient in conserving soil moisture, particularly following light rain; (b) it is often more fertile than the surrounding soil because it has benefited from filtered and deposited organic matter; and (c) it is also a rich source of seed from plants that are endemic to the region, which is an important point in the revegetation of an arid zone.

Experience in Australia and around the world shows that these silt deposits are the first colonized by local plants or sown species. Because these deposits extend up slope with time, the revegetation process continues to spread naturally.

4. Providing shade. Shade often is overlooked as an important factor for the success of revegetation in the hot and dry climates of arid and desert fringe environments. In South Africa, kimberlite, the waste rock from diamond mining, is black, and in the full sun of summer, temperatures in excess of 55°C have been recorded on the rock's surface. Under these conditions very few plants will establish from seed.

Mark Berry, from Anglo-American Mines in South Africa, has established vetiver successfully on kimberlite under irrigation. Moreover, Berry found that in areas next to certain hedges, grasses and other plants have established voluntarily, especially plants that were located mostly next to hedges that provided good shade to the seedlings, indicating that vetiver hedges are able to protect young seedlings from the hot sun.

In Australia, on the Mitchell Grass Downs in Central Queensland, graziers have shown that vetiver hedges provide good shade for sheep on the treeless grassland in the tropics, where heat stress can reduce lambing up to 30 percent. Graziers in these areas call vetiver grass *magic grass* because of its ability to withstand harsh conditions and yet provide useful shade for animals.

When shading is required, graziers should plant vetiver hedges in the general north-south direction to maximize the shading benefit.

5. Protecting soil from wind erosion and plants from sandblasting and sand drift. Strong winds in arid and desert zones are often detrimental to plant growth, eroding surface soil, drying up soil moisture, and physically damaging plants, particularly seedlings. In China, Xia Hanpin has used vetiver hedges to protect tree crops from sand blasting and sand drift in the coastal dunes. Farmers on Pintang Island in southern China used vetiver hedges to protect their vegetable crops and young orchard trees from sand blasting.

Conclusions

Environmental protection. Many countries have used the Vetiver System effectively for environmental protection purposes. In many ways, its success depends wholly on the establishment phase. Once the Vetiver System is established successfully, it will provide a low-cost, natural method of environmental protection, particularly for rehabilitating contaminated lands.

Suitability of vetiver for rehabilitating arid and fringe desert zones. With appropriate applications, vetiver can either overcome or improve the hostile environment of the desert fringe zones. It has had an enormous effect in rehabilitating arid and desert fringe areas in Iberia (Spain). Results from Lorca, in southern Spain, show that vetiver hedges, once established, can survive the harsh conditions, relying on subsoil moisture stored during winter for its summer growth.

Although frost and cold temperatures will stop vetiver growth during the winter, vetiver hedges remain as effective, although dormant, barriers to naturally level the land by spreading runoff water and to conserve the rain that has fallen in the area before it is lost as runoff. When the soil temperature rises in summer, vetiver growth will resume, using subsoil moisture, without competing with the newly established species on the silt fans that feed at shallower levels.

***[Book author's note:** In extremely dry areas where it is essential to use the land or to simply stop erosion, vetiver hedges can be planted initially in the bottom of wide "V" ditches created by a road grader on an averaged contour (evened out—no sharp curves). After the land is "V" ditched, the potted plants are held in a nearby nursery, ready for planting. When the rains start, the runoff pours into the "V" ditch filling it to a depth of 30 centimeters. The vetiver is planted into this water. (It doesn't matter if it is planted under water; it will survive.) Once these hedges are established, they will harvest their own water.]*

Because of its deep-rooting and noncompetitive nature, vetiver should be considered a pioneer plant. It is planted to modify the harsh environment so that indigenous plants can establish naturally. Because of its unique characteristics, vetiver can improve extremely hostile conditions by conserving soil moisture, stopping soil erosion by both water and wind, and trapping eroded soil, organic matter, and seeds. The information reported in this chapter is not mere conjecture; it is the result of field work under extremely difficult conditions. The results achieved here have never been possible before with any other techniques, either biological or mechanical.

10. Vetiver Grass Technology for Mine Tailing Rehabilitation

by Paul Truong

***About the Guest Author:** Paul Truong's powers of observation have led him to experiment with vetiver's innate ability to handle harsh environments and to apply this ability to the problem of handling industrial wastes. The application of his research results for rehabilitating the hideous scars on the landscape and the threat of poisonous pollution that mine dumps and mine tailings present, detailed below, are based on the results and the success he and his team in Queensland, Australia, have had in this field.—JG*

(Disposal of industrial waste has become such a lucrative business that international crime syndicates see it as a way to make millions of dollars; they pay off unsuspecting politicians in small island countries and dump the waste in their back yards. This practice must be recognized and stopped by an international law, if need be.—JG)

Abstract

Vetiver Grass Technology (VGT) was first developed for soil and water conservation in farmlands. While this application still plays a vital role in agricultural lands, vetiver grass's unique morphological, physiological, and ecological characteristics have a key role in the area of environmental protection.

Unique morphological characteristics include a massive, finely structured, deep root system capable of reaching 3 to 4 meters in the first year. In addition, vetiver has tolerance to extreme climatic variations such as prolonged drought, flood, submergence, and extreme temperature. It also has tolerance to a wide range of soil pH, from 3.0 to 10.5, and is highly tolerant of soil salinity, sodicity, acidity, aluminum and manganese toxicities, and heavy metals such as arsenic, cadmium, chromium, nickel, lead, zinc, mercury, selenium, and copper in the soil.

In Australia, vetiver has been successfully used to stabilize mining overburden and highly saline, sodic, magnesic, and alkaline (pH 9.5) tailings of coal mines and highly acidic (pH 2.7) and high arsenic tailings of gold mines.

In South Africa, vetiver has been used effectively to stabilize/rehabilitate "slimes dams." Rehabilitation trials at de Beers diamond mine's slimes dams confirm that vetiver can survive in very harsh environments where the surface temperature of black kimberlite exceeds 55°C. Wastes and slimes dams from platinum and gold mines have also been successfully rehabilitated with vetiver.

Introduction

There have been increasing concerns in Australia and throughout the world about contamination of the environment by by-products of rural, industrial, and mining industries. Most of these contaminants are high levels of heavy metals, which can affect flora, fauna, and humans living in the vicinity of, or downstream from, the contaminated sites. Table 10-1 shows the maximum levels of heavy metals tolerated by environmental and health authorities in Australia and New Zealand.

Concerns about the spreading of these contaminants have resulted in strict guidelines being set to prevent the increasing concentrations of heavy metal pollutants. In some cases, industrial and mining projects have been stopped until appropriate methods of decontamination or rehabilitation have been implemented at the source.

Methods used in these situations have been to treat the contaminants chemically, bury them, or remove them from the site. These methods are expensive and at times impossible to carry out, because the volume of contaminated material is very large, such as with gold and coal mine tailings.

If these wastes cannot be economically treated or removed, then off-site contamination must be prevented. Wind and water erosion and leaching are often the causes of off-site contamination. An effective erosion and sediment control program can be used to rehabilitate such sites. Vegetative methods are the most practical and economical; however, revegetation of these sites is often difficult and slow because of the present hostile growing conditions, which include toxic levels of heavy metals.

Table 10-1. Investigation Thresholds for Contaminants in Soils (ANZ, 1992)

Heavy Metals	**Threshold ($mgKg^{-1}$) Environmental***	**Health***
Antimony (Sb)	20	-
Arsenic (As)	20	100
Cadmium (Cd)	3	20
Chromium (Cr)	50	-
Copper (Cu)	60	-
Lead (Pb)	300	300
Manganese (Mn)	500	-
Mercury (Hg)	1	-
Nickel (Ni)	60	-
Tin (Sn)	50	-
Zinc (Zn)	200	-

*Maximum levels permitted, above which investigations are required.

Because of its unique morphological and physiological characteristics, vetiver grass (*Vetiveria zizanioides* L.), which has been widely known for its effectiveness in erosion and sediment control, has also been found to be highly tolerant of extreme soil conditions, including heavy metal contamination (Truong and Baker 1998).

This chapter highlights research results that show the wide-ranging tolerance of vetiver to adverse conditions and heavy metal toxicities. It also highlights field applications in Australia and South Africa, where vetiver grass is highly effective in rehabilitating mining waste, particularly contaminated tailings. All the research and applications reported in this chapter were conducted using the genotype registered in Australia as 'Monto' vetiver; but DNA typing has shown that 'Monto' is genetically identical to most non-fertile genotypes of *V. zizanioides* such as 'Sunshine' (USA), 'Vallonia' (South Africa), and 'Guiyang' (China) (Adams and Dafforn 1997). Therefore, the following results can be applied with confidence when these cultivars are used for mine rehabilitation.

Tolerance to Adverse Soil Conditions

Studies show that vetiver grass has a tolerance to adverse soil conditions such as high acidity, manganese and aluminum toxicity, soil salinity, alkalinity, and sodicity.

Tolerance to high acidity and manganese toxicity. Experimental results from glasshouse studies show that, when adequately supplied with nitrogen and phosphorus fertilizers, vetiver can grow in soils with extremely high acidity and manganese. Vetiver growth was not affected and no obvious symptoms were observed when the extractable manganese in the soil reached 578 $mgKg^{-1}$, the soil pH was as low as 3.3, and plant manganese was as high as 890 $mgKg^{-1}$. Bermuda grass (*Cynodon dactylon*), which has been recommended as a suitable species for acid mine rehabilitation, has 314 $mgKg^{-1}$ of manganese in plant tops when growing in mine spoils containing 106 $mgKg^{-1}$ of manganese (Taylor, Ibeabuchi, and Sulford 1989). Therefore, vetiver, which tolerates much higher manganese concentrations both in the soil and in the plant, can be used for rehabilitating lands highly contaminated with manganese.

Tolerance to high acidity and aluminum toxicity. Results of experiments in which high soil acidity was induced by sulphuric acid show that, when adequately supplied with nitrogen and phosphorus fertilizers, vetiver produced excellent growth even under extremely acidic conditions (pH = 3.8) and at a very high level of soil aluminum saturation percentage (68 percent). Vetiver did not survive an aluminum saturation level of 90 percent with a soil pH = 2.0; although a critical level of aluminum could not be established in this trial, observation during the trial indicated that the toxic level for vetiver would be between 68 percent and 90 percent (Truong 1996a; Truong and Baker 1996). These results are supported by recent works in Vanuatu, where vetiver has been observed to thrive on highly acidic soil with an aluminum saturation percentage as high as 87 percent (Miller, D., personal communication).

Tolerance to high soil salinity. Results of saline threshold trials show that soil salinity levels higher than $EC_{se} = 8\ dSm^{-1}$ would adversely affect vetiver growth, while soil ECse values of 10 and 20 dSm-1 would reduce yield by 10 percent and 50 percent respectively. These results indicate vetiver grass compares favorably with some of the most salt-tolerant crop and pasture species grown in Australia. (See Table 10-2.)

Table 10-2. Salt Tolerance Level of Vetiver Grass
Compared with Some Crop and Pasture Species Grown in Australia

Species	Soil EC_{se*} (dSm^{-1})	
	Saline Threshold	50% Yield Reduction
Bermuda grass (*Cynodon dactylon*)	6.9	14.7
Rhodes grass (C.V. Pioneer) (*Chloris guyana*)	7.0	22.5
Tall wheat grass (*Thinopyron elongatum*)	7.5	19.4
Cotton (*Gossypium hirsutum*)	7.7	17.3
Barley (*Hordeum vulgare*)	8.0	18.0
Vetiver (*Vetiveria zizanioides*)	8.0	20.0

*Saturation extract

In an attempt to revegetate a highly saline area (caused by shallow saline groundwater), a number of salt tolerant grasses—vetiver, Rhodes (*Chloris guyana*), and saltwater couch (*Paspalum vaginatum*)—were planted. Negligible rain fell after planting, so plant establishment and growth were extremely poor; but following heavy rains during summer (9 months later), vigorous growth of all species was observed in the less-saline areas. Among the three species tested, vetiver was able to survive and resume growth under the higher saline conditions (see Table 10-3), reaching a height of 60 centimeters in eight weeks (Truong 1996a). These results are supported by observation in Fiji and Australia, where vetiver was found growing in highly saline tidal flats next to mangrove.

Table 10-3. Soil Salinity Levels
Corresponding to Different Species Establishment

Species	Profile Soil EC_{se} (dSm^{-1})	
	0-5cm	10-20cm
Chloris guyana	4.83	9.59
Paspalum vaginatum	9.73	11.51
Vetiveria zizanioides	18.27	18.06
Bare ground	49.98	23.94

Tolerance to strongly alkaline and strongly sodic soil conditions. A coal mine overburden sample used in this trial was extremely sodic, with an ESP (exchangeable sodium percentage) of 33 percent. Soil with an ESP higher than 15 is considered to be strongly sodic (Northcote and

Skene 1972). Moreover, the sodicity of this overburden is further exacerbated by the very high level of magnesium (2400 $mgKg^{-1}$) compared to calcium (1200 $mgKg^{-1}$). (See Table 10-4.)

Results from added soil amendments show that while gypsum had no effect on the growth of vetiver, nitrogen and phosphorus fertilizers greatly increased its yield. DAP (di-ammonium phosphate) application alone at 100 $kgha^{-1}$ increased vetiver dry matter yield nine times. Higher rates of gypsum and DAP did not improve vetiver growth further. These results were strongly supported by field results.

Table 10-4. Chemical Analyses of the Coal Mine Overburden

Soil pH (1:5)	9.60	Calcium ($mgKg^{-1}$)	1200
EC dSm^{-1}	0.36	Magnesium ($mgKg^{-1}$)	2400
Chloride ($mgKg^{-1}$)	256	Sodium ($mgKg^{-1}$)	2760
Nitrate ($mgKg^{-1}$)	1.30	Potassium ($mgKg^{-1}$)	168
Phosphate ($mgKg^{-1}$)	13.00	ESP* (%)	33
Sulfate ($mgKg^{-1}$)	6.10		

*ESP (exchangeable sodium percentage) = Na % of total cations

Tolerance to Heavy Metals

Studies show that vetiver grass has a tolerance to heavy metals such as arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, and zinc.

Tolerance levels and leaf shoot contents of heavy metals. A series of glasshouse trials was carried out to determine the tolerance of vetiver to high soil levels of heavy metals. Literature searches indicate that most vascular plants are highly sensitive to heavy metal toxicity and most plants are also reported to have very low threshold levels for arsenic, cadmium, chromium, copper, and nickel in the soil.

Results shown in Table 10-5 demonstrate that vetiver is highly tolerant to these heavy metals. For arsenic, the toxic content for most plants is between 1 and 10 $mgKg^{-1}$; for vetiver, the threshold level is between 21 and 72 $mgKg^{-1}$. Similarly for cadmium, the toxic threshold for vetiver is 45 $mgKg^{-1}$ and for other plants between 5 and 20 $mgKg^{-1}$. An impressive finding was that, while the toxic thresholds of vetiver for chromium are between 5 and 18 $mgKg^{-1}$ and for nickel the threshold is 347 $mgkg^{-1}$, growth of most plants is affected at the content between 0.02 and 0.20 $mgKg^{-1}$ for chromium and between 10 and 30 $mgKg^{-1}$ for nickel. Vetiver has a similar tolerance to copper as other plants do—at 15 $mgKg^{-1}$ (Kabata-Pendias and Pendias 1984; Lepp 1981).

Table 10-5. Threshold Levels of Heavy Metals to Vetiver Growth

Heavy Metals	Thresholds to Plant Growth ($mgKg^{-1}$)		Thresholds to Vetiver Growth ($mgKg^{-1}$)	
	Hydroponic Levels (a)	Soil levels (b)	Soil Levels	Shoot Levels
Arsenic	0.02 – 7.5	2.0	100 – 250	21 – 72
Cadmium	0.2 – 9.0	1.5	20 – 60	45 – 48
Chromium	0.5 – 10.0	NA	200 – 600	5 – 18
Copper	0.5 – 8.0	NA	50 – 100	13 – 15
Lead	NA	NA	>1,500	>78
Mercury	NA	NA	>6	>0.12
Nickel	0.5 – 2.0	7 – 10	100	347
Selenium	NA	2 – 14	>74	>11
Zinc	NA	NA	>750	880

(a) Bowen (1979).

(b) Baker and Eldershaw (1993).
NA Not available.

Distribution of heavy metals in the vetiver plant. Results in Table 10-6 show that the distribution of heavy metals in the vetiver plant can be divided into the following three groups:

1. Very little of the arsenic, cadmium, chromium, and mercury absorbed were translocated to the shoots (1 to 5 percent).

2. A moderate proportion of copper, lead, nickel, and selenium was translocated (16 to 33 percent).

3. Zinc was almost evenly distributed between shoot and root (40 percent).

The important implications of these findings are that when vetiver is used for rehabilitating sites contaminated with high levels of arsenic, cadmium, chromium, and mercury, its shoots can be safely grazed by animals or harvested for mulch, because very little of these heavy metals are translocated to the shoots. As for copper, lead, nickel, selenium, and zinc, their uses for the above purposes are limited to the thresholds set by the environmental agencies and the tolerance of the animal concerned.

In addition, although vetiver is not a hyper-accumulator plant, it can be used to remove some heavy metals from the contaminated sites and can be disposed of safely elsewhere, thus gradually reducing the contaminant levels. For example, vetiver roots and shoots can accumulate more than five times the chromium and zinc levels in the soil (see Table 10-6).

Table 10-6. Distribution of Heavy Metals in Vetiver Shoots and Roots

Metals	Soil ($mgKg^{-1}$)	Shoot ($mgKg^{-1}$)	Root ($mgKg^{-1}$)	Shoot/Root %	Shoot/Total %
Arsenic (As)	959	9.6	185	5.2	4.9
	844	10.4	228	4.6	4.4
	620	11.2	268	4.2	4.0
	414	4.5	96	4.7	4.5
	605	6.5	124	5.2	5.0
Average				**4.8**	**4.6**
Cadmium (Cd)	0.67	0.16	7.77	2.0	2.0
	0.58	0.13	13.60	1.0	0.9
	1.19	0.58	8.32	7.0	6.5
	1.66	0.31	14.20	2.2	2.1
Average				**3.1**	**2.9**
Copper (Cu)	50	13	68	**19**	**16**
Chromium (Cr)	50	4	404	1	1
	200	5	1170	<1	<1
	600	18	1750	1	1
Average				**<1**	**<1**
Lead (Pb)	13	0.5	5.1	10	9
	91	6.0	23.2	26	20
	150	13.2	29.3	45	31
	330	41.7	55.4	75	43
	730	78.2	87.8	87	47
	1500	72.3	74.5	97	49
Average				**57**	**33**
Mercury (Hg)	0.02	BQ	0.01	-	-
	0.36	0.02	0.39	5	5
	0.64	0.02	0.53	4	4
	1.22	0.02	0.29	7	6
	3.47	0.05	1.57	3	3

	6.17	0.12	10.80	11	6
Average				**6**	**5**
Nickel (Ni)	300	448	1040	**43**	**30**
Selenium (Se)	0.23	0.18	1.00	53	15
	1.8	0.58	1.60	36	27
	6.0	1.67	3.60	46	32
	13.2	4.53	6.50	70	41
	23.6	8.40	12.70	66	40
	74.3	11.30	24.80	46	44
Average				**53**	**33**
Zinc (Zn)	Control	123	325	38	27
	100	405	570	71	42
	250	520	490	106	51
	350	300	610	49	33
	500	540	830	65	39
	750	880	1030	85	46
Average				**69**	**40**

BQ Below quantification.

Rehabilitating Mine Tailings in Australia

In Australia, vetiver has been used successfully to stabilize mining overburden and highly saline, sodic, magnesic, and alkaline (pH 9.5) coal mine tailings, as well as the highly acidic (pH 2.7), high arsenic tailings of gold mines.

Coal and gold mine overburden. The overburden of an open-cut coal mine in central Queensland is generally highly erodible. These soils are usually sodic and alkaline. (See Table 10-4.) Vetiver grass has established successfully on these soils and stabilized a spoil dump with 20 percent slopes and promoted the establishment of other sown and native pasture species. Similar successful results were also obtained on a gold mine overburden site.

Coal mine tailings. In an attempt to rehabilitate an old coal mine tailings dam (surface area of 23 hectare and capacity of 3.5 million cubic meters), a trial was set up to select the most suitable species for rehabilitating the site. The substrate was saline, highly sodic, and extremely low in nitrogen and phosphorus. The substrate contained high levels of soluble sulfur, magnesium, and calcium. Plant available copper, zinc, magnesium, and iron were also high. Five salt-tolerant species were used: vetiver, marine couch (*Sporobolus virginicus*), common reed grass (*Phragmites australis*), cumbungi (*Typha domingensis*), and *Sarcocornia* spp.

Complete mortality was recorded after 210 days for all species except vetiver and marine couch. Mulching significantly increased vetiver's survival, but fertilizer application by itself had no effect. Mulching and fertilizers together increased growth of vetiver by 2 tha^{-1}, which was almost 10 times higher than that of marine couch (Radloff, Walsh, and Melzer 1995). The results confirm the findings from glasshouse trials.

Gold mine tailings. Fresh gold mine tailings are typically alkaline (pH = 8-9), low in plant nutrients, and very high in free sulfate (830 $mgKg^{-1}$), sodium, and total sulfur (1-4 percent). Vetiver established and grew very well on these tailings without fertilizers, but growth was improved by the application of 500 $Kgha^{-1}$ of DAP.

A vetiver trial is now being conducted for a large-scale application to control dust storm and wind erosion on a 300-hectare tailings dam. When dry, and if not protected by a surface cover, the finely ground tailings material can be blown away easily by windstorms. Because gold tailings often are contaminated with heavy metals, wind erosion control is a very important factor in stopping the contamination of the surrounding environment.

The usual method for controlling wind erosion Australia is by establishing a vegetative cover; but because of the highly hostile nature of the tailings, revegetation is very difficult and has often failed when native species are used. The short-term solution to the problem is to plant a cover crop such as millet or sorghum; but these species do not last very long. Vetiver can offer a long-term solution by planting the rows at a spacing of 10 meters to 20 meters to reduce wind velocity and at the same time provide a less hostile environment (such as shading and moisture conservation) for local native species to establish voluntarily later.

Old tailings. Because of their high sulfur content, old gold mine tailings are often extremely acidic (pH 2.5 to 3.5), high in heavy metals, and low in plant nutrients. Revegetation of these tailings is extremely difficult and often quite expensive, and the bare soil surface is highly erodible. These tailings are often the source of contaminants to the local environment, both above the ground and underground. Table 10-7 shows the heavy metal profile of gold mine tailings in Australia. At these levels, some of these metals are toxic to plant growth and also exceed the environmental investigation thresholds (*Australian and New Zealand guidelines…* 1992).

Field trials were conducted on two 8-year-old gold mine tailings sites. One site is typified by a soft surface and the other by a hard, crusty layer. The soft-top site had a pH of 3.6, sulfate at 0.37 percent, and total sulfur at 1.31 percent. The hard-top site had a pH of 2.7, sulfate at 0.85 percent, and total sulfur at 3.75 percent. Both sites were low in plant nutrients. Results from studies at both sites indicate that, when adequately supplied with nitrogen and phosphorus fertilizers (300 $Kgha^{-1}$ of DAP), excellent growth of vetiver was obtained on the soft-top site (pH = 3.6) without any liming. But the addition of 5tha^{-1} of agricultural lime significantly improved vetiver growth. On the hard-top site (pH = 2.7), although vetiver survived without liming, the addition of lime (20tha^{-1}) and fertilizer (500 $Kgha^{-1}$ of DAP) greatly improved vetiver growth.

Table 10-7. Heavy Metal Contents of a Representative Gold Mine Tailings in Australia

Heavy Metals	Total Contents ($mgKg^{-1}$)	Threshold Levels ($mgKg^{-1}$)
Arsenic	1120	20
Chromium	55	50
Copper	156	60
Manganese	2000	500
Lead	353	300
Strontium	335	NA
Zinc	283	200

NA=Not available.

Bentonite tailings. Bentonite mine tailings (reject) are extremely erodible because they are highly sodic with ESP values ranging from 35 to 48 percent. They are also high in sulfate and extremely low in plant nutrients. Revegetation on the tailings has been very difficult because first rains often washed away the sown species; what was left could not thrive under these harsh conditions. With an adequate supply of nitrogen and phosphorus fertilizers, vetiver established readily on the tailings, and the vetiver hedges provided erosion and sediment control, conserved soil moisture, and improved seedbed conditions for establishing indigenous species.

Bauxite mine. Vetiver currently is being used to stabilize a very large dam wall of a bauxite mine in northern Australia. Trials are being planned to investigate the possibility of establishing vetiver on the highly caustic tailings, which have pH levels as high as 12. If the trials are successful, vetiver will be used to revegetate these tailings in situ without capping its surface first with topsoil, which generally is not available, and over time, the capillary rise of Na and alkalinity will degrade the topsoil cover, which will affect growth of plants, which have lower levels of tolerance to sodicity and alkalinity.

Rehabilitating Mine Tailings in South Africa

De Beers Mining Company conducted rehabilitation trials on both tailings dumps and slimes dams at several sites and found that vetiver possesses the necessary attributes for self-sustainable growth on kimberlite spoils. Vetiver grew vigorously on the alkaline kimberlite, containing runoff, arresting erosion, and creating an ideal microhabitat for establishing indigenous grass species. Rehabilitation using vetiver was particularly successful on kimberlite “fines” at Cullinan mine, where slopes of 35º are being upheld. It is clear that vetiver is likely to play an increasingly important role in rehabilitation; as a result of vetiver’s success, nurseries are being established at several mines (Knoll 1997).

At Premier (800 millimeters annual rainfall) and Koffiefonteine (300 millimeters rainfall) diamond mines, the surface temperature of the black kimberlite often exceeds 55ºC, a temperature at which most seeds are unable to germinate. Vetiver planted at a 2-meter vertical interval (VI) provides shade that cools the surface to allow germination of other grass seeds (Grimshaw, personal communication).

Vetiver has also been used successfully in rehabilitating slimes dams at the Anglo American platinum mine at Rustenburg and the President Brand Gold Mine (Tantum, personal communication).

Conclusions

As shown in the research results and applications presented in this chapter, the Vetiver System is highly suitable for rehabilitating contaminated mine wastes and tailings. To successfully apply vetiver technology, one needs to have a full understanding of the chemical properties of the materials requiring rehabilitation.

11. Proposed Strategies for Meeting Propagation Needs

At the turn of the twenty-first century, the Vetiver System was known in more than 100 countries throughout the tropics. When establishing the Vetiver System in a new area, however, it is essential that planting material is readily available and in abundance. Demonstrations of the vetiver (*Vetiveria zizanioides*) plant's ability to prevent erosion—for example, to stabilize road or rail cuttings, control leachate from landfills or rehabilitate landfills or mine dumps, or stop mudslides—must be laid out in clear view of the public or those concerned.

After a country's ministry or department of agriculture grants permission to introduce the system on a trial basis, it is important to hold field days at three different times: (1) at planting, (2) during establishment, and (3) when the established hedge is doing its job. When the trial reaches this final stage, there will be a great demand for planting material. If the material is not available, then the farmers or engineers lose interest and may never accept the Vetiver System.

In November 1991, The Vetiver Network distributed a questionnaire to ascertain from people actually growing vetiver hedges how the demand for planting material might be met on a large scale. Of the 148 responses received, 115 came from people who have vetiver. Out of those with vetiver, 89 saw no problems with propagating sufficient material to meet future demand for establishing vetiver hedgerows, whereas 17 respondents thought some problems would exist. The rest either did not comment or were not sure. No regional or climatic trends were apparent among those who responded in the negative.

Among the 17 who thought that future demand could not or would not be possible to meet, 6 reported poor nursery production rates and 3 thought lack of funding and/or government support was the main roadblock to meeting demand for planting material. The remaining individuals did not specify why they thought future demand would not be possible to meet.

Regarding the ability to propagate sufficient vetiver, of the 89 persons responding in the affirmative to the question, nursery production rates were high for 18, moderate for 23, and low for 10, while 5 respondents relied on indigenous vetiver populations and 2 relied on containerized plant production using polybags.

Those respondents with high nursery production rates tended to be in tropical climates, about evenly humid and semi-arid; those with moderate rates tended to be in humid areas, and about evenly distributed between tropical and subtropical areas.

Those who responded to the survey generally did not seem to be concerned about meeting centralized targets, nor were they concerned about the size of areas that potentially could be covered. Their answers reflected an attitude that small-scale propagation by a large number of farmers, non-government organizations (NGOs), locally based projects, and the like, would solve the problem. Almost 80 percent of the respondents indicated that the long-term needs should be met through such a decentralized approach. Other recommendations included micropropagation (tissue culture), containerized propagation, and large-scale government or commercial nurseries.

Several respondents to the vetiver propagation questionnaire recommended using seed. Planting seeds is an extremely dangerous idea. *V. zizanioides* has one great advantage over other “conservation plants”: it has not spread as a weed from seed to become a pest. It will grow only where people plant it vegetatively.

One thing is absolutely essential to remember: DO NOT PLANT VETIVER SEED! The non-fertile *V. zizanioides*, if it seeds, has never been known to produce viable seedlings; but the seeds of some other vetivers are fertile, which is why we who promote the Vetiver System do not recommend planting those species.

Warning: The northern Indian type of vetiver, however, which flowers and seeds freely, can produce some seed that is viable and will germinate, usually only under a fairly narrow range of conditions, such as humid swamps, which normally are not found in agricultural areas (rainfed or irrigated). A program of propagation through seed, however, would result in selection for plants with a greater potential for escaping and becoming invasive, ultimately creating a new weed problem. The Vetiver Network requests that vetiver users take the responsibility not to begin propagating from seed; or, if they already are propagating from seed, to halt all seed-based propagation. It is important to be aware of the risk involved: just one incident of vetiver spreading from plants selected for their ability to sexually reproduce could cast suspicion on vetiver’s use. We have a good technology; let us not lose it intentionally.

Obtaining Vetiver for the Nursery

One of the most important characteristics of vetiver grass is the fact that it can be introduced with little or no fear that it will become a weed. Throughout the history of vetiver’s movement around the world—until today when it is found in almost every country in the tropics—we have never had any report of vetiver’s spreading as a weed from seed. Yet we know that some accessions do flower and seed freely and that these seeds can be brought to germination. We consider that vetiver seed is not good for two reasons: (1) plants from seed display a high degree of heterogeneity (with many of the plants lank and lax), whereas clonal material is uniform; and (2) a high degree of uniformity is essential in a hedgerow. If one begins selecting plants more easily established from seed, a potential problem may be created where one did not exist before. Therefore, it is important for vetiver growers to remember three clear steps: (1) select, (2) collect, and (3) use vegetative material, *not seed*.

When collecting vegetative material, vetiver growers must remember that more than one cultivar of *V. zizanioides* may be available. If the planting material is of unknown origin, it would be wise to put out trials using as many different provenances of vetiver as possible. This is not to say that a start cannot be made with the planting materials on hand, but that for long-term promotion of vetiver as a conservation species, it would be prudent to ensure that one uses the best material possible for a particular area and the conditions of that area. Finally, when planting the collected material in the nursery, vetiver growers should throw away older plant parts that have flowered or seeded, because they will exhibit reduced vigor and decreased growth rates. It is important to use young, vigorous plant material when planting the nursery and when establishing hedges.

Using Indigenous Populations of Vetiver

In this section, I stress the importance of using *V. zizanioides*, rather than local species of vetiver that are not proven *zizanioides*.

The following paragraph, an abstract from a report by P. K. Yoon of the Rubber Research Institute of Malaysia (RRIM), following his review of project work in Bangladesh, points out the possible pitfalls in using indigenous plants (Yoon 1992):

With the ready availability of Vetiver growing wild in the country, the first reaction was that nurseries would be redundant. When needed, Vetiver could be collected and transported back for planting. This assumption, however, may be affected by (1) transport and collection costs and logistics; (2) adverse weather condition (for example, the project team was supposed to collect the plant material in early July, but the collection was not carried out because of floods); (3) possible weakened Vetiver plants in the field that may have been weakened by over-grazing.

In addition to being aware of Yoon's concerns, vetiver growers must be aware of possible pitfalls when collecting plants from native populations. For example, what happens when growers select types that reproduce more readily from seed? Vetiver growers must consider carefully the circumstances under which they find the wild vetiver. If growers observe plants spreading non-uniformly along a waterway or within a floodplain or wetland, they would recognize that this particular type is not readily establishing from seed. If they observe large, uniform patches or areas of vetiver, however, they would know that such growth patterns may indicate a potentially weedy type of vetiver. Even in the first case with plants that have spread in a non-uniform way, vetiver growers must take caution. They should perform a few tests on the germination rate of the plant's seeds. If the seeds readily germinate under controlled conditions, they should look for other sources of planting material where seed germination is not a problem.

Identifying Different Cultivars of Vetiver

The area of plant identification and selection is sorely lacking in information in many countries, and the need for such information is becoming increasingly critical (see Chapter 3). Now that DNA "fingerprinting" is available through The Vetiver Network, this service should be checked through the Web site, www.vetiver.org. The Vetiver Network has shown that great differences exist among various accessions of vetiver; this knowledge is borne out repeatedly whenever researchers make comparisons between gross morphology and biomass production. Therefore, before any major nursery production of vetiver is undertaken, the planting material sourced must be proven *V. zizanioides*, and should preferably be of a proven cultivar.

As always, of course, any plants introduced from other countries must be run through the national phytosanitary system. This service is usually fast and free, whereas smuggling takes only one event to introduce a new pest or plague that could cripple a major crop and quash the livelihood of farmers (just as the cassava mealybug from Latin America created a famine disaster in Africa). Like any plant, and especially one propagated vegetatively from biologically active tissues, any of a multitude of exotic afflictions can hitch a free ride in a shipment of vetiver cuttings. Experience at the U.S. Department of Agriculture (USDA) shows that more than 100 harmful organisms can hide in the vegetative stage of grasses. Many of these (such as viruses, fungi, and bacteria) may not be visible to the eye; others may not harm the vetiver (it will look healthy) but infest other grasses (potentially including valuable crops such as maize, rice, or sugarcane). These organisms can include hard-to-detect and hard-to-control pests such as stem borers, nematodes, rusts, or smuts. For example, in Guam, an alert entomologist (R. Muniappan of the University of Guam) detected two species of scale insects (*Aclerda* sp. and *Aulacaspis madiunensis*) hiding deep under the leaf sheaths of imported vetiver cuttings. These species had never been reported in the region, but in Asia, Africa, and South America they cause necrotic spots and subsequent black sooty mold infestations on sugarcane. As noted by Muniappan, “Scale insects are highly cryptic and their presence could escape notice except under the most rigorous inspection regime” (Dafforn, personal communication). A decent respect for our moral obligation, “First, do no harm,” demands that any imported planting material be inspected and approved by plant pathologists certified by the national plant-protection authority, and that such planting material not be introduced (for example, as the cassava mealybug was) by “well-meaning” politicians, whose VIP baggage is usually not searched after visiting a neighboring country where they have been impressed by a new plant they may have seen.

Managing Nurseries

To ensure an adequate supply of vegetative material for planting vetiver hedgerows, vetiver growers should establish nurseries well in advance of the optimal planting time. The timing will be determined primarily by the urgency for protection and climate. Analysis of the information on the propagation questionnaires showed no correlation among rainfall, minimum temperatures, or length of growing season and months in the nursery, or in yield of planting material from the nursery. This information suggests that the most important variable is the management of the nurseries: the better the management, the faster the plants grow and the higher the production.

Undoubtedly, climate does affect growth, and even the best nursery management cannot overcome all climatic constraints. In looking at the propagation questionnaires, the worst nursery production rates tended to be in colder locations. Vetiver is a tropical plant. It prefers a warmer climate. It is also a C4 plant (grows more actively than a C3 plant and is a more efficient converter of sunlight), which means that as the temperature rises, vetiver will continue to grow faster and faster, providing it is not constrained by moisture and lack of nutrients. Therefore, in areas where temperature is a constraint to nursery growth, the strategy should be to have the vetiver as well established as possible when coming into the warmer months.

Best estimates for subtropical areas suggest that minimum soil temperatures above 15°C are necessary for growth to begin. Vetiver growers should locate nurseries in soils that warm the fastest in the spring and in which cold air drainage is good. Moist soils heat up and maintain heat better than drier soils. If possible, growers should mulch the nursery with the vetiver cuttings going into the cold period; they should irrigate, fertilize, and weed the nursery.

Gueric Boucard, once a large-scale vetiver producer in Leakey, Texas, suggested burning back the vetiver if its leaves are killed by a frost. He suggested that by waiting for the plants to dry out after the frost and then burning them, they would come back earlier and more rapidly in the next growing season.

How long vetiver growers grow vetiver in the nursery depends on their local conditions. They should (1) use their own judgment and experience, (2) ask the opinions of others who have grown the plants successfully, and (3) know their area intimately. Growers should manage their nurseries in a way that results in the best production possible.

Selecting Nursery Soils

If possible, vetiver growers should select sandier-textured soils for growing vetiver plants in their nurseries because sandy soils make it much easier to lift the vetiver clumps at harvest. Sandy soils, however, are drought-prone soils. Whereas it is always the best practice to irrigate the nursery, in sandy soils, it is an absolute necessity if growers want to achieve even average production rates. Growers who write to The Vetiver Network about their experiences usually recommend sandy-to-loamy soils. Growers can easily identify types of soils by moistening the soil and squeezing it in their hands—a sandy soil will stick together in a clump that will easily crumble when touched and handled, while a sandy loam also will stick together in a clump but will bear careful handling without breaking. A clay loam soil can be handled freely without breaking. Vetiver growers should avoid using soils that are too clayey for their nurseries. If when moistening the soil and forming a clump, the clump has “ribbons,” the soil it is too clayey.

Preparing the Nursery

Vetiver growers should prepare the nursery land to provide a well-aerated rooting zone, with clods broken up. If fertilizer, such as farmyard manure (FYM), animal manure (pig or chicken manure seem best), green manure, and/or oil seed cake, is available, growers should plow it into the soil during land preparation. They should avoid overhanging trees, or remove them, because vetiver plants require full sun for rapid establishment.

Planting Vetiver

When preparing to plant vetiver, growers should irrigate the soil or wait until soil moisture levels are good before transplanting into the nursery. They should plow a shallow furrow to accommodate the slips, which they will plant not more than 2 centimeters deep. It is not necessary to be concerned about the amount of root on the slips; vetiver will establish without roots. (Some people who have practical experience growing vetiver report that residual roots on the slips serve no purpose at all. They contend that vetiver slips grow only after they put out new roots.) Growers should plant two to three tillers every 15 to 40 centimeters.

If growers’ nurseries have little fertilization and/or little or no irrigation, they should space the plants farther apart. If the plants need to be in the nursery for longer periods, growers will need to provide wider spacing between the plants to allow room for more tillering. Growers should allow a spacing of 15 to 40 centimeters between rows.

Adding Fertilizers

If possible, vetiver growers should test soil to ascertain the levels of available soil nutrients and to aid in deciding the nursery's fertilizer requirements. Although optimum levels of fertilization are not known at this time, the benefits of fertilization to nursery production are certain.

Work in the United States has shown an increase in tiller production of 56 percent one year and 183 percent the next year between unfertilized and fertilized vetiver (Igbokwe et al. 1991). Researchers conducted this particular experiment using 241 kilogram/hectare of 13-13-13—31 kilogram/hectare total nitrogen (N), 14 kilogram/hectare available phosphorous (P), and 25 kilogram/hectare water soluble potassium (K)—in soils with extractable nutrient levels of 68 kilogram/hectare (moderate) and 216 kilogram/hectare (low) of P and K, respectively.

In India, researchers recommend 250 kilogram/hectare of di-ammonium phosphate (DAP), which is the equivalent of 53 kilogram/hectare of N and 58/hectare of P. It is also reported from India that split doses of urea at 45, 75, and 105 days after planting is beneficial. They also are using doses of urea at 50 to 125 kilogram/ha—21 kilogram/hectare to 58 kilogram/hectare N.

Irrigating the Nursery Soil

Because the purpose of the nursery is to provide optimum conditions for the plant to maximize production, irrigation in the nursery is essential to good production rates. Although growers can use dryland nurseries, such nurseries will not produce the quantity of material that irrigated nurseries can.

Irrigation, in combination with good management practices, can more than pay for itself by reducing the unit cost of planting material to insignificant sums. Without irrigation and management, labor costs will keep the unit cost of planting material high because of low production. The only good alternatives to irrigation are nursery establishment in landscape positions that maintain adequate levels of soil moisture throughout the nursery period (for example, bottoms of gullies with watersheds more than 10 to 25 hectare, along stream banks).

In the semi-arid zone of India, on soils with low water-holding capacities, growers provide irrigation every 4 to 5 days for the first 2 months and about every 7 days thereafter.

Weeding the Nursery

Because weed competition can affect nursery production, vetiver growers should weed nurseries as necessary. Growers in Andhra Pradesh, India, reported that unweeded nurseries produced 60 percent fewer tillers than did weeded nurseries. Growers from nurseries in Malaysia reported that vetiver grew well in competition with *Borreria* sp. and other sedges, though it was noted that Borreria is not a very competitive weed.

If growers establish nurseries in sandy-to-loamy soils, they will reduce labor needed for weeding. They also may reduce weeding costs by spacing rows to accommodate mechanical or animal-drawn implements for inter-row cultivation.

While herbicides are generally cost-effective in nursery use, The Vetiver Network has little information at this time on specific herbicides and their use alongside vetiver. Researchers in India report using atrazine in nurseries, and researchers in Malaysia are carrying out work on this subject. Igbokwe et al. report that Roundup (glyphosate), Fusilade 2,000 (fluazifop-p-butyl), and sethoxydim will effectively kill vetiver and therefore are not recommended (Igbokwe et al. 1992). In Malaysia, P. K. Yoon also reported that Paracol damaged vetiver tops when it drifted onto them unintentionally (Vetiver Information Network 1992). In this case, however, the plants fully recovered within 2.5 months.

Pruning Vetiver Plants in the Nursery

From all accounts, pruning increases tiller production, and researchers recommend pruning once every month. They do not recommend pruning below 40 centimeters because, according to our best information, pruning below this level may retard growth. Growers can use prunings as mulch to reduce water loss and slow weed growth. If labor is expensive, a mechanized grass-cutter would decrease labor input to less than 1.5 man-days per hectare per cutting.

Managing Pests

Whenever growers produce plants in nurseries, they always risk the possibility of pests and disease affecting the plants' growth. With vetiver, growers usually have no problems with pests and disease, however, because of the plant's fungicidal and pesticidal properties. Nevertheless, when growers introduce a new plant to an area, they must observe initial pest problems and treat them if necessary.

P. K. Yoon has reported fungal attacks within crowded nurseries in Malaysia (*Nigrospora* sp., *Curvularia* sp., and *Helminthosporium* sp.). He effectively treated the plants by topping the affected plots at 40 centimeters (Vetiver Information Network 1992).

In Weili County, Sichuan Province, the People's Republic of China, vetiver growers found a so-called "sticky worm"—a 5-centimeter long x 1-centimeter in diameter worm with a red dot on its forehead—in a nursery. The worm seemed to concentrate on vetiver leaves to the exclusion of other available weeds and grasses. The growers achieved control with a contact insecticide (Vetiver Information Network 1992).

The Boucards in southern Texas reported to the *Vetiver Newsletter* that they had severe damping off (a common nursery disease) problems some 15 years ago when they first began planting vetiver. They achieved control by applying fungicides (Vetiver Information Network 1992). The Vetiver Network notes, however, that no other nurseries have reported the problem and thus assumes that it is not a common phenomenon at this time. In fact, The Vetiver Network has received no reports of significant nursery pests or diseases.

Culling

Culling is the process by which growers eliminate weak and "off-type" specimens in the nursery. By not allowing such plants to take up nursery space, growers save time and money.

A nursery should have the goal of producing only high-quality, healthy, and vigorously growing plant material that is the only material worth planting, regardless of whether it is vetiver or any other plant. It is extremely foolish to waste time and resources planting poor-quality material out in the field. It can cause frustration, extra labor, and even failure.

To achieve the aim of providing farmers with good-quality material, vetiver growers should throw away any plant that does not look good. Production planning should allow for a minimum of 15 percent of nursery production—20 percent of total estimated production as being substandard. Vetiver growers should live by the adage—If in doubt, throw it out. They should train themselves and their nursery workers to get rid of poor plants and poor plant parts. At harvest, they should throw out tillers that are not healthy and vigorous. Those who purchase vetiver slips should tell the nursery growers that they will buy only quality tillers.

Dealing with Low-input Nurseries and Low-cost Production

Previous articles in the *Vetiver Newsletter* have stressed a high-input approach to vetiver nurseries; from a planning perspective this makes sense. Growers should never start off by asking, "How cheaply can I do this?" The correct question is, "What is the best job that I can do with the resources at my disposal?" When managing a vetiver nursery (and in most other activities), economies of scale and inputs exist—the bigger the operation, the cheaper the unit cost of production, and up to some optimum, the returns to production for any given input will often more than pay for themselves.

Vetiver is a tough plant and will grow under some fairly unfavorable conditions. But because it is a plant, it is tough only relative to other plants. If it has no moisture or nutrients upon which to draw, it will not grow. If it is choked out by weeds or stomped on and grazed from the moment it is put in the ground, it will not grow. This is not to say that if growers cannot afford irrigation, fertilizer, and a lot of labor that they cannot grow vetiver in a nursery. Rather it says that if growers cannot provide these things from purchased inputs, they can provide a better environment through planning.

For minimizing inputs for vetiver production, The Vetiver Network shares the following growers' suggestions, most of which would be appropriate for the individual user or small groups.

- Instead of establishing formal nurseries, plant slips along the roadside, etc. On the coffee plantation, we leave them for 2 years, during which time we cut them for mulch. We get up to 250 tillers/plant. *(From Mr. Shimelis Kebede in Ethiopia, where about 500 kilometers of vetiver hedges grow on the plantation where he is located.)*

- Plant double rows of vetiver as hedges; the next year, uproot one row and use it to gap fill the other. Then plant another double row with the rest; repeat each year. Plant a nursery only if vetiver is scarce. *(From Mr. R. S. Patil.)*
- Maintain a small nursery with year-round production. Take plants whenever you need them and always replant what you take. *(From Mr. F. W. M'buka.)*
- Engage in the casual propagation of plants wherever there is space and good moisture, such as in paddy bunds, banks of dams, and streams. *(From Mr. Mihir Kumar Jha.)*
- Establish local, farmer-managed nurseries in the wetter sites within each watershed—in all watersheds a spot can be found that is wet throughout the year. *(From Mr. Gunnar Jakobsen.)*
- Contract with farmers to produce small amounts of vetiver; give them enough material to establish about a 750-plant nursery. Buy it back at an agreed-upon price. *(From Mr. P. C. Romkes.)*
- Provide credit and procurement contracts to small farmers. *(From Mr. Konaje Gopalkrishna.)*
- Small individual nurseries and farmers nurseries are best. *(From Mr. Ranjit Kumar Roy, Mr. M. Singa Rao, Mr. Chris Eijkemans, and Mr. Vaughn Redfern.)*
- Take tillers from established hedges. *(From Mr. Michael Poshkus and Mr. Alemu Mekonnen.)*
- Establish small nurseries and plant at the onset of the rains; a good water supply makes all the difference. *(From Mr. Michael Poshkus.)*
- If there is no hurry, simply remove slips from your own established plants year by year and extend the length of the hedge. *(From Mr. C. Buford Briscoe.)*
- Establish your nursery in damp valley bottoms. *(From Mr. Robert J. Sims.)*

P. K. Yoon also provides us with the following " recipe" for a low-input nursery (Vetiver Information Network 1992):

A large block of approximately 0.2 ha was ploughed and rotovated. Tillers were directly planted with a planting distance of 15 cm x 15 cm. One round of dried chicken dung was applied at one week after planting. This approach ensures low establishment cost. There was little maintenance cost—with planting in the normal rainy season, watering was not needed. Also, there was no weeding nor any pest and disease control measures. Plants were growing well by 2.5 months and managed to compete with…weeds. Sampling of 100 clumps at 4 months showed average of 11 tillers per clump (farmer's report). This rate of production was considered satisfactory because of the low input.

Production from Yoon's low-input nursery, at 4 months, would provide enough material for about 40 to 60 kilometers of hedgerows, assuming a 20 percent cull and two or three slips every 15 centimeters.

Using Raised-bed Nurseries

Raised beds may have an advantage over planting in the ground because of reduced labor inputs for harvesting the plants and weeding. The raised beds themselves might be formed either by hand or with a walking tractor, with the latter the less expensive of the two.

In areas where labor costs limit nursery management options, the raised-bed system may result in lower plant production costs. The following information is adapted from the work of P. K. Yoon of Malaysia (Vetiver Information Network 1992).

Vetiver growers who prepare raised beds should base the width of the beds on the number of rows of vetiver slips that they will plant across the bed. Experience in Malaysia shows that if time in the nursery is to be more than 3 months, the grower should plant no more than two rows of vetiver in each bed since, after 3 months of satisfactory growth, the plants in the central rows tend to grow and multiply more slowly as a result of shading. Unless the amount of available land is a constraint, or time in the nursery will not go past 3 months (or past the time at which under nursery conditions the plants would enter into severe light competition), then two rows of vetiver slips planted 15 centimeters apart work well. If growers can (or must) use more than two rows, then for easy management, they should not prepare the bed width any wider than 1 meter.

To ensure good growth, Yoon recommends 6 grams of 5-5-5-1(Mg). Yoon also recommends the trickle irrigation system used in the polybag nurseries. On two occasions, in harvesting his nurseries at 5 months, Yoon's average yields from the two-plant/row system were 21.1 tillers/plant (±0.59) and 20.6 tillers/plant (±0.92), based on counting 486 and 185 plants, respectively.

In a six-plant/row nursery, Yoon established plants on a 15 x 15 centimeter spacing, with a trickle irrigation system in beds that had received a liberal application of dried chicken dung. Each bed was about 1 x 50 meters with 0.9 meters spacing in between and had 1,800 plants. In total, he planted six beds with 10,800 plants. The plants were ready for use in the field after 2 months; however, for multiplication purposes, he left the plants to grow longer. He estimated that these beds produced more than 150,000 tillers after the first 3 months.

On a per hectare basis, Yoon's production is equivalent to about 189,000 plants producing about 2.63 million tillers in 3 months, which is sufficient planting material to establish about 131 to 195 kilometers of hedgerow, assuming two or three slips each 15 centimeters without any culling of plants. In practice, it is a good idea to assume that some percentage of plants should not be used because some material will be older and less vigorous. Assuming a 15 percent cull still leaves adequate material to establish 110 to 167 kilometers of hedgerow using top-quality plants.

Using Containerized Nursery Stock

A number of individuals on The Vetiver Network use polybags or other containers in which to grow vetiver in the nursery. While costs are higher using this method, it has certain advantages for particular situations. The advantages of containerized stock are as follows:

- Establishment time is reduced considerably because plants grown in containers are planted in the field with well-developed, relatively undisturbed root systems.

- Planting with containerized stock is almost equivalent to putting out a one-year hedgerow immediately. At close spacing, the containerized material with its larger plants, in effect, gives an almost functional hedgerow within the time it takes for the roots to penetrate the surrounding soil and anchor the plant.
- Under high-stress situations (for example, poor and non-friable soil with low nutrient content, severe erosion from multiple directions, and difficult climatic conditions), the use of polybag materials with their vigorous root systems encased in a core of soil will allow early establishment and growth when transplanted.
- Because polybag production should rarely result in plants that must be culled, nursery output should be close to 100 percent of production.

Situations in which the increased cost may be justified would normally be those in which protection of high-value infrastructure is the goal. Examples of this might be for the farmer who has constructed a new house on a steep slope, for new road cuts or bridge wing-walls, or on any fill slopes or main irrigation canals. In other words, the cost would be justified literally anywhere where the cost of stabilization would be measured against the replacement costs of the infrastructure should stabilization methods fail.

Containerized stock might also be more economic in stabilizing gullies. Mike Materne, agent of the U.S. Soil Conservation Service, found that he could take containerized plants and, using old welding rods as pins, establish hedges right across areas in which concentrated flows were causing active down-cutting. In 1990–91, Materne was brought into Fort Polk, Louisiana, where the fifth infantry is trained in the use of motorized tanks, to control massive erosion caused by the tank training. He used vetiver grass hedges as a means of control for the first time in the United States, and this proved successful (National Research Council 1993). The potential use in the areas of infrastructure protection and gully control is enormous.

For containerized planting, P. K. Yoon found that polybags (0.05mm thickness) of 13 x 18 centimeters work well. The grower can use multiple tillers instead of single tillers. In this way, the tillers need only regenerate their root systems; also the time in the nursery to produce quality plants may be reduced.

In preparing tillers for polybag planting, Yoon suggests cutting the tops (slips) to about 20 centimeters with the roots cut to 4 to 5 centimeters. At planting, he suggests burying not more than 2 centimeters of the slips. To ensure good growth, especially of the root system, he suggests putting 6 gm of 5-5-5-1(Mg) into the polybags one week after planting.

Yoon also reminds us that because vetiver is sensitive to shade, the arrangement of the polybags is critical. As they do with raised-bed planting, growers should use only two rows of polybags. With more than two rows of polybags, the plants in the center row(s) will be shaded and thus perform poorly. For the same reason, the spacing between the polybag rows should be one meter.

Yoon prefers mechanized watering to normal watering because of better control and quality of watering. The trickle irrigation system is favored in Malaysia because it is cheap to install. But Yoon says growers may use any irrigation system and that he has seen overhead sprinkler systems that appear to meet the need.

In Bangladesh, production of one polybag of quality planting material (with more than 10 tillers) was calculated at US$0.05 each (circa 1992).

A plan for an irrigated 4-hectare polybag nursery in Bangladesh showed estimated nursery startup costs at US$3,000. The nursery would produce 1.3 million plants annually on a 4-month cycle; that is, a farmer could raise and distribute three lots of plants per year. This yield would provide enough planting material for 195 kilometers of hedgerows per year when planted 15 centimeters apart. Recurrent costs would be covered under the US$0.05 per polybag plant. Regular monthly pruning to 40 centimeters encourages tiller formation.

Establishing Mechanized Vetiver Nurseries for Large-scale Production

This section is based on an article contributed by Gueric Boucard (Texas, USA) who, with his brother Victor, had operated the largest vetiver farm (of which we at The Vetiver Network are aware) in the world.

Because their father was an enthusiast about the vetiver plant, the Boucard brothers were involved with vetiver for most of their lives. Their motivation for farming vetiver in recent decades had been for producing oil from the root. Their operation for this type of farming would serve equally well for establishing mechanized nurseries and hedgerows, however, especially since their operation was an irrigated one, as should be any nursery operation.

In American agriculture, “large-scale” is a relative term. The Boucard’s company, American Vetivert Corporation (AVC), had had up to 200 acres of vetiver under cultivation in southern Texas; they called it large-scale vetiver farming, primarily because of its large drain on the company’s small research and development budget. On the other hand, AVC’s farming partner had some 5,000 acres under the plow at any given time, and another 5,000 acres in cow pastures and idle farmland. But certainly, the large-scale mechanized propagation of vetiver would seem to have considerable merit in developed countries.

The question that arises is, “How does one propagate vetiver on a large scale?”

Propagating vetiver on a large scale is relatively easy because the grower has only 15 or 20 mistakes and pitfalls to avoid. Unfortunately in agriculture, it takes one full calendar year to discover the results of each mistake and correct them. Therefore, after 17 years of experimentation, AVC could make some basic recommendations to those who want to do large-scale planting and harvesting of vetiver. (Note: certain requirements that pertain to high-quality root production do not apply to the growing of vetiver for the harvesting of “slips.”)

Vetiver will grow in sand, heavy clay, rocky soils, volcanic soils, swamps, and saline river deltas; in fact, vetiver will grow just about everywhere in tropical and subtropical climates, although good roots with high-quality oil occur in only a few of the above. Once the right soil and geographical location have been selected, the main problem lies in developing adequate farming machinery. Unfortunately, specialized vetiver farming machinery is not to be found in the catalogues of John Deere, New Holland, and International Harvester.

Full mechanization of the vetiver crop is an absolute necessity for large-scale propagation, especially in the United States. Often, however, the patient and skillful modification of existing conventional farm machinery can produce satisfactory results. Growers may find that a 90 percent mechanization of a particular agricultural operation may be commercially acceptable, while the achievement of the 100 percent mechanization goal may be US$1 million down the road and may bring little additional profit. It is along these lines that AVC developed its own special machinery. Yet, regardless of all the special farming equipment that AVC developed, vetiver remains in the category of labor-intensive crops, such as vegetable crops, fruit crops, and tobacco.

One important distinction, however, separates vetiver from other labor-intensive crops, and this distinction makes all the difference in the world. Fruit and vegetable crops have to be harvested within a narrow time frame, and very large-scale operations of several thousand acres are rarely practical. Vetiver, however, is a perennial grass that can be harvested at virtually any time of the year in the tropics. A 3,000-acre farm (1,200 hectare), taken a day at a time, is the same as a 6-hectare small farm operation.

The Boucard brothers developed some specialized machinery for handling their large vetiver crop in the field. This machinery is possibly the only equipment that has been developed commercially to handle the vetiver crop. The following list indicates what can be done commercially to adapt or develop farm machinery for a specific crop. (The equipment listed below is most likely not available on the commercial market.)

1. **Vetiver transplanter.** The AVC transplanter is a 4- or 6-row machine for 30- to 38-inch (76.2- to 96.5-centimeter) rows. It requires two people per row to plant 8- to 10-inch (20- to 25-centimeter) tall vetiver seedlings of 2-inch (5-centimeter) diameter, 3 inches (7 centimeters) deep and 18 inches (46 centimeters) on the row. The mechanism allows the injection of water and fungicide, root activator, or any other chemical with each seedling. The machine is a modified tobacco transplanter that can plant 8 to 10 acres (3 to 4 hectare) per day. Gueric Boucard has confirmed that his planter could be modified easily to accommodate both closer spacings between slips and planting across steep (by U.S. standards) slopes.

2. **Vetiver grass mower.** Having tried all commercial lawn mowers, AVC can assert with confidence that no commercial mower of any design, currently available on the U.S. market, will mow a 24-inch-diameter vetiver clump. The special sickle bar mower designed by AVC and mounted on a New Holland self-propelled mower will even mow vetiver to ground level at nearly normal mowing speeds. In the event that all the clumps will be used either for replanting or for sale to others for erosion hedges, the entire field will have to be mowed 8 inches (20 centimeters) above ground to accommodate the mechanical transplanter. The cost of manual shaving of root from the clumps will have to be offset by revenues from the sale of the clumps.

3. **Vetiver root digger.** After modifying, testing, and destroying several potato diggers, peanut diggers, and rock pickers, AVC developed its own heavy-duty vetiver root digger.

The farmer must pull the digger with a large four-wheel-drive tractor, such as the Steiger tractor or other makes of similar horsepower and wheel traction. The machine goes 16 inches (40 centimeters) deep and uproots two rows of vetiver clumps with each pass. Given good loose, sandy soil, the digger shakes the roots clean before they fall into the wagon riding next to the digger. In less advantageous soil conditions, the farmer has to use a stationary tumbler to shake the roots again at the processing shed where the seedling preparation takes place.

4. **Vetiver stump slicer.** After the roots are shaven, the clumps with 8-inch-long (20-centimeter-long) leaves remain to be divided into seedlings of the adequate uniform size to accommodate the mechanical transplanter. AVC has devised a machine with two sets of gang saws that slice the clump into clusters of seedlings (4 to 6 seedlings per cluster) measuring 2 x 2 inches, and 8 inches long. A farmer would not need this machine if he were preparing large 12-inch-diameter clumps for planting fast-developing erosion hedges. This is not to say that the smaller seedlings could not be used for erosion hedges. But the shorter the growing season, and the shorter the rainy season, the more advisable it is to plant large clumps to get the hedge established quickly.

Using Alternative Propagation Methods

This section is adapted from the Board on Science and Technology for International Development (BOSTID) publication, *Vetiver: A thin green line against erosion* (National Research Council 1993).

At this time, researchers and farmers propagate vetiver mainly by root division or slips. The vetiver grower usually rips a slip off the main clump and jabs it into the ground like seedlings. Although the growth may be tardy initially, the plants develop quickly once roots are established. Growers in Malaysia have measured a growth of 5 centimeters per day for more than 60 days. Even where such rapid growth is not possible, the plants often reach 2 meters in height.

It is easy to build up large numbers of vetiver slips. The plant responds to fertilizer and irrigation with massive tillering, and each tiller can be broken off and planted. It is important to put the nurseries in light soil so workers can pull up the plants easily.

Planting slips is not the only way to propagate vetiver. Other vegetative methods follow:

- **Propagating tissue culture.** Micropropagation of vetiver began in the late 1980s.
- **Ratooning.** Like its relative sugarcane, the vetiver plant can be cut and left in the ground to resprout.
- **Lateral budding.** Researchers in South Africa are successfully growing vetiver “eyes” (intercalary buds on the surface of the crown) in seeding dishes.
- **Using culms.** Because young stems easily form new roots, using culms can be an effective means of propagating the plant. Laying the culms on moist sand and keeping them under mist result in the rapid formation of shoots at each node. Using culms is an effective way to propagate new plants from hedge trimmings.

· **Using cuttings.** One Chinese farmer has successfully grown vetiver from stem cuttings. He planted the cuttings, each with two nodes, at a 60-degree angle and then treated them with a rooting hormone—in this case, IAA (indole acetic acid). He achieved a 70 percent survival rate. Interestingly, he cut the stems in December, buried them in the ground over winter, and took stem cuttings from these in early spring, which he planted in April.

Multiplication by Using Culm-branches

P. K. Yoon developed a system for multiplying vetiver by using culm-branches (Yoon et al. 1996). Using this system, when growers repeatedly topped vetiver clumps at 40 centimeters when the clumps were more than 3 months old, the cut-culms produced many branches at the internode. The growers then detached these branches for planting.

A trial was set up to study the multiplication and growth of these culm-branches, which were separated into the following types.

A—Most vigorous with young shoots (with roots)

B—Less vigorous with young shoots (with roots)

C—Most vigorous (with roots)—single plant

D—Less vigorous (with roots)—single plant

E—Least vigorous (without roots)—single plant

F—Terminal shoots

G—Young shoot plants that were growing horizontally (with small roots/without roots)

All types produced a good root system under mist, and transplanting was successful into polybags, nearly 100 percent for all types (lowest, 99.6 percent for type E).

Multiplication by Using Culm-cuttings

Growers should cut back clumps of vetiver to 30 to 50 centimeters to encourage tillering. Early observations suggest that cutting the plant back to less than 30 centimeters resulted in dieback of many culms under Malaysian conditions. An ad hoc trial testing 30-, 40-, 50-, and 60-centimeter cutback height suggested 40 centimeters to be the best height with least setback to growth, minimum dieback, and good tillering.

Growers normally discard the tops after cutting the vetiver clumps back to a 40-centimeter height. If the clumps are 3 months old or older, however, the cut tops include many culms. Each culm has varying numbers of internodal buds, which can be induced to sprout and produce new plantlets under mist. Also the tops, chopped up, make excellent mulch for organic gardeners.

Yoon tested the following three methods of rooting under mist:

1. **Layering of culms.** The grower buried the whole stem in a sand bed with the following results after 5 weeks: (a) with the leaf-sheath intact—23.2 percent rooted; (b) with the leaf-sheath removed—28.4 percent rooted; and (c) with the leaf-sheath slit—35.7 percent rooted.
2. **Rooting of individual node with leaf-sheath intact.** At 5 weeks, 5.1 percent rooted; at 9 weeks, 14.6 percent rooted.
3. **Rooting of individual node with leaf-sheath slit.** At 5 weeks, 31.4 percent rooted; at 6 weeks, 52.7 percent rooted, and at 8 weeks, 76.3 percent rooted.

The third method—rooting each nodal culm-cutting with the leaf-sheath slit—was the most promising.

An assessment of 5-month old clumps in the ground yielded 16.4 ± 1.4 cuttings. The number of cuttings from each clump was highly variable. Note that the above work was done under mist. Based on experience with other crops, however, similar results would likely be obtained if materials were rooted in sand beds under polythene sheet to keep the atmosphere moist; this has not been specifically tested because of the time constraint.

Assessing Different Tiller Types

Preliminary observations suggest that each clump of vetiver produces different types of tillers; thus their growth and tiller formation are quite different. This variation in tillers leads to high variations in response to experimental treatments in which assessment is by tiller formation and dry matter production. This variable could be one of the causes for the lack of significant effect of fertilizer, soil types, etc., previously reported. The experimental error may be higher than the treatment effect. To overcome this error, the tiller types must be sorted out and the within-population plants studied before planning any experiment. The starting material must be of the same tiller type and must be fine-tuned to minimize experimental errors.

The four major types of tillers are as follows:

Type A
With these tillers, which are the most mature and which multiply fast, the culm produces a variable number of culm-branches, thus highly influencing dry matter production. This type of tiller is not good for experimentation.

Types B and C
Although they have no culm formation, these mature tillers are suitable for raising plants for experimental purposes.

Type D
The youngest tillers tend to give variable growth.

For field propagation and establishing a Vetiver System, however, large-scale nurseries are essential.

Conclusions

Vetiver is easy to multiply at low cost. Under normal conditions, multiplication by planting with tillers will give satisfactory results. Refined methods of vegetative propagation by culm-branches and culm-cuttings, however, may be considered from two points of view. One, they will be of little value in mass vegetative propagation because they may not be commercially cost-effective. Two, they will be of value in the following scenarios: (1) initial stage of multiplication of a newly found cultivar; (2) initial stage of multiplication of a newly imported cultivar; and (3) in cases in which base cultivars are imported at high cost from other countries.

Certainly these methods are much cheaper than the tissue culture method. Once the base source for multiplication is established, however, the normal method of splitting the tillers should suffice. In the early phase of P. K. Yoon’s trials, all methods using all plant parts were used. This accounts for the large amount of material that he has produced and distributed.

12. The Potential for Growing Vetiver for Commercial Purposes

***[Book author's note:** The following text is abstracted from a letter that Gueric Boucard sent to The Vetiver Network (circa 1991). It envisions the development of a unique, vetiver-based, farming/commercial operation. The Boucard brothers of Leakey, Texas, once operated the largest vetiver farm in the Western world.—JG.]*

It would be fair for the principals at American Vetivert Corporation (AVC), as producers of vetiver and other essential oils, to caution vetiver enthusiasts that vetiver farming for the purposes of root production and essential oil production is not to be looked on as a new crop for every farmer to get into on any significant scale.

We estimate the world consumption of vetiver oil from all sources to be 2,000 drums per year, or roughly 1 million pounds. (See book author's note at the end of the chapter.) Considering the yield of roots per acre and the yield of oil per ton of roots, approximately 10,000 acres (4,047 hectare) of vetiver worldwide are planted by small farmers in garden-size plots in countries such as Haiti, Indonesia, China, and Réunion island. Apparently, producers in the Réunion island and Brazil do have larger fields and some degree of mechanization.

A vetiver plantation of 1,000 acres (405 hectare) would have to claim a 10 percent market share, and one new 2,000 acres of production would immediately create a glut, and typically, the price of the oil would drop below the cost of production for several months, hurting all the producers in third world countries, and perhaps putting them out of business.

The large-scale mechanized propagation of vetiver, however, would seem to have considerable merit in other areas of agriculture. It could be grown for combined biomass fuel production or as a source of vetiver seedlings for planting erosion hedges in the entire southern United States and Mexico. For instance, based on AVC's own yields of vetiver grass per acre, a 3,000-acre (1,214-hectare) irrigated vetiver farm could produce 120,000 tons per year of dry biomass fuel (vetiver leaves). Because vetiver is a perennial grass that can be harvested (mowed) all year round, the entire 3,000 acres could be mowed once or twice a year at the rate 8 or 16 acres per day, while leaving time for other chores. To make up for rainy days, one could mow perhaps a maximum of 50 acres (20 hectares) a day and furnish an average of 329 tons per day; that is, 14 tons of fuel per hour to fire a boiler.

Again, based on AVC principals' own experience of firing boilers with waste biomass on a smaller scale, such an amount of fuel (taken at 6,000 btu/lb) could produce sufficient steam to generate 14 megawatts of electricity. Assuming that the operation of such a large-scale vetiver grass farm would cost US$100 per acre per year (grass farming only), the cost of biomass fuel would translate into US$0.002 per kilowatt-hour, notwithstanding the cost of operating the power plant. Power utilities would purchase the electricity at about US$0.03 per kilowatt-hour, generating more than US$3 million of revenues for the farm. Or a farmer could sell the dry, palletized vetiver leaves as roughage to feed mills, or as fuel to existing power plants and cement kilns at US$10 per ton, for US$1.2 million per year, without the capital cost and the headache of running a power plant or any other major industrial facility.

After 3 years, the diameter of the vetiver clumps will become so large that the plants will touch each other on the row and become too large (about 24 inches diameter) for the mower wheels to ride on the soil between the rows. The clumps will have to be uprooted, divided, and replanted; replanting would require only 20 percent of the uprooted vetiver. There will be considerable root production from this operation, and although the quality and the yield of the roots of 3-year-old plants is poor, sufficient oil could be extracted from such roots to pay for the operation and generate a profit, without upsetting the vetiver oil market.

Tearoom Inc., of Leakey, Texas, a distiller of essential oils, has a standing offer to purchase vetiver roots at US$350 a ton. At a root yield of 3 tons per acre, this translates into more than US$1 million of additional revenues for the farm.

Still, some 70 percent to 80 percent of the uprooted clumps would be available for sale to farmers for planting erosion hedges. Assuming that one-third of the farm (1,000 acres) would be replanted every year, just so that no plant is ever more than 3 years old, then 1,000 acres of 3-year-old clumps up to 24 inches (61 centimeters) in diameter would produce 2.6 linear miles (4.2 kilometers) of hedges per acre, or a total of 2,600 solid miles (4,184 kilometers) of vetiver clumps 24 inches wide.

Preferably, such large clumps should be at least quartered for planting erosion hedges with clumps of 12-inch (30-centimeter) diameter on 18-inch (46-centimeter) centers. If that is the case, then after using 20 percent for replanting, the 1,000 acres could furnish enough extra material to plant 12,480 miles (20,663 kilometers) of erosion hedges per year—assuming the clumps are quartered and planted 18 inches apart. Given the economy of scale, if the 12-inch-diameter clump seedlings were to be sold to farmers at US$0.05 a piece, the farming operation would have additional revenues of US$2,196,480.

From the point of view of erosion fighting, the farmer could plant 1 mile (5,280 feet) (1,609 meters) for US$176. After just one summer's growing season, the vetiver would grow to a solid and permanent hedge. The cost of doing the same thing with any other erosion-fighting method would be significantly higher and perhaps prohibitive for most farmers.

As shown above, the total yearly revenues of such a farm could add up to more than US$4.2 million, and it could do a lot of good things in the process. A rough estimate of capital and operation costs for this hypothetical 3,000-acre vetiver operation would be US$5 million, of which 60 percent would be for the irrigated farm and irrigation system, 20 percent for farming and processing equipment and buildings, and 20 percent for operating capital.

***[Book author's note:** According to information from the International Trade Center, in 1989 the world trade in vetiver oil comprised about 250 tons or 550,000 pounds (249,480 kilograms); because of the increased interest in aromatherapy, however, international demand and price for* *vetiver oil has nearly doubled in the past ten years. This increase has been a boon for many traditional growers and requirements have been easily met by expanded production.*

Also harvesting vetiver leaves for mulch and baling them for sale to commercial organic farmers or home gardeners could become a profitable sideline. One bale of pesticidal/fungicidal vetiver mulch could cover a large area of garden once fed through a mulching machine. This mulch lasts on the ground for the best part of a year, longer than any other mulch we know of, controlling pests and some diseases at the same time it is retaining moisture in the soil. A bale of vetiver "hay" could sell for as much as US$10. At an estimated 40 tons of dry matter/acre/year and 30 bales/ton, an acre of vetiver for mulching could produce US$12,000/acre (US$30,000/hectare).

Baled vetiver tops are nonperishable, are virtually bug proof, and could be stored and exported worldwide.—JG]

13. Vetiver Grass Technology: International Expansion

How do we measure the global impact of the Vetiver System? International donor agencies go to great lengths and cost to evaluate the impact of their development programs. Because the Vetiver Network is a volunteer organization and has no surplus funds, we do not have this luxury; it is difficult for us to monitor the positive effects of our programs. It is possible, however, to assess progress with the Vetiver System since 1986, the starting year for the revival of the vetiver grass (*Vetiveria zizanioides*) technology. Here is what we have accomplished:

- In 1986, I introduced the vetiver grass technology to India. By the year 2000, some 138 countries knew about the technology and more than 100 were using it in one form or another.
- In 1986, no networks existed to connect people who employed the technology. By 2000, at least 25 vetiver networks were actively sharing information and experiences.
- Since 1989, The Vetiver Network has produced 23 formal newsletters—the *Vetiver Newsletter*—with a distribution of more than 3,000 copies per newsletter. Other networks have produced newsletters regularly—LAVN (Latin America), EMVN (European and Mediterranean), SAVN (South African), PRVN (Pacific Rim-Thailand), WAVN (West African), VETINETPHIL (Philippines), and CVN (China).
- Since 1987, The Vetiver Network has distributed more than 200,000 handbooks about vetiver grass technology and establishing the Vetiver System.
- The Vetiver Network's home page, www.vetiver.org, established for the World Wide Web in 1996, had received more than 40,000 hits by mid-year 2000.
- Today, more than 800 non-governmental organizations (NGOs) throughout the world use vetiver grass technology.
- Some 800 government agencies use the technology.
- About 1,000 research stations/agencies throughout the world receive The Vetiver Network's *Vetiver Newsletter;* many of these research facilities carry out vetiver research.
- In Ethiopia, more than a half-million farmers know about vetiver grass technology and many are now using it, with the numbers increasing every season as planting material becomes available.
- In Malawi, it is government policy to promote the Vetiver System.

Not only has vetiver grass technology grown in numbers, it has grown in application. In 1986, vetiver grass technologists applied the Vetiver System solely as an erosion control measure. By 2000, technologists were using it for stabilizing highway and railway embankments; rehabilitating mine lands; stabilizing river, canal, and drainage banks; stabilizing seashores; reducing the power of wind; providing shelters for sheep; mitigating pollution control associated with municipal trash dumps; stabilizing housing construction sites; purifying eutrophic water bodies; and providing pesticide/fungicide mulch for organic farmers.

Knowledge of vetiver grass technology and the awareness of its importance have also grown. In 1986, few engineers knew anything about vetiver grass; today, many do. For example, in 1999 the Madagascar Society of Engineers formally recognized the Vetiver System as an important technology for stabilizing roads.

In 1986, the Vetiver System was associated only with government projects. Since then, the use of vetiver grass technology has spread from the government sector to the commercial. By 2000, more than 800 commercial and private individuals were receiving the *Vetiver Newsletter*. An increasing involvement of the private sector in establishing the Vetiver System is pervading enterprises that serve the engineering sector. Good examples of such enterprises are found in China, El Salvador, Malaysia, the Philippines, South Africa, and Thailand.

Vetiver grass technology has also become a player in establishing programs for international economic development. The Vetiver System has become a frequent component in bilateral funded projects in countries such as China, Costa Rica, Ethiopia, Ghana, Honduras, India, Indonesia, Madagascar, Malawi, Panama, Papua New Guinea, the Philippines, Sri Lanka, Tanzania, and Zimbabwe.

International gatherings focusing on vetiver grass technology now abound. In addition to conducting numerous site-oriented workshops, leaders in the vetiver field have convened numerous international conferences devoted to the Vetiver System, and most other conferences that pertain to soil erosion control and biological engineering now include papers on the Vetiver System.

The community of vetiver grass proponents, technologists, and researchers, as well as novices and the curious, actively engage in furthering their knowledge and sharing their experiences. People throughout the tropics and sub-tropics send letters and e-mails to The Vetiver Network requesting information about the technology. At The Vetiver Network, we receive feedback from unlikely places, which suggests that the technology is now becoming quite well known and a lot more is happening with the Vetiver System than we really know about. When we started the vetiver initiative, most scientists had either never heard of the technology or thought that it could be confined to only the low altitude Wet Tropics. Vetiver grass technology has indeed come a long way.

Since its inception and acceptance as a viable and sustainable system of soil and moisture conservation, the Vetiver System has spread across the tropics and even into cooler areas bordering the tropics. This chapter takes the reader to many countries around the world where workers use the Vetiver System. Most of the anecdotes have come to The Vetiver Network via letter or e-mail from satisfied workers.

Weed potential

It is very important that any plants used for soil and water conservation do not become weeds in the local environment. It is therefore imperative that only sterile cultivars are used or recommended. We cannot emphasize this point enough. As pointed out in Chapter 3, DNA fingerprinting has shown that almost every vetiver outside its native South Asia is a non-fertile type. Not all of these have a long track record, but several of the cultivars have been grown under close observation for decades, or on an extensive scale including hundreds of millions of individual plants. Genetic similarity and multiple replications of results support traditional knowledge in considering these plants to pose no more risk of weediness than any other domesticated crop plant. Indeed, in this age where horror stories of invasive organisms are common and there seems to be a watchdog group on every corner, it has been gratifying (though not surprising) that vetiver has been examined by almost every environmental nonprofit and government agency around the world, and been given a green bill of health even in Australia, which has perhaps the world's most strict regulations on exotic organisms.

Three vetiver cultivars were found already in Australia when word of our World Bank work began making news. A non-fertile line ('Monto') was selected and its sterility rigorously tested. Since 1989, this cultivar has consistently produced no caryopses (seed) when grown under glass house and field conditions or in dryland, irrigated, and wetland habitats. Paul Truong, who has shepherded vetiver in Australia, tells the following story about the yearly testing of 'Monto' for fertile seeds:

Every year for about six or seven years, I sent vetiver flowerheads from at least ten locations to be tested for seed viability at the Seed Lab of the Queensland Department of Primary Industry, as required by the Department of Environment people there. Every year negative results came back. I also noticed that the results, which I needed to put in my report to them every year, took longer and longer to come back to me. About three years ago, the Department decided to shift the Seed Lab to the University [of Queensland] *and they had a sort of goodbye party for the staff. Although I talked to the senior technician at the lab many times concerning the tests, I had never met her in person. So I came to the party to say goodbye to her, and particularly to thank her for her tremendous work. I came up to her and introduced myself; she looked at me with a sad expression and said "I am so sorry, I could not find any thing for you in all this time, and what are you going to do now?" I was really puzzled and asked her what she meant. "You are trying to select a fertile strain of vetiver, aren't you?" I said, "No," and explained to her what I was trying to prove. We all had a good laugh and she said, "I thought over these 6-7 years you have been trying desperately to breed a fertile strain of vetiver for soil conservation. In the first couple of years, I didn't take much notice of it and just did the routine TZ test of the samples, but the last few years I felt so sorry for you that I spent a lot more time on the samples looking for a viable seed for you. The routine sample is to test 3-4 replicates of 100-150 florets each. In your case, I took between 400-500 florets to be sure that I did not miss any good seeds for you." Anyhow, as we said goodbye, her parting words were, "You can tell the Department of Environment people that 'Monto' is sterile, and I have spent the last 3-4 years trying to disprove it without success." I felt really bad about it, as I should have explained it to her much earlier, but I've really trusted 'Monto' ever since.*

After the many years of intensive examination by the Queensland Department of Primary Industry, this cultivar was registered as the genotype 'Monto' vetiver (named for the Monto District, where in 1989 the first field trial in Queensland was conducted). All research and development application works conducted in four states of Australia—Queensland, New South Wales, Victoria, and Western Australia—have used 'Monto' vetiver. The cultivar shows only some minor morphologic and genetic differences from the 'Sunshine' genotype, and tolerates the climatic extremes of the semi-arid areas in central Australia, the Wet Tropics of north Queensland, and the temperate regions of southeastern Australia. Although only one vetiver species, *V. zizanioides*, is recommended for soil conservation, and only the clone ‘Monto’ can be used in Australia, at least five other species of vetiver are indigenous to Australia (Simon 1989). Ironically, none of these are suitable as hedge plants. The Australian experience with vetiver—carefully and rigorously selecting and testing an introduced genotype while wisely rejecting use of the potentially pestiferous but native species—is a good example of the care that should and has been shown with vetiver around the world.

With the recent advent of DNA fingerprinting, knowledge about ‘Monto’ can be extrapolated to fellow clones worldwide. Because all vetiver research conducted in Australia has been based on ‘Monto’ vetiver, all the Australian results can be applied with confidence to fellow clones around the world. One of these is the ‘Vallonia’ cultivar, which has been used extensively in sugarcane in South Africa by the same family for 100 years, without any seeding or other ecological problems. The experiences with ‘Monto’ and ‘Vallonia’ reinforce one another. The same with the ‘Fiji’ clone: Fiji has used vetiver for 50 years for soil and water conservation in the sugar-growing areas. During that period, vetiver has never escaped or shown any weed potential (Truong and Creighton 1994).

Similar examples (‘Guiyang’ in China, ‘Sunshine’ in the United States) from a dozen other countries exist, but even more important than such “recent” observations, there are types of vetiver that for centuries have been selected and cultivated in South Asia and elsewhere for their essential oil. A good example is Mauritius and Réunion island, where vetiver has been produced on a commercial scale for more than 200 years without evidence of weediness, colonizing, or pestiferousness. Vetiver has been in Indonesia for perhaps 1,000 years, and in Sri Lanka and southern India for even longer. Most of these traditional selections rarely flower and many have never been known to set fertile seed. As a group, these are usually called “South India” or “nonflowering” types (though they occasionally flower). Like sugarcane, they are extremely well behaved. It seems these types were spread throughout the tropics in the last century, both for oil production and because they were used to protect the edges of sugarcane fields from erosion. The old essential-oil types are grown in every tropic soil and clime, and have never been reported to invade or naturalize. They are exceptionally persistent, however, sometimes growing in the same row for 100 years or more, which is why they are legal as boundary markers in parts of Africa and Asia. In Louisiana, solitary plants still stand in pastures as sentries indicating where houses were destroyed during the American Civil War in the 1860s. It is also this quality that helps make them premier hedge plants: they will stay where they are put, but they do not wander. (See Dafforn 1996 for a fuller discussion of environmental concerns about vetiver.)

Although modest sprouting (>2 percent) has been observed in almost every “non-fertile” clone of vetiver under ideal trial conditions, seedling establishment and growth in the field has never been observed in any of millions of ‘Sunshine’ type plants in hundreds of locations in literally every environment. This modern scrutiny makes all the more believable the observations made in South Asia over hundreds of years that the elite vetivers used for oil and hedges have no more weed potential than other domesticated grasses such as wheat or rice. Jack Harlan, the eminent geneticist and scholar of domestication, who was familiar with vetiver from his work in Asia and Africa, was bolder than most people in his claims about vetiver when he said the following (Dafforn 1996):

The wild vetiver is weedy; it's a seedy plant that has fertile pollen and normal meiosis, and it gets around on its own. I think the [traditional] *oil-type vetiver is domesticated; it is not fit for survival in the wild. Because of pollen sterility and irregular meiosis in the South India type, I see no objection to calling it a domesticate. How does this sterile plant get by? Humans have made the sterility persistent by intervention. One could make the claim that it is a cultigen.*

Soil Erosion Control, Water Conservation, and Crop Production in India

During the years 1990 to 1995, researchers in southern India studied the effect of vetiver hedges on soil and water conservation and on the yield of rainfed crops (sorghum, red gram, and castor). They conducted the experiments on shallow, gravelly alfisols averaging a 2.5 percent slope.

Vetiver hedges planted on the contour reduced the runoff and soil loss by 66 to 76 percent (1993–94) and 67 to 97 percent (1994–95) as the hedges became more established. The hedges also increased mean soil moisture by 5 to 9 percent in the 0 to 45 centimeter depth and increased crop yields from 7.0 to 22.4 percent (Rao et al. 1996). But vetiver hedges are not new to India.

Farmers from the southern Indian *taluka* of Gundalpet have been using vetiver hedges on their farms for more than 100 years, and possibly 200 years (anecdotally). For many generations they have used vetiver grass, commonly known as *Khus Khus* in India, principally as a hedge on field boundaries. So far, The Vetiver Network has identified 28 villages with thousands of farmers who use vetiver hedges. Gundalpet has an average rainfall of about 650 millimeters, its soils are shallow alfisols, and the land can best be described as gently rolling (maximum 5 percent slope). Farmers and their families, both young and old, described the benefits of the vetiver hedges—benefits that new users in other parts of southern India and the world also confirm.

General benefits

- Vetiver hedges have a long survival rate. Many of the hedges are more than 100 years old.
- The hedges provide fodder, which is cut every 2 weeks throughout the year, providing an equivalent production of 14 tonnes per hectare.
- Vetiver improves soil moisture as is evidenced by more even crop growth and good yields in dry years.
- Vetiver can be used as a complete low (30 centimeters) boundary hedge for land ownership demarcation.
- With vetiver hedges planted, farming is less risky because of greatly reduced runoff and retention of silt, organic matter, and fertilizers in the field behind the hedges, which allow for higher use of fertilizers compared to non-practitioners.
- The fields of farmers who have vetiver hedges retain more fertilizer.
- Vetiver hedges provide a complete barrier against creeping weed grasses such as Bermuda grass (*Cynodon dactylon).*

Erosion control

- Vetiver hedges have provided soil erosion control because terraces up to 1 meter high on slopes of about 2 percent have developed over time on boundary hedges planted across the slope.
- With the protection of vetiver hedges, micro-catchments have fully stabilized, with virtually no evidence of erosion.
- The hedges have minimized streambed and bank erosion.

Soil moisture improvement

- Compared with groundwater tables of non-vetiver neighbors, groundwater tables appear higher in protected areas as measured by water levels in the village wells.
- Because of soil moisture improvement associated with contour cultivation, crops show significant yield improvements.

System cost to farmers

- The cost per hectare for establishing a vetiver hedge when using hired labor is rupees (Rs) 80 for digging planting material plus Rs 40 for planting slips for a total cost of Rs 120 per hectare (Rs 14/US$).
- The cost of maintaining a vetiver hedge is virtually zero.

Other characteristics confirmed at Gundalpet

- Vetiver grass is resistant to all pests and diseases (farmers' observations during living memory).
- Crops grow close to vetiver with no yield loss.
- It is easy to maintain hedges to a 50-centimeter width by close ploughing, which results in a minimum amount of cultivated land being lost (compared to 5 to 6 meters lost when contour bunds are used for erosion control).
- When vetiver hedges are green, they are fire resistant.
- Seeds from vetiver hedges do not germinate, so vetiver does not become a weed. In more than 100 years, vetiver has never escaped from the original hedges.
- Vetiver leaves make excellent mulch, thatch, and brooms.

Using the Vetiver System for Soil and Moisture Conservation around the World

Many people from around the world are now using vetiver grass technology to improve erosion control and their farming methods. The following sampling of examples illustrates the Vetiver System at work.

Sri Lanka. During the last century in Sri Lanka, farmers planted tea gardens, using an up-and-down-the-slope system without any erosion control, resulting in the loss of more than 1 meter of topsoil. In addition, unplanned and careless land clearing each year results in a soil loss of as much as 250 tonnes per hectare.

Although no research data are available, research workers have observed significant results in soil and water conservation on those lands in Sri Lanka that now are protected by vetiver hedges (Navaratnam 1996).

Malaysia. Since 1992, through the efforts of P. K. Yoon of the Rubber Research Institute of Malaysia (RRIM), owners of rubber plantations, oil palm plantations, and orchards have adopted the Vetiver System as their preferred method for controlling erosion and sediment and for stabilizing land.

Indonesia. Although vetiver grass, compared with other grasses in the upland farming areas in Indonesia, is effective in controlling soil erosion, the people of Indonesia have been slow in adopting the Vetiver System. Because of the upland farmers' low level of income, they chose to use species that give direct, short-term benefits, such as elephant grass (*Pennisetum purpureum*), Leucaena (*Leucaena* spp.), King grass (*Tripsacum laxum*), *and Setaria* spp. Yet only vetiver hedges have reduced the soil loss from 120 tonnes per hectare per year (control) initially to 13.2 tonnes per hectare per year and 0.6 tonnes per hectare per year for the second and third years, respectively. The other grass species are mainly unsuitable for conservation purposes (Hermavan 1996).

Thailand. To conserve soil moisture in orchards, researchers in Thailand planted vetiver grass in a semicircle of 2 meters radius down slope from the tree, resulting in the best conservation of moisture and consequent increase in yield. Planting the grass at other spacings—a semicircle of 4 meters radius and a straight row 4 meters from the trees—conserved less moisture, with the straight row conserving the least.

Studies on row spacing at Chiang Mai show that vetiver planted in a single row had better growth than vetiver in double-row planting. In nurseries, wider spacing provided a higher tiller number and bigger hill size than did closer spacing. There were no significant differences in crop yield between the row treatments. Both single and double rows significantly reduced soil loss compared to the control plots, but planting double rows resulted in an unnecessary waste of planting material. There was no difference in soil loss between the row treatments. The vetiver plots also conserved soil moisture longer than did traditional farming practices (Intaphan, Boonches, and Vathatum 1996).

Philippines. Researchers in the Philippines looking at the nutritive value of vetiver grass found that the grass shows lower levels of macronutrients, particularly phosphorous (P) (0.1 percent), but that it is higher in micronutrients than the commonly used forage species such as Para grass (*Brachiaria* spp.), Napier grass (*Pennisetum purpureum*), and some legumes (Salamanca et al. 1996). Therefore, if used as the main feed for grazing animals, which is certainly not recommended, vetiver needs to be supplemented with some other concentrates. In times of drought, vetiver hedges can be trimmed, chopped up, and fed to livestock; but the whole object of the grass being unpalatable is to stop stock from grazing it out of the ground. Usually vetiver is a "last resort" forage for most livestock.

Fiji islands. About 50 years ago in Fiji, I first developed the concept of using vetiver grass, instead of conventional structures, for soil and water conservation for the sugarcane growers. Farmers in Fiji, particularly those on small farms, now widely use the Vetiver System as a standard practice for soil and water conservation. As in other countries, the Vetiver System has proven to be effective in soil erosion control, and when properly implemented, the system has improved sugarcane yields up to 55 percent, while at the same time increasing the number of ratoon crops from two to at least seven.

Despite this improvement, some tenant farmers are still reluctant to implement the Vetiver System on new plots, and some have even removed the previously well-established hedges. The outcome has resulted in massive soil erosion and loss of cane production. The main reasons for low adoption and rejection of the Vetiver System are complex and include socioeconomic factors, land use policies, land ownership issues, agronomic practices, and lack of extension effort. But mainly, as on the island of St. Vincent in the Caribbean, the hedges have been doing an excellent job for the past 50 years. Young farmers have taken them for granted, being totally unaware of their importance, since the hedges were established before they were born and nobody explained the need for them (Truong and Gawander 1996).

Australia. Paul Truong and his colleagues have developed numerous vetiver systems for agricultural and forestry applications in Queensland, Australia, from rainfed cropping in low rainfall regions to the Wet Tropics (Truong et al. 1996). They used the Vetiver System to replace contour banks in steep sugarcane lands on the wet tropical coast where the traditional method of soil conservation using contour banks presents a problem for farm machinery operation (the channels and banks can be dangerous for large machinery to cross). Vetiver hedges, which can be cut and crossed, offer a solution to that problem.

Also, because the vetiver hedges do not convey runoff as contour banks do, but filter it, the hedges can be laid out with a diagonal opening allowing machinery to pass through. Little erosion will be caused by this gap.

Under rainfed farming conditions, researchers found that mature vetiver hedges can compete with the adjacent rows of crops. In drought conditions in Queensland, 2-year-old hedges reduced establishment, growth, and yield of two rows of grain sorghum adjacent (1.5 meters) to the hedges. Growth and yield were not affected when soil moisture was not limited, as under irrigation (Dalton and Truong 1996). The shading effect of tall hedges also can severely affect the establishment and early growth of seedlings in adjacent rows up to 1.5 meters from the hedges. A lower hedge height will reduce shading effects and water competition with crops at planting.

Farmers in Australia also have used vetiver hedges effectively to stabilize gully erosion in both cropping and grazing lands. When planted on the contour above the gully head (or straight across the active gully), hedges will slow down runoff water, spread it out, and stop the advancement of the gully head. Once the active erosion at the gully head is controlled, gully floors are quickly revegetated with native species and are stabilized (Truong 1996b).

Other significant applications of the Vetiver System in Australia include protecting dam walls against severe rilling and wave action (lap erosion), providing shade for sheep in treeless tropical grasslands, and stabilizing roads and waterways in forestry plantations (Somes 1994).

South Africa. In South Africa, farmers have used the Vetiver System to protect crops such as beans, bananas, and chilies. The two crops that benefited most from the Vetiver System, however, are coffee and sugarcane.

At Vallonia Sugar Estate near Durban, Maxime Robert has fully incorporated the Vetiver System into the management of his farm in the KwaZulu province of Natal. He has used 'Vallonia' vetiver successfully for stabilizing steep slopes, farm roads, and stream banks, and for replacing contour terraces. Recently he successfully extended the Vetiver System into a macadamia orchard on steep lands.

Zimbabwe. Sugarcane growers in Zimbabwe are using the Vetiver System extensively in large sugar and coffee estates.

At Sarabica Coffee Estate in Chipinge, Zimbabwe, the owner, Sandy Scott, replaced contour banks (terraces) with vetiver hedges, making vetiver grass technology the standard soil conservation measure. Planting the hedges between the rows of coffee, Scott reported that, in addition to providing soil and water conservation effects, the hedges have reduced maintenance costs, facilitated traffic for farm machinery, and provided mulch for weed control.

Scott also found that spraying the coffee plants for pests kills many useful predators; now, however, the predators breed in the vetiver rows, safe from the sprays—or is it that the presence of the vetiver hedge repels coffee pests?

Also, in a manner similar to the South African experience, the Vetiver System has been instrumental in stabilizing farm roads, controlling erosion in sugarcane fields, and particularly in stabilizing and preventing silt from entering drainage ditches and irrigation channels. Jano Labat has developed a unique method of stabilizing drainage channels by planting a row of vetiver at the top of the channel to trap sediment in runoff water from the road entering the drain, and then planting another on the top of the concrete-lined drain to protect it from erosion and, at the same time, trapping more sediment (Grimshaw, personal communication).

Malawi. In Malawi, the Vetiver System technologies are now part of the government's soil improvement package. After expressing initial reluctance, agricultural and soil conservation staff now universally accept the technology. The key to effective application has been the use of an A frame for establishing level contours.

Before accepting the Vetiver System, farmers in Malawi virtually were being penalized by having to construct 50-centimeter "contour" ridges and furrows by hand, then planting their crops on top of the ridge, away from the moisture. This method was a misguided government dictum that not only impinged on the farmers' efforts to prepare their land for planting, but it gave the farmers no benefit. Farmers now can see the benefit of the vetiver hedges from the added soil and moisture conservation. The hedges have taken the drudgery out of field preparation, have increased yields, and virtually have drought-proofed the farmers' crops.

One extension worker, when asked to explain the reasoning for the ridge and furrowing method, said that he was told, "the weeds mainly grow in the furrows" (which of course is where the moisture is).

Using the Vetiver System for Flood Erosion Control in Australia

The Queensland Department of Natural Resources (QDNR) has used the Vetiver System successfully in Queensland on the Darling Downs floodplains as a supplement to or an alternative to strip cropping, which relies on the stubble of previous crops for erosion control of fallow land and protection of young crops. During drought or when growing low stubble-producing crops such as sunflower and cotton, however, strip cropping provides little protection. Truong planted eight separate hedgerows of vetiver, totaling almost 6,000 meters, at 90-meter intervals, on a strip-cropped site. Flume tests found that the vetiver hedges, when fully established, provided adequate protection from floodwater over the 90-meter spacing on 0.2 to 0.35 percent land slope (Dalton, Smith, and Truong 1996).

Results during 1997 to 1998, which included several major flood events, have been excellent. The hedges successfully reduced flood velocity and limited soil movement, resulting in little erosion in fallow strips and the complete protection of a young sorghum crop from flood damage. The incorporation of vetiver hedges as an alternative to strip cropping on the floodplains should result in more flexibility, more easily managed land, and more effective spreading of flood flows in drought years with low stubble-producing crops. An added benefit is that now fallow strips are no longer necessary; the area cropped behind the vetiver hedges at any one time could be increased by up to 30 percent—a major "plus"—30 percent more production from a simple, sustainable input.

Using the Vetiver System in Environmental Applications

Both the morphological and physiological characteristics of vetiver grass make it highly suitable for environmental protection in the areas of bio-remedial, filtering, and rehabilitation of polluted lands.

Bio-remedial applications. More people from around the world are using vetiver grass technology in bio-remedial applications. The following examples illustrate the Vetiver System at work.

Thailand. Researchers who studied cabbage crops grown on a steep slope (60 percent) recognize the important role that vetiver hedges play in the process of capturing and decontaminating agrochemical runoff, especially pesticides such as carbofuran, monocrotophos, and anachlor, and in preventing them from contaminating and accumulating in crops down slope (Pithong, Impithuksa, and Ramlee 1996).

Other researchers found that vetiver grass can absorb substantial quantities of lead, mercury, and cadmium in wastewater (Suchada 1996). They also found that a decoction of methanol extracts of ground stem and root matter were effective in preventing the germination of a number of both monocot and dicot weed species. The results of their research indicate the potential of vetiver extract as a natural pre-emergent weedicide (Techapinyawat, Sripen, and Komkris 1996).

Australia. Landfill and industrial waste sites are usually contaminated with heavy metals such as arsenic, cadmium, chromium, nickel, copper, lead, and mercury, which are highly toxic to both plants and humans. The movement of these contaminated materials from these sites needs to be adequately controlled to prevent them from entering the water table.

Research conducted in Queensland, Australia, has shown that vetiver is highly tolerant to high levels of heavy metals such as arsenic, cadmium, calcium, chromium, lead, mercury, nickel, selenium, and zinc (Truong and Claridge 1996; Truong 1994).

Results of the research indicate that vetiver grass is the most suitable of all plants for use in rehabilitating these contaminated sites and have conclusively proved that vetiver can be used to rehabilitate the highly erodible slopes and drainage lines, while at the same time, can also help reduce leachate from these contaminated sites (Truong and Claridge 1996).

Researchers also found that vetiver is highly resistant to nematodes and that young vetiver plants are immune to all major species of *Meloidogyne nematode,* which makes vetiver highly suitable as a companion or hedgerow crop (Truong et al. 1996).

Filtering. The barrier formed by the thick growth of a vetiver hedge and its deep root system is an effective filter of both coarse and fine sediment in runoff water. Sediment in runoff needs to be trapped on site or it will not only be lost to the farmer forever, but it will go on to pollute and silt up streams, harbors, roads, and other infrastructure. Vetiver hedges trap chemical pollutants adsorbed by these products of runoff; holding the pollutants in situ lessens off-site pollution.

Thailand. The Royal Development Project uses vetiver hedges extensively to stabilize earth banks and to filter runoff water from farm dams and fishponds.

Australia. Farmers use vetiver filter strips extensively in Queensland to trap sediment in both agricultural and industrial lands. At a working quarry, vetiver hedges planted across the waterways and drainage lines reduced erosion and trapped both coarse and fine sediment, resulting in less silting of the dam water. Such practices will extend the life of the dam enormously, making low dam construction a more economic proposition.

Land rehabilitation. More people from around the world are using vetiver grass technology for land rehabilitation. The following examples illustrate the Vetiver System at work.

Australia. Vetiver is highly successful in rehabilitating old quarries where few species can be established because of the hostile nature of the soils and the environment. Vetiver is able to stabilize the loose surface, protecting it from wind scald and runoff so other species can colonize the area between hedges. After 2 years, the trial site was completely revegetated with vetiver and local species (Truong et al. 1996).

In Queensland, QDNR has used vetiver grass technology successfully to stabilize mining overburden and highly saline, sodic, and alkaline (pH 9.5) tailings of coal mines and the highly acidic (pH 3.5) tailings of a gold mine. It has used vetiver successfully to stabilize and rehabilitate an extremely erodible acid sulfate soil on the coastal plain where actual soil pH is around 3.5 and oxidized pH is as low as 2.8 (Truong and Baker 1997). QDNR has also used vetiver to rehabilitate salt-affected lands caused by both dryland salinity and irrigation (Radloff, Walsh, and Melzer 1995).

South Africa. Tony Tantum, in cooperation with several mining companies, has proved that vetiver can be used effectively and economically to stabilize/rehabilitate “slimes dams” (tailings) (Tantum, personal communication). As a result of DNA typing by Adams and Dafforn, South African mining companies can apply vetiver research results conducted in Australia with confidence because ‘Monto’ vetiver is identical to ‘Vallonia’ vetiver being used in South Africa (Adams and Dafforn 1997).

Tony Tantum has also been involved in the successful stabilization of slimes dams at platinum and gold mines. It is very important to stress here that at all the successful sites (as compared to the reported failures), researchers set and applied strict technical standards. Workers planted vetiver barriers under professional supervision with good-quality planting material, at the correct distance apart, to rapidly form a dense hedge. Tantum also finds that chicken manure, which is readily available, gives vetiver a great start.

Although vetiver is highly effective in mining rehabilitation and is accepted by the major mining houses in South Africa, the mine rehabilitation section of the Chamber of Mines of South Africa still uses Hippo grass (*Pennisetum* spp.). This species has similar morphological characteristics to vetiver but does not have its persistence and tolerance levels to adverse conditions, particularly low soil pH. It takes time and demonstration to change old habits, or to accept a new technology.

Engineering Applications

Because of its special morphological characteristics of stiff and erect stems and an extensive deep-root system, vetiver has provided a very effective means of flood mitigation and steep slope stabilization.

Using the hydraulic characteristics of vetiver in Australia. Researchers conducted the pioneering work on the hydraulic characteristics of vetiver hedges under simulated flash flood deep flows in the aboveground flume at the University of Southern Queensland in Australia. They needed these hydraulic parameters for designing and incorporating vetiver hedges into a strip-cropping layout to control flood erosion on the floodplains of the Darling Downs (Dalton, Smith, and Truong 1996).

In hydraulic terms, on slopes steeper than 5 percent, apart from slowing the flow in the zone immediately upstream of each hedge and spreading it out, the hedges will not materially affect the volume or rate of flow.

Concerning the sediment trapping of vetiver hedges, the most important factors are hedge spacing and the thickness (density) of the hedge. Closely spaced hedges will minimize the quantity of sediment entrained by the flow. Dense hedges will maximize the depth upstream, the length of the backwater, and the settling time for particles and hence the proportion of the sediment trapped. As terraces form and the percentage slope decreases, the length of the backwater will increase and the sediment-trapping efficiency will also increase—providing the hedge that grows out of the sediment layer remains dense and upright and is not overtopped by the flow (Smith 1996).

Steep Slope Stabilization. Batters of both cut and fill slopes can be stabilized effectively by establishing vetiver hedges on contour lines or across the slope. The deep-root system stabilizes the slope while the hedges spread runoff water, reducing rill erosion and trapping sediment and providing a favorable environment for colonization by indigenous species.

Malaysia. In 1992, P. K. Yoon conducted the first roadside batter stabilization trials (Yoon 1991). The success of these trials and, most importantly, the results of the innovative research and its application conducted by Diti Hengchaovanich have led to the large-scale acceptance of the Vetiver System for steep batter stabilization on major highways in Malaysia (Hengchaovanich 1997).

The research established that the tensile strength and shear strength of vetiver roots in soil blocks are equivalent to one-sixth that of mild steel reinforcement. This strength is as strong as, and in some cases stronger than, many hardwood tree species that have been used previously in stabilizing steep slopes.

Results from this study gave engineers the quantitative parameters needed for designing civil construction projects. The results of the study have led to the wide application of vetiver grass technology in Malaysia and the acceptance of vetiver grass as an effective means of batter stabilization by main roads and railway engineers in Australia as well.

In 1996, Malaysia was leading the world in the application of vetiver hedges for erosion control and slope stabilization in tropical highway engineering. Hengchaovanich concedes that the design is still somewhat conservative, treating vetiver as a "bonus" or an added assurance. Over time, once the vetiver hedges have become more established, a better understanding of the design parameters, especially with the evapotranspiration and hydraulic aspects of the hedges, will result in giving vent to bolder and more innovative designs, maximizing the full potential of vetiver grass (Hengchaovanich 1996; Hengchaovanich and Nilaweera 1996).

Already this work has shown that trying to stabilize "cuts and fills" under extreme conditions of tropical rainfall is better done with a dynamic biological system capable of "bending with the flow" but staying in place, than is done with a static system of concrete or construction that can be isolated, bypassed, or broken, leading to further damage and needing costly and constant repair. But this does not preclude combinations of both the dynamic and static systems working together.

Thailand. Although at this stage, road batter stabilization with vetiver is limited to only the northern regions of Thailand, its effectiveness has been varied because the quality of planting material, planting methods, maintenance programs, and particularly the layout have not been of suitable design. The results are excellent at some sites, but failures have occurred at others because of poor supervision.

Philippines. Through the recommendation of the World Bank, the Philippines Department of Public Works and Housing has started using vetiver for highway batter stabilization. The results so far have been disappointing because, once again, the engineers, who specified vetiver application to the laborers, who then planted the vetiver, had no previous experience or training in the use of vetiver for steep slope stabilization. These failures are due entirely to poor understanding, which leads to improper application. Vetiver is a tool, and like any tool, a user must learn how to use it properly to maximize the results.

Australia. In June 1992, Truong conducted the first vetiver trial on batter stabilization on a steep (1:1) railway cutting. They conducted the trial on a highly erodible sodic soil in northern Queensland, Australia. 'Monto' vetiver planted on the contour stabilized the batters allowing the inter-row spaces to be completely colonized by indigenous vegetation in 6 months. Fifteen months later, this highly erodible slope was at last stabilized by a mixture of vetiver and local native vegetation (Truong, McDowell, and Christiansen 1995).

South Africa. As yet, South Africa has not used vetiver in stabilizing major highways, but its application in the KwaZulu province of Natal for stabilizing both cut and fill batters, roads, and drainage lines resulting from massive earth shaping in the development of industrial parks has now gained wide acceptance by the engineers and planners of these projects throughout the province.

On an international basis and despite the outstanding results in all these countries, highway engineers did not readily accept the application of vetiver for batter stabilization until 1996, following Hengchaovanich's presentation at the first Australian Vetiver Workshop (November 1996) of the work done in Malaysia. From then on, the Australians have used 'Monto' vetiver to stabilize an embankment of 32 kilometers of a steep railway line on a mountain range in southeast Queensland. Main roads design engineers have now specified vetiver for both batter stabilization and runoff water control.

In 1995, Australian researchers started a trial to compare the relative effectiveness of the native Australian vetiver species, *V. filipes, Lomandra longifolia*, and 'Monto' vetiver in a comparative trial for batter stabilization.

Following a prolonged period of rain with 400 millimeters in total, the sections planted with the Lomandra and native vetiver collapsed, while the 'Monto' vetiver section remained intact.

These results clearly show the unique characteristics of *V. zizanioides* compared with other vetiver species and other grasses that have been recommend for conservation purposes

Conclusion

From the results of research and the success of numerous workers as presented above, it is clear that we now have enough evidence that vetiver grass technology is ready to move out of the farm gate, beyond the soil and water conservation applications in agricultural lands, to protecting the environment in general, with particular emphasis on rehabilitating contaminated lands, mining wastes, and bio-remedial applications, including wetlands and aquaculture.

The only way to achieve effective results with vetiver grass technology is to emphasize the importance of the following:

- Appropriate design;
- Correct application techniques; and
- Maintenance of the hedge for two seasons.

When a planned Vetiver System meets these strict specifications, it will achieve the system's effectiveness.

14. Networking and Establishing a New Technology

by Richard Grimshaw

About the Guest Author: *The author of this chapter, Richard Grimshaw, is currently the Chairman of The Vetiver Network. Since the mid-1960s, he has worked in tropical and semitropical countries as an agricultural extensionist, soil conservationist, and World Bank agriculturist. He and I started the modern vetiver era when we worked together in India during the mid-1980s. On his return to Washington in 1987, Grimshaw set up an informal worldwide network for disseminating information about the Vetiver System. At the time of his retirement in 1994, he was the World Bank's agricultural adviser for Asia. In 1995, he established The Vetiver Network as a formal non-governmental organization. Since then he has raised about US$1 million to support the operations of The Vetiver Network around the world.—JG.*

For hundreds of years, farmers in India (Gundalpet, Karnataka) have used vetiver grass (*Vetiveria zizanioides*) to demarcate farm boundaries. In other parts of India (Orissa), farmers have used it to stabilize rice field bunds and interfield channels. Other countries, such as the Philippines and Thailand, traditionally have used the Vetiver System to stabilize rice field bunds. Historically, vetiver grass was well known in many tropical countries for its aromatic and medicinal properties. Thus, as a practical farmer-based technology, it was not difficult to introduce it on a wider scale for an extended range of applications. Earlier in the twentieth century, the sugar industry had recognized the value of vetiver grass for conservation purposes, and it was used for this purpose in the West Indies and South Africa. In the 1950s, the Vetiver System was introduced to Fiji for soil conservation for expanding cane growing onto steep and erodible lands. John Greenfield, a talented New Zealand agronomist and the author of this book, had been responsible for introducing vetiver grass to Fiji. In the 1980s, Greenfield worked for the World Bank in India, and it was there that he and I started the current Vetiver System initiative.

In 1986, the Vetiver System was pilot tested on a number of World Bank-funded watershed projects in the lower rainfall areas of central India. At that time, much opposition was expressed by government soil conservation departments (they were more interested in the budget and in popular, costly engineered structures that created many opportunities for corrupt practices) and by some scientists who viewed the Vetiver System as a threat to their carefully crafted, long-term research agendas that focused primarily on constructed engineered systems. Fortunately, some officials, often the more junior ones (primarily from the non-governmental organization [NGO] community), supported the Vetiver System and it is these persons who can take credit for India's continuing interest in vetiver grass technology.

In 1987, I returned to the World Bank's offices in Washington. D.C., where in 1989, I took the opportunity to establish a worldwide Vetiver Information Network (VIN). VIN was the real start of an intensified effort to put the Vetiver System in front of millions of potential users. Not long after, VIN was able to draw on research results that were generated by, among others, Bharad in India and P. K. Yoon in Malaysia (Bharad and Bathkal 1991; Yoon 1991). Both scientists made invaluable contributions to the Vetiver System and helped turn it into a respectable technology that met scientific criteria.

Activities of The Vetiver Network

In 1989, VIN distributed a published monograph to VIN members; in that year we had 76 members who knew about vetiver and used it (Greenfield 1989). In March 1990, after earlier distributing two circulars, VIN published and distributed the first formal VIN newsletter (newsletter number 3). Since that time, 23 newsletters have been published and distributed to between 3,000 and 4,000 readers. People in more than 100 countries receive the *Vetiver Newsletter* regularly. These hard copy newsletters, the central and most important means of information transfer, are supported by other forms of communication, including booklets, an Internet Web site, CD-ROMs, and videos.

In November 1995, after my retirement from the World Bank, I recreated VIN as The Vetiver Network, a nonprofit charitable organization located in Virginia, USA, with start-up funds from an anonymous UK Trust. I appointed a board of directors and raised some funds. In 1995, Monsanto awarded The Vetiver Network the John Franz Sustainability Award of US$100,000 for the best environmental technology. Further financial support came from the Royal Danish government and the World Bank. Since 1995, we have raised about US$1 million, which has enabled The Vetiver Network to support NGOs and other agencies and users around the world in initiating the Vetiver System programs.

Since late 1996, The Vetiver Network has provided technical and funding assistance for establishing 25 regional and national vetiver networks, including networks for the Amhara Region of Ethiopia, China, Europe and the Mediterranean, Latin America, Madagascar, the Philippines, Southern Africa, the Pacific Rim, Thailand, Vietnam, and West Africa. Other networks have been developed or are being developed in Cameroon, Haiti, Nigeria, the Seychelles, and Tanzania, as well as 10 in South America. Regardless of the stage of development at which these networks are operating, all of them are administered by dedicated people who strongly believe in the potential of the Vetiver System.

These networks do more than just disseminate information; they actively support collaborative field initiatives with communities, government agencies, NGOs, and private sector enterprises. These networks and those yet to be developed will in the long term be the prime movers of the technology. Some, such as the Latin America Vetiver Network (LAVN), the China Vetiver Network (CVN), and Vetiver Network Philippines (VETINETPHIL), already have taken on such roles and are strongly affecting the accelerated rates at which the Vetiver System is being adopted in their areas of influence. The Pacific Rim Vetiver Network (PRVN), administered by the Royal Development Projects Board (RDPB) of Thailand with the personal support of His Majesty the King of Thailand, has successfully disseminated Vetiver System information. PRVN also published two papers: one on the environment, written by Paul Truong of Australia, and one on engineering, written by Diti Hengchaovanich of Thailand (Truong and Baker 1998;

Hengchaovanich 1998). Both papers have had an important effect on those people who received and read them.

The efforts of Sumet Tantivejkul, then Secretary General of RDPB, and the officers of the Lands Department, who under His Majesty's guidance, undertook an extensive research and development (R&D) program of the Vetiver System that culminated in the First International Conference on Vetiver held at Chiang Rai in 1996 (Royal Development Projects Board 1996a; 1996b). This R&D laid the foundation for wider adoption of the technology in Thailand and elsewhere in the world. The Thai government has been generous in supporting the Vetiver System, not only in words, but also in funds, and has welcomed numerous overseas guests for visits and training in the Vetiver System. Contrary to common perception, it was the RDPB, and not The Vetiver Network, that coined the description of vetiver grass as the *miracle grass.*

The Vetiver Network has provided small grants (about US$10,000 each) to 20 agencies (including NGOs) for the development of local vetiver field initiatives. Most of these development projects have proven successful, including projects funded by the mini-grant programs administered through CVN and VETINETPHIL. Small grants to NGOs in Ethiopia have led to literally tens of thousands of Ethiopian farmers' learning about the Vetiver System. In that country, one man in particular, Alemu Mekonnen, has been responsible for disseminating the technology.

Although most of the grants have been small, a number of useful spin-offs have come about because of the grants, including feedback on performance and farmers' perceptions of the technology, catalytic impact on surrounding areas, and often the spawning of fledgling networks that involve other agencies and NGOs. For example, Ngwainmbi Simon of Cameroon, with some support from The Vetiver Network, established a small vetiver-focused project—Belo Rural Development Project (BERUDEP). Then together with other NGOs and government agencies, he established a Cameroon Vetiver Network.

Most of the groups that receive grant funds from The Vetiver Network would never have had the opportunity to receive a grant from a foreign donor, or even a local donor. When The Vetiver Network made the grant with the clear objective of the promotion of a single technology—in this case, the Vetiver System—most recipients proved to be able and committed to carry through with the objective.

The Vetiver Network has granted funds to a group of Australian researchers, under the coordination of Paul Truong, to undertake some small but useful experiments relating to the Vetiver System. The approach has leveraged other funds and personnel to support The Vetiver Network's modest input. The Vetiver Network has made available a few travel grants that have enabled some of the best vetiver resource people to attend key workshops designed to accelerate the adoption of the technology in other sectors. This has been particularly true in the engineering sector where Truong (Australia) and Diti Hengchaovanich (Thailand) have been instrumental in convincing engineers in Australia, China, Madagascar, Malaysia, the Philippines, Thailand, South Africa, and Vietnam on the merits of using the Vetiver System.

Madagascar provides a good example of how experienced personnel convinced many engineers and environmentalists of the value of the technology. Within two years of the initiation of a Vetiver System program in Madagascar, the Madagascan Society of Engineers had formally adopted the vetiver grass technology as an important input in designing and constructing engineered earthworks, and the adoption rates for a range of the Vetiver System applications are accelerating.

The Vetiver Network has awarded US$80,000 as prize money to more than 60 people who have demonstrated and undertaken useful research and development of the Vetiver System. These awards, though not large, have provided both incentives and recognition to vetiver supporters around the world. Not only have many of these people produced important scientific verification of vetiver's potential, but they have also provided feedback of actual development programs. The Vetiver Network awards have been made in conjunction with the King of Thailand Vetiver Awards, the latter funded personally by His Majesty the King of Thailand.

Finally, The Vetiver Network has made it central to its strategy to assure a steady stream of hard copy newsletters, handbooks, CD-ROMS, videos, slides, and copies of papers to whomever requests the information. Most are provided at no cost, and all are technically focused and relevant to the Vetiver System. The most successful publication, and that most widely distributed, is Greenfield's handbook, *Vetiver Grass: The Hedge against Erosion* (1987). The World Bank has published four editions of this practical field guide, and more than 200,000 copies have been circulated in English, Spanish, and Portuguese. In addition, many thousands of copies have been translated by various agencies into other languages, including Chichewa (Malawi), French, Gujarati, Hindi, KiSwahili, Malagasy, Mandarin, Nepali, Pidgin, Swazi, and Zulu. Just recently, The Vetiver Network learned that the World Bank-funded agricultural R&D project in Ethiopia will publish the handbook in three of the country's most important languages. Copies of the French, English, and Spanish versions are also available on the Internet at The Vetiver Network's site: www.vetiver.org. Two other publications have received wide distribution: (1) the review of the technology by the National Research Council (NRC) under the chairmanship of Nobel Prize winner Norman Borlaug in *Vetiver Grass—A thin green line against erosion*; and (2) the World Bank's technical paper number 212, *Vetiver Grass for Soil and Water Conservation, Land Rehabilitation, and Embankment Stabilization*, which Larisa Helfer and I edited (Grimshaw and Helfer 1995).

Accomplishments

It is not easy to quantify the results of The Vetiver Network's activities, because like most other nonprofit organizations, funds for monitoring and evaluation do not receive the highest priority. This does not mean, however, that The Vetiver Network neglects monitoring and evaluation; rather it means that we gather results in the form of feedback from individuals and agencies involved with programs. Ultimately, we can measure success in users' demands for a new technology—in this case, for vetiver plant material—and currently, in every country where vetiver grass technology is being used, demand is greater than supply.

The Effectiveness of Vetiver Grass Technology Based on Research and Field Experience

We can measure the effectiveness of vetiver grass technology by examining the experience in research and in the field in areas such as soil and water conservation, crop yields, forestry development, engineered structure stabilization, pollution control, groundwater improvement, flood control, land rehabilitation, and disaster mitigation.

Soil and water conservation. The Vetiver Network has received a mass of information indicating that the Vetiver System is one of the most effective means of reducing soil loss and runoff. The following researchers, among others, have consistently shown that, when vetiver hedgerows are planted across cultivated slopes, soil losses can be reduced by as much as 90 percent and runoff losses by up to 70 percent: Allison (1998), Bharad (Bharad and Bathkal 1991), China Vetiver Network (1997), Dreyer (1997), Grimshaw (1996; 1997a), Howeler (1996), Juliard (1997), Liyu Xu (1997), Lodha (1996), Nehmdahl (1999), Pawar (1998), Robert (1993), Rodriguez (1995), Ranganatha Sastry (1995), Shelton (1996; 1998), Simon (1998), Subudhi (Subudhi, Pradhan, and Senapati 1998), Suyamto (Suyamto and Howeler 1999), Thailand (1994; 1996), Truong (1996b; Truong and Baker 1996), Tung (Tung and Balina 1991), and Yoon (Yoon et al. 1996). The results of their studies can be sustained year after year as long as the hedgerows are maintained.

Crop yields. Experimental work in India by Bharad in the semi-tropics and by Howeler in the Wet Tropics demonstrated that crop yields significantly improve when the Vetiver System is used for soil and moisture conservation (Bharad and Bathkal 1991; Howeler 1996). Rao's investigation of the effect of the Vetiver System on alfisols in southern India shows significant increases in crop yields, increased soil moisture, reduced runoff, and reduced soil losses (Rao et al. 1996).

Forestry development. Vetiver has been used successfully in southern India on the Maheshswaram Watershed Development Project in conjunction with eucalyptus plantations. In southern China, Liao Baowen undertook some trials with eucalyptus, stylosanthes, and vetiver (Liao Baowen, Zheng Dezhang, and Zheng Songfa 1996). He found that vetiver reduced soil and water loss (54 percent and 18 percent, respectively, over the control plot) better than did *Stylosanthes* sp. Five-year-old eucalyptus on average had a 16 percent increase in diameter at breast height compared to the control. Plantation tree species such as eucalyptus and teak have little undergrowth, and the soil is generally unprotected; large amounts of sheet erosion often occur under these conditions. With the Vetiver System having a positive role in mitigating such problems, foresters might want to consider new planting designs to accommodate the Vetiver System.

Engineered structure stabilization. Tantum, Truong, Yoon, Xia Hanping, and others demonstrated the effectiveness of the Vetiver System for embankment stabilization (Tantum 1993; Truong 1999; Yoon 1995; Xia H. P. et al. 1999). Hengchaovanich and Nilaweera, in a very important paper, demonstrated vetiver's stabilization effect on highway embankments (Hengchaovanich and Nilaweera 1996). They quantified the properties and tensile strength of the root system of vetiver grass, and for the first time, its impact on the shear strength of soils. They found that the average root strength was one-sixth that of mild steel. This paper has been well received by engineers because it was something they understood, and their interest and response have been generally positive.

Pollution control. Truong and Xia Hanping quantified the effectiveness of vetiver in reducing the dangers of polluting substances and heavy metals, and its use in mitigating environmental problems of controlling leachate from municipal trash dumps, industrial waste sites, and mine tailings (Truong 1996b; Xia Hanping et al. 1997). Quantifiable results from the field clearly demonstrate how planners can use the Vetiver System as effective streamside buffer strips against surplus nitrate and phosphate runoff from agricultural lands (Truong et al. 2000). Truong's work demonstrates that vetiver grass is more tolerant than most other plants to heavy metals, and thus will survive levels of high toxicity.

Groundwater improvement. Although no detailed experiments have been carried out regarding groundwater improvement, good evidence suggests that the Vetiver System improves groundwater recharge. This result is expected since rainfall runoff has been reduced by as much as 70 percent where the Vetiver System is applied. Mounting evidence also exists that the root structure of grasses such as vetiver has the capability of punching through hardpans (Kemper, personal communication). Thus the downward movement of water is increased and aquifers are recharged. Measurements of water levels in wells in Mysore and Orrisa (India) show that when associated with vetiver grass hedgerows, water levels are higher than those that are not associated with vetiver.

Flood control. Dalton, Smith, and Truong demonstrated the effectiveness of vetiver grass hedgerows in reducing flood damage to cultivated lands on the Darling Downs of Queensland, Australia (Dalton, Smith, and Truong 1996; Dalton 1997). For the first time, quantifiable data were developed to support the dynamics of reduced erosion losses and the impact of the hedgerows on protecting and improving the standing crops and changing farm management practices.

Land rehabilitation. Field observations show that the Vetiver System can be used for rehabilitating extremely degraded soils. Use of the Vetiver System on India's ussar (saline) lands of Uttar Pradesh resulted in the eventual reforestation of large areas of wasted land (National Research Council 1993). In India's Orissa state, G. C. Niak used the Vetiver System as the key technology for watershed management programs (Kumar 1996). In Fiji, India, and Australia, for example, the Vetiver System application has resulted in preventing and rehabilitating gullies. Mining companies are using the Vetiver System more frequently to rehabilitate tailings and other polluting sources related to the mining industry (Berry 1996). Truong has carried out a series of practical research programs in Australia, all of which are leading to a clearer understanding of this important use of the technology (Truong 1999; Truong and Baker 1996).

Disaster mitigation. Following the aftermath of Hurricane Mitch in 1998, Thurow and Smith found that where vetiver hedgerows had been planted in Honduras, very little damage had occurred (Thurow and Smith 1998). In El Salvador, Miranda reported only three cases of Vetiver System failure on highways that had been protected by vetiver, and these occurred where the contractors had not adhered to the engineering design standards (Miranda 1999). Before Hurricane Mitch, Balbarino cited the usefulness of the Vetiver System for preventing cyclone damage to crop fields in the Philippines (Balbarino 1997).

Other applications. Labat of Zimbabwe has used vetiver for thatching houses (Labat, personal communication). (Note: If people use proper thatching techniques, vetiver thatch will last "forever.") Mekonnen of Ethiopia writes to say how important vetiver is for thatching the traditional "tulkul," where most other grasses are no longer available. Vetiver's major commercial use is for its aromatic oil—an essential ingredient of the perfume industry—extracted from its roots. Other uses include handicrafts, medicines, pest-free mattress and pillow stuffing, floor mats, and privacy "fences" (Mekonnen, personal communication).

Agronomic Research

Over the past decade, researchers and users have examined many aspects of vetiver grass to try to better understand its characteristics and function. The Rubber Research Institute's leading plant scientist, P. K. Yoon of Malaysia, undertook perhaps the most exhaustive and practical evaluation (Yoon 1991; 1993). He examined most aspects, including vetiver's adaptation to a wide range of growing conditions (such as soil conditions, shade, rainfall, fire tolerance, water logging, and fertilizer requirements), propagation techniques, and field planting applications. He developed new systems of propagation (foam rubber-core growing media), developed criteria for handling plant material in the nursery and the field, and created the first technical specifications for the engineering community. In Thailand, the Royal Development Projects Board and the Lands Department undertook a wide range of experiments and demonstrations that tested the effectiveness of the technology; they also developed improved systems of propagation and field applications (Thailand 1994). The tissue culture propagation program, which was outstanding in both output and cost-effectiveness, achieved a lot more than most people are aware of. This program would be worth documenting.

Centro Internacional de Agricultura Tropical (CIAT) scientists carried out some useful research that mapped and compared the root growth patterns and dynamics of vetiver grass compared to other useful conservation grasses such as lemon grass (*Cymbopogon* spp.) and Guatemala grass (*Tripsacum laxum*) (Tscherning et al. 1998).

Two scientific investigations, one old and one new, demonstrate how vetiver grass technology and the vetiver plant capture the imaginations of people associated with vetiver.

First, Xia Hanping discovered some early (1950s) investigations and trials by Chinese scientists relating to the propagation techniques of vetiver (Xia Hanping 1997). At that time the plant had just been introduced to China for essential oil purposes, and plant multiplication was a critical issue for expanding the vetiver oil supply to the perfume industry, just as it is today when the Vetiver System is introduced for the first time to a country as a bioengineering tool.

Secondly, in 1997, Robert Adams and Mark Dafforn published their hallmark paper that for the first time, set out the results of DNA testing of vetiver grass accessions collected from around the world (Adams and Dafforn 1997). Three important conclusions emerged from that work: (1) much of the vetiver grass now forming the basis of the worldwide Vetiver System initiative is of the same genotype—'Sunshine' (*V. zizanioides*)*;* therefore, research results from one country can be used quickly by another without the need for prolonged and exhaustive testing; (2) the few seeds of this predominantly used cultivar 'Sunshine' are infertile and in the field, so the cultivar is not invasive, and therefore, not considered potentially weedy; and (3) because the ‘Sunshine’ genotype is so prevalent, we need to look for other cultivars as backup in case of a genotype failure caused by a yet-to-be-identified disease.

Socio-economic Research

Yudelman, Greenfield, and Magrath conducted economic analyses that confirm that the Vetiver System has a robust internal rate of return (IRR) (Yudelman, Greenfield, and Magrath 1990). This finding is not surprising, because the cost of establishing and maintaining the Vetiver System is low when compared to the cost of establishing and maintaining engineered structures. The analyses of data from many projects confirm the economic efficiency of the technology, with the IRR often more than 100 percent. Ranganatha Sastry compared the costs of the Vetiver System to the costs of traditional earthen structures recommended by the Soil Conservation Department of Karnataka, India, and showed the cost-effectiveness of the Vetiver System—lower establishment costs and virtually no maintenance costs—compared to engineered structures (Ranganatha Sastry 1996).

Farmers, even those who cannot read and write, are good observers when it comes to what is happening to their soil, manure, and crops. They are also good when it comes to apportioning their precious labor resources. Feedback from a study, the HIMA/DANIDA project in Tanzania, indicates that farmers prefer the Vetiver System to other conservation technologies because the labor input is less (Mgalamo and Qaraeen 1996). Mekonnen in Ethiopia writes that women like the technology because it is less physically demanding than “Funya juu”—the most common alternative form of engineered terrace (Mekonnen 2000). In Ethiopia, a woman can build about 15 meters of earth terrace per day, compared to planting 200 meters of vetiver hedgerow per day.

Three separate reports from Tanzania, El Salvador, and the Philippines all indicate that when farmers were offered the option of three or four different conservation barrier systems, about 80 percent consistently preferred the Vetiver System and continued to use the technology in subsequent years (Mgalamo and Qaraeen 1996; NOBS 1997; Balbarino 2000). Comparative studies by Howeler undertaken in Vietnam, Thailand, and Indonesia show that most farmers under study found the Vetiver System to be overall the most profitable (Howeler 1996).

The economic assessment of using the Vetiver System for stabilizing earthworks has been neglected. Xia Hanping reports that on field trials in Guangdong Province of China, the cost of stabilizing highway embankments with the Vetiver System is 10 percent of the cost of conventional engineered systems (Xia et al. 1999).

In some cases in Malaysia and El Salvador, highways were continually being partially destroyed because of high rainfall, runoff, and difficult soil conditions. The use of the Vetiver System provided near total stability and thus reduced annual maintenance costs significantly. Under such circumstances, the IRR must be infinite. In Madagascar, the Vetiver System has been promoted vigorously in the past 2 years as a technology for highway stabilization; the results and the demand for the technology speak for themselves. In Madagascar, irrigation canals stabilized with the Vetiver System have required no maintenance since their construction 8 years earlier.

Many levels of costs may be associated with the Vetiver System, depending on nursery technology and planting methods. The least costly method is by dividing existing hedgerows and planting bare-rooted material as new hedges in adjacent fields. Most farmers who have a ready supply of vetiver grass use this technique. In India, using this method, a single person can plant a minimum of 100 meters of hedge a day. Thus on gently sloping lands (less than 5 percent), the cost of protecting 1 hectare of land is only about US$3. Costs increase when nurseries have to be maintained, and earlier I estimated that in Madagascar costs increase to about US$4 to US$12 per hectare when plant material has to be propagated in nurseries, transported to a site, and then planted (Grimshaw 1997a). Costs further increase when containerized plants are produced and used on special high-cost sites (highways). Containerized plants in Madagascar cost about US25cents each. Thus the cost per 100 linear meters of hedgerow will be in the order of US$150. The hedgerow will protect about 100 m^2 of embankment, which is much cheaper than the cost of conventional systems (which varies throughout the world).

A lot of site information is available on the costs and benefits of the Vetiver System, but the information needs analyzing (sounds like good opportunities for graduate student studies).

Networking—A Means of Disseminating Technology

The Vetiver Network was one of the early organizations to network a single technology. Subsequently, other vetiver networks were formed in association with The Vetiver Network. Together, the networking process has been successful. If a new technology is to be introduced, it is worthwhile setting out some of the reasons for this success of the networking process:

- The networks focus on the Vetiver System and not on other comparable technologies (although they acknowledge that other technologies may be used effectively in conjunction with the Vetiver System or as stand-alone technologies). One of the failures of many technology initiatives and development programs is that sometimes too many options are introduced that prove to be overcomplicated as a message and for the messenger. Lower-level extension workers often think that delivering one or two good messages will produce better results than bringing multiple messages. Furthermore, the Vetiver System is an exceptionally good technology that is superior to all other vegetative systems—feedback from users confirms this fact. Some bilateral donors think that beneficiaries need to have many options to choose from. This view is acceptable only if the intended beneficiary fully understands what the options are. Fifteen years ago, hardly anyone knew about the Vetiver System; thus the need was for a single technology approach to disseminate the Vetiver System technical message.
- The message is technically simple, low cost, and effective when applied correctly. The Vetiver System is really a very simple technology to apply, and good demonstrations quickly convince potential users. “Seeing is believing” is an important aspect of passing the message on to new users. One user wrote to The Vetiver Network, “we read, we did, and it worked”—what better accolade than this.
- The technology requires a much lower labor input than traditionally engineered systems, and once established, it needs little maintenance. On average, a person can construct 15 meters of traditional terrace per day, compared to 200 meters of the Vetiver System hedgerows per day. This saving in time means that a hectare of land can be protected in 2 or 3 days, compared to

40 days for traditional terracing; therefore, it is an attractive technology for resource-poor farmers.

- The Vetiver System is gender positive. For example, Ethiopian women like the technology because building the terraces with vetiver is not as hard work as traditional terracing. They also see many useful social by-products from the grass, including thatch, weaving materials, medicinal supplies, mattress stuffing material, snake excluder, privacy hedges, and a host of other uses. Women in the Philippines like the technology because they can develop mini-nurseries to produce containerized vetiver plants to sell to the commercial sector for highway stabilization purposes. They call it "cash grass."
- The Vetiver System is unique because vetiver grass can be applied over a wide range of ecological conditions (hence a basis for wide adoption) and for many environmental and economic uses—the two often combined. It is difficult for most people to believe that the grass will grow over a wide range of extreme conditions. But it is true: one species will do the job of many. Once planners and users are convinced of vetiver's versatility, and promote it as such, the technology adoption accelerates rapidly.
- "The end user comes first" is a basic principle of The Vetiver Network. Users are more important than government officials and scientists. The Vetiver Network recognizes that the latter are useful, but we do not forget that it was the users, in the first place, who developed the technology; and it is the users who come up with many of its refinements.
- Most information that we receive at The Vetiver Network is immediately fed back to users. It is published in the *Vetiver Newsletter* and on The Vetiver Network's Web site (www.vetiver.org). There are no delays.
- With the end user as the peer reviewer, we have no formal peer reviewers. The user either uses the information or rejects it. As long as The Vetiver Network receives material that is readable and relevant, we will publish it. No peer reviewers reject the material as unworthy of publication; nor do they reject the material because it conflicts with their own agendas. No supervisors seek authorship in return for publication.
- The Vetiver Network provides incentives (awards) to encourage active participation. The awards program has been successful; not only does it encourage research, but it also acknowledges many unnoticed people in the Vetiver System who work hard with little recognition. A Vetiver Network award is often a coveted prize, even if it is just a certificate. (In the future, if The Vetiver Network has limited funds, certificates may be the only way we can recognize worthy contributions to the furthering of the Vetiver System.)
- Most vetiver researchers and users have generously shared their information. Because of the open approach taken by The Vetiver Network, those involved with vetiver have been keen to provide feedback, although we do not get all the feedback that we would like and encourage those who have received to also give.
- In most countries, committed individuals make great efforts to disseminate information about the Vetiver System and to organize training. In addition, about three dozen individuals around the world have really made a difference in "moving the technology." Among them and foremost is His Majesty the King of Thailand and his daughter, Her Royal Highness Princess Maha Chakri Sirindhorn of Thailand. Others include Paul Truong, Australia; Ngwainmbi Simon, Cameroon; Xia Hanping and Xu Liyu, China; Joan Miller and Jim Smyle, Costa Rica (now of the United States); Alemu Mekonnen, Ethiopia; Linus Folly, Ghana; Govind Bharad, India; Stephen Carr, Malawi; P. K. Yoon, Malaysia; Cornelis des Bouvries, the Netherlands; John Greenfield and Don Miller, New Zealand; Ed Balbarino and

Noah Manarang, the Philippines; Mike Pease, Portugal; Duncan Hay and Tony Tantum, South Africa; Narong Chomchalow and Diti Hengchaovanich, Thailand; Glenn Allison and Paul Zuckerman, United Kingdom; Ken Crismier, Mark Dafforn, Criss Juliard, and Noel Vietmeyer, United States; and Jano Labat, Zimbabwe. These are but a few of the many active participants of The Vetiver Network—they and others have all created change.

- Of the information that is networked, 99 percent is delivered at no cost to the recipient, and it is delivered fast. Early in its operations, The Vetiver Network found that people either do not like paying for new information, or they do not have the money to pay for it, or they cannot get the foreign exchange even if they have the money. So we have a policy that it is better to get the information out at our cost rather than not get the information out at all—or in some limited amounts. Occasionally, we ask people to pay or to make a donation. But the success of the Vetiver System is partly because we have delivered good information quickly and at no cost.
- The Vetiver Network has deliberately set a policy that encourages affiliated networks to take the lead at regional and national levels. Although The Vetiver Network led in the beginning, we have made great efforts to devolve responsibility and fund-raising to local networks. We have provided from US$30,000 to US$50,000 per network to help networks get off to a reasonable start. Mostly the response has been good and the networks have done far more than we originally anticipated. Networking vetiver technology appears to be self-sustaining. If The Vetiver Network closed down we could be assured that the Vetiver System adoption would continue at an increased rate, particularly in those areas that are using it widely. This says much for the technology and for the way the technology has been disseminated. Many countries and sectors still do not know much about vetiver. Thus, we think it is important to keep The Vetiver Network operating in some form or other.
- In our effort to disseminate information, we find that technology such as the Internet home page (www.vetiver.org) and CD-ROMs provides powerful tools. A picture is worth a thousand words, as Chapter 16 illustrates so well. The Vetiver Network has made a point of sending out videos and slides relating to the technology and its uses, and now that CD-ROMs are so inexpensive (US$1,500 per thousand CDs), it is possible to send out all we know about vetiver at a very low cost. The current CD that we give away includes 20 newsletters, important vetiver papers and articles, the vetiver database, five pictorial presentations, and the "Green" book in English, French, and Spanish (Greenfield 1987). The Internet also provides a good information source about the Vetiver System. The Vetiver Network's home page, with links to other vetiver network sites, contains all we know about the Vetiver System (some 15 megabytes). More people are using the Internet, and if just 20 percent of those who access vetiver.org actually do something with what they have learned, then the return to the annual cost of running the home page (about US$1,000 per year) and the associated Web site will indeed be high. As organizations with similar interests establish other Web sites and site managers make interlinks among sites, we can expect an acceleration of hits on The Vetiver Network site.
- Hard copy newsletters are an essential component in disseminating information to most recipients. Because most of our participants do not have computers, we cannot do without hard copy newsletters. For those who do have computers, accessing the Internet can be expensive or impossible. The Vetiver Network and local network newsletters, therefore, are essential. We have found tattered issues of the *Vetiver Newsletter* for sale in remote book

fairs in the heart of India. We have learned that one newsletter often is circulated to 50 other readers, proving once again that hard copy is still a powerful tool.

- Internet dissemination is a powerful information tool for NGOs and other agencies that plug into the World Wide Web. Once these agencies have access to the information, they disseminate to a wider audience of users. The Vetiver Network's home page has played a vital role in information dissemination, and in the future, will become even more important as more users and potential users come on line. Other NGOs like The Vetiver Network, which have limited financial resources, should find the Internet enormously useful for information transfer. Along with our home page, the use of e-mail has greatly enhanced communication among the networks and among users. Network coordinators can become real communication facilitators if they use the system to its full capability.
- The Vetiver Network itself is unencumbered by bureaucratic processes. We were fortunate to raise about US$1 million dollars, most of which was quickly disbursed under simple agreements to recipients (other vetiver networks and NGOs). We processed most grants from start to delivery within six weeks. Much of the time, we work on trust, and most times the trust pays off in successful programs. The number of times when trust failed is so few that it has made little difference to the overall outcome. We gave really successful grant support to those organizations whose leader(s) were already fully committed to the technology and who had a real sense of commitment to their own people and to the environment. All the people who received the grants were volunteers in the sense that they already had personal incomes (a salaried job, pension, and so forth). The grantees took on the Vetiver System because they believed in it.

Conclusions

What of the future? Future expansion of the technology could come from the following three directions:

1. The spontaneous establishment of new national and local vetiver networks and the expansion of existing networks without financial assistance from The Vetiver Network could expand the use of vetiver grass technology. We hope governments and donor agencies, which might include international agencies and trade organizations such as Rotary International and Lions Clubs International or such local equivalents, will provide assistance.
2. As governments and other agencies become more appreciative of the value of the Vetiver System, they will include it in their technical strategies and be more active in its promotion and application; this especially applies to the Food and Agricultural Organization (FAO) of the United Nations. When agencies better appreciate the cross-sector linkages that the Vetiver System affects, agencies will be better motivated to jump on the vetiver bandwagon.
3. When private sector enterprises that are realizing the importance of vetiver grass technology—and the fact that it can be applied profitably—expand, they will actively market the technology, and thus, will affect a whole string of enterprises from small plant material producers to landscapers and construction companies.

The dissemination of the Vetiver System has undoubtedly been a successful initiative, and we have far exceeded our original objectives. Rather than just being a carrier of words, the initiative has been a creator of actions. This process will continue, probably not with The Vetiver Network in the prime spot, but through the actions of users and scientists working in better communication and harmony in the field. The Vetiver Network's own future is, and has always been, rather fluid; we change course depending on the availability of funds and the needs of users.

The Vetiver System has proven to be a successful technology because it is simple, low cost, and effective. It is also an exciting technology because its use seems to be boundless, and therefore, it is a unique technology to use and experiment with. It is also a technology that is available to everybody without being tied up in bureaucratic practices. Although "hard" engineering alternatives may continue to be financially attractive to corrupt officials and profit-optimizing entrepreneurs in developing countries, The Vetiver Network believes that the success of the Vetiver System will speak louder and will literally "take hold" in spite of such opposing forces.

Perhaps it has been a good thing that The Vetiver Network has generally been poor financially. We have been able to identify with and better understand those who have difficulty starting something new and have come to realize that small amounts of financial support placed quickly and correctly can make a difference to hundreds, even thousands, of rural people. We also have learned that if available good technologies, which are low cost and relatively simple, are applied properly, they can make great changes to people's lives. What we need is vision, dedication, and commitment. The CEO of a successful company was asked how to be successful in creating change—his answer was, "One has to be repetitive and boring." I state that in my work with the Vetiver System, I have had to be both repetitive and boring; but it has been worth it.

We at The Vetiver Network are optimistic that the organizations that we would expect the most support from, such as the UN's FAO and the Consultative Group on International Agricultural Research (CGIAR), to name two important agencies, will begin disseminating the technology. When such agencies start to think outside the box, worthwhile new technologies will be given a chance. Because the objective of these two organizations is to increase food production and develop new techniques for making agricultural production more sustainable, the Vetiver System is the obvious solution. It can revolutionize subsistence cropping and help save small ocean islands from losing their precious soil. The Vetiver System is something to which they should be giving their utmost support.

15. How To Plan and Execute a Countrywide Vetiver Program: The Madagascar Generalities and Specifics

Based on a paper by Criss Juliard

About the Author of the Paper: *Criss Juliard, the author of the paper on which this chapter is based, is a senior project manager at Chemonics International, Washington, D.C. He is a user, proponent, and researcher of vetiver. He started an organic farm in the Caribbean in the early 1970s and has been implicated in tropical environmental and agricultural practices ever since. Juliard has managed private-sector and agriculture-development projects in North Africa, the Caribbean, Madagascar, and West Africa. While director of a USAID-funded agribusiness and rural infrastructure rehabilitation project in Madagascar, he "stumbled" onto the Vetiver System. The project had to resolve the age-old problem of rural road maintenance; the solution had to be low tech and low cost. He held a rural conference on soil conservation and invited Richard Grimshaw as one of the speakers. From there evolved a national dissemination program that became the basis of this chapter. Juliard currently works in Senegal.—JG.*

This chapter provides an understanding of what is involved in establishing a major vetiver program as a new project for a country—the cost, the organization, the logistics, and the ultimate benefit.

Not all programs are as involved as this one was. In most cases, a Vetiver System can be introduced inexpensively using existing extension services, government nurseries, and farmers' field days; but the description of Madagascar's vetiver program presents practical uses of the private sector as the catalyst and main instigator to launch a countrywide dissemination and adoption program.

Overview of Madagascar's Veitver Program (1994–99)

In Criss Juliard's model for the practical application of the Vetiver System in a new country, he describes Madagascar as "a country eroding into the sea."

In the late 1990s, Juliard headed a U.S. Agency for International Development (USAID)-funded technical assistance project to stimulate the agribusiness sector and to rehabilitate rural infrastructure in two of Madagascar's six regions. The infrastructure component improved farm-to-market transport. It spent US$13 million over 5 years to rehabilitate rural roads and partially rehabilitate a railroad. When the project was designed, vetiver was not known.

Rehabilitating the roads proved to be an easier task than assuring their maintenance at reasonable cost. The hypothesis was that maintenance could best succeed by using a participative approach with the local population, who had the specific interest of protecting their investment. The project staff with government consent formally turned over management of the roads to road users associations composed of villagers living alongside the roads and agricultural enterprises with an interest in the area.

The associations and project staff witnessed serious problems when some of the new and costly engineered works washed out during a cyclone; erosion and massive landslides threatened other areas under rehabilitation. Together, they searched for solutions, an effort that led them to vetiver.

Initially, they contacted The Vetiver Network through the Internet. The Vetiver Network subsequently provided the project with information, guidance, experience, and visual aids to tackle the problems that had already occurred and to develop a capacity for avoiding new ones. This information led to a sensitivity and awareness campaign in the two regions where USAID was implementing roadwork and agricultural intensification. Subsequently, in response to requests for assistance in setting up vetiver in other regions of the country and as a way to ensure long-term support from businesses, donors, professional associations, and government at the national level, the initiative expanded on a national level.

The overall cost for disseminating the Vetiver System, first in the project area and later on a national scale, was roughly US$40,000 over three years. To this amount, approximately US$464,000 was contracted out to private firms for purchasing, transporting, planting, and applying the system. We estimate that project-based technical assistance, which provided supervisory management and quality control cost, was about US$196,000 over three years. In addition to USAID funding, the project also benefited from approximately US$50,000 of in-kind contributions from other organizations. As a result, contractors planted and cared for approximately 160 linear kilometers of vetiver hedges (1.6 million plants) that protected more than 400 kilometers of roads and associated masonry works, 20 kilometers along a railroad line, and 30 hectare of watershed basins and agricultural lands.

The project used approximately 200,000 of the 1.6 million plants in agricultural plots to improve soil quality. Cost per planted meter averaged about US$2.90. The cost of protecting rural roads and masonry works with vetiver varied from 1.2 percent to 4.6 percent of the rehabilitation investment. On average, the vetiver cost was 3.1 percent of the rural road cost. The Vetiver Network estimated that vetiver would extend the life of the road by 30 to 100 percent, thus greatly increasing the rate of return on the rehabilitation investment.

Over the course of the project, the vetiver activity assumed greater importance than the project team had anticipated at the outset. Through the project's participation with new partners—the National Environment Office, Ministry of Public Works, World Bank, United Nations Development Program (UNDP), the U.S. Peace Corps, World Wildlife Fund, and CARE who operated on a national scale—the technology became better known, and demand for the plant and technical support outpaced the supply. Fortunately, private nurseries quickly responded by expanding their production. When planning a project on a regional or national scale, it is important to secure the enthusiasm of large nurseries that can shift production rapidly from the needs at the initial stage to those of a more mature vetiver market.

After three years of intensive vetiver outreach activity, vetiver dissemination in Madagascar reached a significant scale. The project had established a core of people skilled in the technology and a critical mass committed to its use. The adoption rate was high and the demand remains strong two years after the project ended.

How did the country get to this point? What specific actions led to achieving this critical mass state?

Looking back, Juliard concluded that the dissemination strategy was developed as much by chance as by design. He indicates, however, that a good part of the success can be traced to the manner in which the following three questions were addressed:

1. Who will disseminate?
2. With what materials?
3. By what means?

Two or three previous attempts at vetiver dissemination in Madagascar had not succeeded. They believe the USAID project efforts were rewarded because they—

- Got the right people involved and committed;
- Supplied the planting materials; and
- Provided technical support to ensure the people applied the technology correctly.

Below, Juliard discusses the manner by which the project addressed these three concepts and gave them priority—and how you, as leaders and communities, can address these same concepts as you disseminate vetiver.

1. Get the Right People Involved

At the heart of a vetiver dissemination program is the effort put into involving the right people and organizations committed to promoting the technology. Every program needs a locomotive, and it is preferable that the wagon-puller (lead organization) be an independent body that has most of the following attributes:

- A mandate to achieve results in a field related to agriculture, environment, or infrastructure;
- Access to financial resources that permit it to achieve results;
- The ability to organize and create catalyzing events;
- Attained credibility through their performance in a related field; and
- Commitment and drive to establish partnerships with other organizations.

Organize an event. To get people and organizations to address a common problem, organize an event such as a disaster preparedness seminar, a soil conservation workshop, or an engineers' conference on road maintenance or a rural fair.

In Madagascar, as an early catalyst to get people thinking about solutions to the massive erosion problem, Juliard organized a conference called “Effective Technologies Used To Preserve Agricultural Soil and To Reduce Erosion.” Vetiver was one of the field-tested technologies that practitioners presented to a diverse audience of agronomists, engineers, non-governmental organizations (NGOs), researchers, ministries, and donors.

Such an event becomes the catalyst to help conceptualize the scope and breadth of a vetiver program. It enables individuals and implementing bodies with the drive, ideas, and nurturing skills to emerge as actors who will take the idea from conception to reality.

It is useful to have an eye-catching presentation by a vetiver practitioner who has slides, reports, and scientific evidence and background information on vetiver in other regions or countries. Richard Grimshaw (United States) was the main advocate of vetiver technology at the conference, and he helped establish vetiver’s credibility. The conference revealed that other organizations had previously tried vetiver, but their efforts had failed because of the inappropriate application of the technology (not respecting spacing, using non-hardy plants, and providing insufficient attention to maintenance). Good technical and supplier information is available at The Vetiver Network’s Web site (www.vetiver.org).

The catalytic event, such as a fair or conference, can also serve as a preliminary planning platform to discuss issues such as target beneficiaries, resource requirements, sources of planting material, participating organizations, short- and medium-term goals, and a schedule of follow-on planning exercises.

Involve both big-picture people and the details folks. At the early stages of the program, the lead organization needs to contact, and bring together in a kind of “informal” club, professionals representing the engineering, agricultural, environmental, financial, forestry, business, and NGO sectors, especially those who have a sense of the big picture and policy issues.

Get people on board who are busy, who already carry many responsibilities, who have a wide network of contacts, and who work under a private umbrella. They are the candidates most likely to push a balanced vetiver initiative. They possess the know-how for accessing key institutions, documents, reports, and opportunities for developing a vetiver market.

Also include people and organizations that have the best records of working closely at the local level—farmers cooperatives, producers groups, and village associations. These people are the resources who will focus on the details such as local networks, culturally attuned techniques to transmit information, village-level logistics and customs, and ground-truthing practices. They are critical to a national campaign because they complement the big-picture visionaries; they help resolve practical problems at the village and local levels.

Remember that it is often the details at the local level that stump a well-planned national vetiver program.

Create an information network among key people and lead organizations. Critical to a national vetiver program is networking information about the plant, its 15 different uses, the virtues it brings to the land and people, including those who multiply, buy, advise, research, teach, train, and trade; those who hold local and national offices; and those who work in regional and national public services. These groups must understand the plant, the technology, and what the Vetiver System has achieved in other countries.

Basic information about vetiver exists in abundant supply. In addition to The Vetiver Network Web site (www.vetiver.org), important documents that help planners and communities get started are (1) the World Bank Technical Paper #273 (Grimshaw and Helfer 1995); (2) the World Bank's green book, *Vetiver Grass: The Hedge against Erosion;* (Greenfield 1987); (3) the National Research Council's *Vetiver Grass: A thin green line against erosion* (National Research Council 1993); (4) P. K. Yoon's *A Look-See at Vetiver Grass in Malaysia* (Yoon 1991); (5) The Vetiver Network newsletters, as well as regional newsletters (VETIRIM, South African Vet Network, Mediterranean Network); and (6) numerous CDs (also available from the Web site).

To create the information network, the lead organization must establish a communication plan and a strategy that will transmit to a variety target groups massive amounts of information about vetiver uses, application, and research. Regardless of the target group, the program requires large quantities of visual aids and documents. The lead organization must use these documents to support those who can organize workshops and seminars, make pitches at schools for organizing "vetiver planting days," assure press reporting, and support the large number of information requests that eventually become a large part of the national dissemination program.

An active communication budget is estimated to be US$6,000 to US$10,000 per year, more if translation is an issue. Elicit help from journalists and the media when there are success stories to report, bring them to visit demonstration sites, and put them on a mailing list to receive all the documents the program generates on vetiver and its use in the country.

After several months, the lead organization needs to adapt the communication plan or awareness campaign to four types of 'beneficiary' groups. The challenge is to conduct the communication plan simultaneously with each group and to aim at the four segments of the active population within the group, and not necessarily the director, president, or chief:

1. Vetiver users and direct beneficiaries;
2. Private businesses;
3. Local officials; and
4. Donors, professional associations, and ministries.

Vetiver users and direct beneficiaries. The first group, by far the largest and the most important, includes the rural farmer, village associations, and regional development NGOs. To reach them, use a community-based, participatory approach. Hold meetings. Find out their major environmental, agricultural, and disaster mitigation issues and learn how they see how they should be resolved. Be prepared to introduce several techniques, including vetiver. Use individuals who are good at village-level mobilization to conduct these early meetings.

To introduce vetiver, it is best to have a catalyst such as a village level project, a major local event such as "earth day," or a road rehabilitation activity, such as a bridge or a road that washed out. The village has to have a felt need to use vetiver. Be prepared to show pictures, give a slide or portable computer presentation of how vetiver is used, and provide simple handouts in the local language of how vetiver has benefited others in the same situation.

Private businesses. The awareness campaign for the second group centers on private businesses, nurseries, agriculture suppliers, handicraft wholesalers, essential oil processors, transporters, landowners looking for an investment idea, construction firms, and business associations. The lead organization's focus with this group will be to develop and create markets for vetiver. With this group use figures, costs, profits, and reports on testing experiences. Provide on-site training visits, conferences, and technical presentations on how vetiver is used commercially in other countries.

Local officials. The third group includes local officials in the regions where vetiver has the best chances of helping soil erosion campaigns or addressing environment-related issues. Visits, discussions, slide shows, demonstration sites, and presentations on how vetiver can give their locality a competitive edge are very useful. Local officials have to see the political advantage to their region before they commit to supporting a vetiver program. This legitimate concern is to be addressed in the communication strategy. Explore the possibility of putting a vetiver demonstration site in the region, making sure you have the capacity to ensure proper installation and maintenance.

Donors, professional associations, and ministries. Technicians and decision-makers at the ministry level (agriculture, forestry, environment, land planning, public works, transport), professional associations (order of engineers, agronomist associations, craftsmen), and donors compose the fourth target audience of a communication strategy. This group is hardest to reach; many have set ideas, are not risk takers, and are comfortable with what their group has done before. One way to reach this group is by participating with them in technology seminars, conferences, and workshops. You can issue press releases, set up demonstration booths, and distribute books and brochures. You must repeat visits to ministries and donor offices.

Establish partnerships. Establish partnerships with businesses, construction firms, NGOs extension services, environment projects, students and teachers at local schools, professional associations of engineers, agronomists, and rural development specialists. Most important is the support and understanding of people in the private sector. It has been the experience in several countries that giving the lead to government ministries or research institutions to promote vetiver systems has not produced the best results.

Establish networking through newsletters and mailing lists. Establish a network among all partner organizations, individuals, and ministries. Use electronic newsletters as a way to maintain communication among all these interested parties. Appoint one person to gather information and edit a newsletter that is Internet-based. Keep the text short and crisp, and send it regularly. For those who cannot be reached by e-mail, fax the newsletters; and as a last resort, mail them through the post. The newsletter mailing list should be expanded and updated regularly.

Prepare reports. Finally, to expand the information network, it is good practice to prepare a report of the year's activities and lessons learned, and above all, to record the program with cameras (digital cameras are preferable) for the first couple of years. The Vetiver Network wants to receive reports and pictures. Use your reports to further extend information and to sensitize groups in other areas. Use a digital camera to facilitate transmitting progress and success pictures to people in the network. Put a digital camera into your planning budget.

When taking photos of the technology's progress, consider these two important points: (1) take photos before the technology was applied to the area; and (2) make sure all follow-up photos are taken from exactly the same spot each time, especially with identifying trees or hills or buildings in the background.

2. Supply the Planting Materials

A sound vetiver strategy requires planning for a surplus of plant material. The need for plants during every planting cycle almost always exceeds supply. Juliard recommends promoting at least the following three types of plant material sources:

1. Private nurseries and growing fields of vetiver to supply the plant in clumps or plastic bags;
2. Roving nurseries to supply on-the-spot replanting material; and
3. Small plots in the gardens of people committed to the technology for multiplication, gifts, starters, experimenting, practice, and testing.

Juliard also recommends random "roadside" nurseries where anybody can have access to vetiver plants. Here is how you, as leaders and communities, can promote and supply the planting materials.

Nurseries and growing fields. Encourage growers to establish nurseries and growing fields of vetiver in well-watered, sandy soils and to obtain the skills of professionals to run the nurseries. Where the cultivation of vetiver for essential oil exists, entice the producers to provide cut clumps as starting material. Encourage nurseries to prepare plants in three forms: clumps, rooted individual nursery bags, or "meter ribbon" and bare-root individual tillers.

As a basic multiplication technique, the nursery multiplies from its primary source by in-ground planting, not potted planting. Nursery workers should plant original tillers in rich loose soil, 30 centimeters on a square. A warm, wet climate generally allows a multiplication rate of about 30 to 60 tillers per clump over a 6-month period. The nursery can use part of the multiplication stock to put plants in polybags and part to be sold as tillers (two to three shoots per tiller) for direct planting. The goal is to have several hectares in continual production so that every month, as growers take plants from the nurseries, they can replant five to six times the amount for multiplication and expansion.

Roving nurseries. Encourage growers to establish roving nurseries or temporary multiplication centers for rural roads, hard-to-get-at watersheds, and other isolated spots where established nurseries are far away and the cost of transport is high. Transporting plant material is one of the costliest links in the vetiver technology chain, which is why the on-site nursery is so important. The roving nursery was an extremely useful implementation tool in Madagascar. It allowed for rapid deployment of resources to isolated areas for short periods of time, and it reduced the overall cost of material by about 20 percent.

A roving nursery is one that is established close to the planting area by a professional nursery person for a particular planting season. It is a temporary multiplication center that has easy access to soil, water, labor, and land. The plants multiplied in this nursery will equal the approximate number of plants needed for the site. Suppliers bring tillers or clumps to the site for a speedy production cycle. Vetiver technologists recommend that all soil erosion applications of vetiver be planted from polybagged or ribbon-strip plants rather than from newly separated tillers. While this method may increase overall costs, it ensures immediate protection of hillsides and roads for each forthcoming rainy season since the plant no longer goes through its dormancy phase.

Juliard recommends the following steps for establishing, running, and maintaining a roving nursery:

> ***Soaking.*** To accelerate rooting, place tillers that have just been separated from clumps into a “cow-tea” bath (*pralinage* in French) damp sandy soil for 4 to 6 days. Make sure the cow manure juice or soil covers the root and crown section of the plant. New white roots will emerge. Transplant these plants directly into polybags, or plant them directly in hedgerows. Cow manure bathing eliminates the browning phase that vetiver goes through when it is multiplied. Reduce handling and dry days to the minimum.
>
> ***Using cow rather than bull manure.*** Female manure has a greater concentration of the hormone needed to stimulate new root growth. Do not let plants soak more than 7 days without adding soil or dirt to the bath.
>
> ***Quick rooting.*** Dig a trench approximately 40 centimeters wide and 30 centimeters deep. Insert a plastic sheet the length of the trench and up the sides to form a watertight reservoir. Fill the trench with 10 centimeters of the cow tea and soak the tillers upright. Make several of these trenches so a continuous amount of tillers is available for transplanting.
>
> ***Transporting.*** For access to hard-to-reach mountainous planting areas, transport the tillers (which have already rooted from the soaking cycle) in baskets lined with plastic, allowing the roots to remain soaking in small amounts of cow tea. Carry the baskets to the sites, where the plants can remain unplanted for up to 2 weeks while in the basket.
>
> ***Establishing small garden plots.*** People responsible and involved in the vetiver dissemination program (staff, managers, supervisors) need to be users, practitioners, and experimenters. The best way to do this is to have small production plots right at home that can become the source of gifts of vetiver to anyone who comes by for questions, information, or hints. Prepare vetiver plants in nice pots to give away at every occasion, such as dinner parties, holidays, and birthdays. With every give-away, encourage the

recipient to multiply the plant and the technology. Provide them with little written documents explaining the plant's uses and benefits.

Transporting and unloading vetiver. Transport plants either as clumps or tillers or in bags. Clumps are easiest to transport, and clumps and polybagged plants last longer in transport. Uproot clumps and transport them so they can be watered daily. (In hot humid areas, however, it is not a good idea to water the clumps because they can rot, especially if they are kept in jute bags.) In a loaded truck, the transporter must agree to water the clumps so the bottom plants get soaked during transport. We suggest packing clumps in jute bags, trimming leaves and roots (leaves, 25 centimeters; roots, 5 centimeters), and packing polybagged plants in crates, if possible, or placing them horizontally (providing the packing and transport time does not exceed 2 days). Bunch tillers together in clumps of 10 or 12 and trim them the same as the clumps. Stack them neatly, transport them bare (which makes them easier to water), and cover them with wet burlap to protect them from sun and evaporation.

Timing. Minimize the time between transport and replanting. Clumps can last up to 2 weeks, but every day you leave them unplanted decreases their survival rate. Do not store the bagged plants in a shaded area for any length of time—they need sun and water.

Maintaining proper moisture. Do not transport bagged plants when the soil in the bag is wet. Bagged plants transport best when dry for 2 days. Also, if possible, do not water the nursery for 3 days before loading and transporting (otherwise you will have muddy transport vehicles).

Unloading. Unload plants in clumps or bunches as near to the planting site as possible. Handle the plants as little as possible. If the plants sit for more than 1 day before planting, arrange for someone to water them.

3. Provide Technical Support to Ensure Applying the Technology Correctly (some suggestions)

For a vetiver dissemination program to succeed, users must apply the technology correctly; for this to happen, the program needs a core of five or six well-trained professionals (such as engineers, agronomists, foresters, and nurserymen) and a larger group of on-the-ground extension agents.

The first group provides training, field support, and networking at the implementing organization level. The second group works directly with groups who grow, plant, and care for vetiver at the base. It is best to recruit the second group from a pool of recent graduates (of agronomy, engineering, or forestry schools), from NGOs, and from rural development projects.

The younger, more dynamic, and eager-to-learn individuals tend to be the best people to work with the second group. As individuals or members of an organization, they must be ready to live on site, particularly during the planting season and immediately after it. In Madagascar, the project used an apprentice (expert junior) program that placed recent graduates in villages to work on agribusiness efforts. With some assignments, workers promoted vetiver full-time; with others, workers filled in when needed. The same approach is being applied in Senegal.

Most implementing organizations should be companies that construct roads, associated agro-forestry contracting services, or NGOs. The most effective way to ensure that these organizations will implement the technology correctly is through detailed, carefully written contracts that provide them with detailed instructions of what you or your organization expect(s) at every step of growing, planting, and caring for vetiver.

Selecting plant sites. Experience in Madagascar proved that, in all areas where vetiver is to be planted in hedgerows, workers should prepare the soil and trenches for each day's planting in the following way:

- Dig furrows or trenches 25 centimeters deep and about 20 centimeters wide.
- Add 2 to 4 kilograms of animal fertilizer or compost per linear meter.
- Mix the soil well.
- Have watering cans handy.

The best time to plant is during the early part of the wet season.

When planting along masonry works—such as along culvert exits, bridges, causeways, and gabions—workers should cut the furrows 10 centimeters from the masonry and along where the fill dirt meets the concrete so the vetiver can bond the two mediums as it grows.

When planting on an embankment, hillside, or cut that is exceptionally steep and the soil is hard, workers should dig individual holes rather than furrows for each plant, spaced 10 centimeters apart, horizontally, at about a 45-degree angle, so the vetiver (preferably from a potted source) can fit in as a plug. The roots growing downward will protect the cut from erosion. It is critical that the supervisor explain how to plant on the contour and that the correct process is followed.

When planting on curved river embankments where floodwaters move at high speeds, workers should plant in the following way:

- Dig cross furrows in a quadrant pattern so the vertical hedge can slow the flow and reduce the current.
- Plant vetiver hedges perpendicular to the flow of water.
- Plant hedges on the up-stream and down-stream side of a cement crossing or bridge pillars to stabilize the footings and gabions and to prevent water swirls (eddies) that loosen the soil under the cement structures.
- Space the lines 1 to 2 meters apart, depending on the slope.

Juliard suggests starting at the top of the watershed and moving downward as plant material and time permit, which avoids having plants being washed out as the speed of runoff increases down the slope. By the time you have reached the gullied areas near the bottom of the slope, the runoff has been spread out by the hedges and its speed has been greatly reduced. Plant on the contour.

Vetiver can survive for several months under water as long as its leaves protrude.

Other tips to tell workers are as follows:

- Since vetiver likes sun, avoid putting plants under bridges or in shady areas.
- Along masonry drains, plant a row of vetiver just uphill from the lip of the drain to prevent silting.
- Where large erosion gullies have been formed, dig the furrow at the base of the gully and work your way up with successive rows several meters apart.
- To stabilize the plant during rainy season, drive a wooden stake through the “crown” of the plant, and if needed, keep the plastic bag, cutting out only the bottom.
- On downhill curves, dig short furrows to plant vetiver in a herringbone style so that the water is directed away from the road surface to the inside drain ditch, and so that the speed of rushing water is reduced. The hedge can grow slightly into the road surface to increase the catchments of the herringbone pattern.

On sites where fill dirt has been excavated, begin long rows of vetiver hedges from the base of the excavation site upwards to prevent further erosion. Be sure to respect the leveled contour process. Place double rows of vetiver along the lowest drainage points of the zone. Constantly check the selection and digging of the furrows as they are being dug and have a supervisor outline the exact path the planting furrows are to follow along the slope’s contour to facilitate the work of those who dig the furrows.

It is important to remember that vetiver technology allows for experimentation. You might not get it right the first time, but at least you can modify and change the application points as the water runoff changes course.

Estimating the number of plants required. For the first season, make broad estimates of plant needs. Use the rough number of 10 to 12 plants (either tillers or polybag plants) per linear meter or approximately 11,000 plants for every kilometer of hedgerow planted.

After the first year, make estimates more precisely. For each site where vetiver contour hedging is proposed, establish an on-site planting matrix or itinerary. For a road site, the planning/planting matrix table will include for each kilometer, on the column side of the matrix, a breakdown of the road by 100-meter lots, and down the row side of the matrix, a list of all roadside items (for example, roadbed left and right [L&R], bridge, access ramp to bridge, culvert, embankment L&R, ridge, gully, drain ditch, retaining wall, gabion, masonry ditch, cement crossing, downward curve, and raised roadbed).

For each section of the road that needs to be protected, the program manager (or engineer or vetiver specialist) estimates the number of linear meters of vetiver hedge needed to protect the engineered work, embankment, or fill site. After the organization benefiting from the planting records and reviews the estimate, the manager finalizes the planting matrix and inserts it as part of a planting agreement or contract. The manager uses the matrix to plan the budget and to estimate the number of plants, people, and time required to complete the planting cycle. Most importantly, however, people will use the planting matrix to review the work to be completed and to establish the basis for agreement on the priority zones and areas in which the partnership will concentrate efforts.

When working on the planting matrix, the manager needs to remember to look far uphill beyond the road site to check if runoff from heavy rains might eventually come from areas far from the road and might need to be deflected using vetiver hedges. These areas will need more time for planting, transporting plants, and watering than will those areas adjacent to the road.

Requirements for replacing vetiver plants that dry out, wash away, or are eaten over the course of a year vary from 10 percent to 30 percent. The manager will calculate this requirement in the plant estimates.

The manager will use an adapted matrix to plan a watershed protection activity, an agricultural terracing project, or reforestation and will derive an estimating number of vetiver plants needed from the number of walked-through linear meters identified for each project.

Planting and supervising planting. After losing a high percentage of plants that were planted "bare root," our field staff recommends planting vetiver from rooted stock, either in polybags or in ribbon strips (see Narong Chomchalow's Technical Bulletin No. 2000/1 of the Pacific Rim Vetiver Network, Office of the Royal Development Project's Board, for an excellent presentation of "strip" planting, http://prvn.rdpb.go.th). Exceptions exist, but generally the survival rate of rooted plants is higher than that of bare root tillers—98 percent versus 75 percent. The polybags add good soil to the planting area, require less water, and are more easily fixed (by putting a stake through the root system), thus reducing the chances of washouts during periods of heavy rain. Try to get nurseries to plant vetiver by the meter in ribbon strips.

Considering their recent experiences in Madagascar, the field staff recommend the following:

- Keep spacing between plants 10 centimeters (the space of a closed fist) or less. Mix animal or organic compost at the bottom of the planting trench. Cover the crown of the plant with soil, but do not plant too deeply.
- Be sure to compact the earth around each plant—"heal" it with the feet—and make sure that the earth around each plant is slightly lower than ground level, creating a small depression or gully that will retain water. The compacted, hard earth will reduce erosion caused when heavy rains fall before the vetiver hedge has had time to develop. Avoid mounding earth around plant leaves. Trim the vetiver leaves to 30 centimeters and place the cut leaves parallel to the planted vetiver, but on the uphill side. Water plants daily for 3 to 4 weeks if it does not rain. Putting the cut vetiver leaves along the planted trenches will reduce evaporation and begin trapping eroding soils.
- On very steep embankments, put a stake through each plant's root system to stabilize plants. If the area is riddled with rills, plant vetiver with the polybag but cut out the bottom to enable roots to spread. Push a wooden pole or bamboo stake through the bag after planting it in the trenches.
- Make sure contractors have large bags on hand at the construction site to collect and dispose of used polybags. The controlling engineer could count used nursery polybags as

a way to control the number of plants planted and to ensure that no used polybags are left to the wind.

- Make sure the site or supervisory engineer establishes the planting schedule with the contractor.
- Begin planting vetiver only after road construction and engineered works are complete.
- Five days after contract award, make sure the planting contractor submits to the supervisory engineer the plan of where, how, and with whom he will allocate equipment and tools to be used for the work.
- After the schedule and plan are set and work commences, make sure the controlling engineer keeps a daily log of all activities of the day (the number of plants planted, number of meters dug, number of meters planted, number of people on site, and observations). The contractor and controller must agree on plant and meter counts to ensure proper payment papers are processed.
- Make sure the controller ensures that 100 percent of planted material is alive, free of disease, watered, and in good, vigorous shape.
- Make sure the controller indicates in the detailed operational plan the number and location of plants to be planted, and jointly with the contractor, determines deletions or additions to the original planning.
- Motivate workers by talking to them about vetiver and giving each worker a small handout that describes the virtues of the plant and how to plant it correctly. This effort increases their interest, quality of work, and commitment to the program—and each worker becomes an agent of dissemination. Give them T-shirts with some logo or quote about vetiver.
- Follow up planting by watering, gap filling, weeding, and trimming. While this important phase may seem straightforward, be sure to include it in the contract of the implementing team.
- Under the contract, space out payments for planting vetiver over several phases; for example, first payment when establishing the work site, second payment when completing 40 percent of the work, then 80 percent of the work, then 90 percent. Make the final payment (10 percent of total contract) only after 4 weeks, after all planting is completed and the engineer or controlling entity has conducted a follow-up visit.
- Make sure the contractor replaces all plants that have not succeeded and those that washed away. For the vetiver hedge to be effective and for the technology to have credibility, replacing dead or damaged plants (gap filling) is a “must.” Implementing groups also must aim and insist on a 100 percent success rate. Contact the contractor, village groups, or other entity to ensure that someone provides additional watering to the vetiver hedge if there has been no rain after the contract ended.
- Plan or provide for weeding about 1 or 2 months after planting, and preferably 6 months thereafter. Weeds growing near or along the crown of the plant seriously slow vetiver growth since shade prevents new tillers. If the furrows have been well fertilized, weeds will grow more quickly than the vetiver.
- Within 6 to 8 months of planting, trim the plants to about 50 centimeters (knee high). After that, trim the hedges once, preferably twice a year. Use the trimmed leaves as mulch, as thatch, and in handicrafts.

Conclusions

Although Madagascar's vetiver program began within a small project that addressed a specific problem in two regions of the country, it expanded nationally because a demand market was established as well as an accompanying supply, which came only from private nurseries. These nurseries responded quickly; they also became the vectors of dissemination and market development. Producers knocked on the doors of potential large-scale users—public works projects, irrigation construction, and road and railroad maintenance entities. To expand the knowledge base, Juliard established a series of networks based on various end users. A dynamics ensued, in which demand for the plant and accompanying service providers challenged suppliers of plant material, technical support, and researchers, and produced a process for expanding the use of vetiver throughout the country.

Inertia can be established to keep the process dissemination going with an ever larger number of village associations, businesses, environmentalists, researchers, universities, donors, public infrastructure, projects, and NGOs being brought into the network though workshops, rural fairs, professional association seminars, and personal visits. Keep the media informed and take them to visit successful sites.

The lesson learned is that we cannot go into an area or a country and initiate a vetiver program because it is "good" and "it works" elsewhere. The starting point is the demand rather than the supply. No matter how good our system or technology may be, we have to identify the "demand" or the "needs," and pursue that initially. After addressing a primary need for vetiver (erosion control and road maintenance in the case of Madagascar, rural income in Senegal, hurricane mitigation in El Salvador), a better chance exists for the other derived uses of vetiver to take hold. In Madagascar, Juliard believes a "critical mass" point has been attained because demand and supply are now growing and reinforcing each other.

On the demand side, the Ministry of Public Works has indicated that all road contracts will require a vetiver clause, and that vetiver is to be used to protect engineered works and roadbeds throughout the country. The Order of Engineers, which has included vetiver in its norms to protect roads, dikes, and watercourses, states that use of vetiver will be required in all terms of references in which soil erosion is an issue. The European Union and the Japanese Development Agency require that road and irrigation projects in Madagascar funded by them must use vetiver where soil is threatened. Two World Bank projects (the livestock project and a rural infrastructure project) are using vetiver. CARE, Catholic Relief Services, and the Worldwide Fund for Nature are using vetiver in the infrastructure projects they finance.

On the supply side, seven private nurseries now produce vetiver, some in large quantities. Eleven construction companies have experience in planting vetiver and using the technology successfully. Approximately a dozen NGOs produce vetiver for their members and for sale in the agricultural sector, and approximately 30 village-level associations have small nurseries to produce plant material for road maintenance and agricultural intensification. The project has provided training in vetiver technology to engineers associations, officials from the Ministry of Water and Forests, and staff of the extension service at the Ministry of Agriculture. The project also provided vetiver training to development organizations such as the Peace Corps, as these organizations incorporate vetiver into the training of their volunteers.

Because of the efforts of many individuals and organizations, Madagascar reached the point of “sustainable” use of the vetiver grass system. The country reached that point by involving the right people at the outset, ensuring a reliable source of planting material and service providers, and training people to apply the technology correctly.

16. A Photographic Record of the Vetiver System

Since introducing the vetiver system of conservation in 1986 and having it accepted in 1993, when it was investigated by a select panel from the U.S. National Research Council (NRC) as a “safe,” economic method of conserving the soil and moisture that are essential for sustainable agricultural production, the Vetiver System has come a long way.

Throughout the tropics, more than 100 countries now accept vetiver grass technology, and vetiver has had a positive effect on the lives of thousands of people in developing countries. Vetiver also is affecting the agricultural production systems in developed countries by making them more sustainable. In these countries, vetiver also prevents erosion; rehabilitates wastelands, mine dumps, and quarries; stabilizes roads, railway lines, bridges, sea walls, rice paddies, and landfills; prevents pollution; and cleans up the runoff entering essential aquifers.

Since its development as a conservation technology, the Vetiver System has grown into a diverse system of natural environmental protection. It has clearly demonstrated that it has a permanent place as a soft approach to natural resources engineering.

“Seeing is believing.” Those were the words of one new innovator when he saw his first demonstration of vetiver in the field.

This chapter provides photos of field applications sent to us from people all over the world so you can see the Vetiver System in action—and so you can believe in the technology as so many beneficiaries throughout the world believe.

Figure 16-1. A man measures the root system of a vetiver plant after two seasons of growth. The plant had been dug out of a bank in Malaysia and the roots washed clean. In this case, the roots had reached two meters in red latosol soil.

Figure 16-2. This complete 13-month-old vetiver root system, measuring 50 centimeters wide by 210 centimeters long (tapering off, out of the photo), demonstrates why vetiver grass is such a perfect plant for soil and moisture conservation. When planted as a hedge across the slope, all that is visible to the eyes are the leaves and stems forming a dense barrier. What is not obvious is the root system that combines underground to form a perfect biological barrier to hold back moisture, to prevent tunneling in sodic soil, and to generally "nail" soils to the slope, preventing slips and mudslides. We know of no other plant with such a deep-penetrating root system acting as an underground filter.

Figure 16-3a. This 30-year-old vetiver hedge, planted on a 50 percent slope in the Fiji islands, has built a natural terrace 3 meters high (cut-away section marked by red line) and stabilized the slope. Over the years, the hedge, which is permanent and sustainable, has cost the farmer virtually nothing to maintain.

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Figure 16-3b. This 10-meter-wide constructed soil conservation bank in Maharashtra, India, built just two years earlier on the black cotton soils, has burst. The field officer is standing on the break. The bank cost a lot of money to build, will cost more money to repair, and occupies too much land. It is useless.

Figure 16-4a. This photo shows a breached stone terrace, a typical problem occurring in China and India. A vetiver hedge planted along the front of the masonry wall (as shown in the illustration in Figure 16-4b) can prevent such problems.

Figure 16-4b. The illustration shows how vetiver can be used to stabilize stone terraces while letting the drainage water filter through. The advantage of this system is that the hedge levels out the beds behind the hedge, giving a better distribution of moisture and nutrients and leading to higher yields, with no need for back-of-terrace drainage.

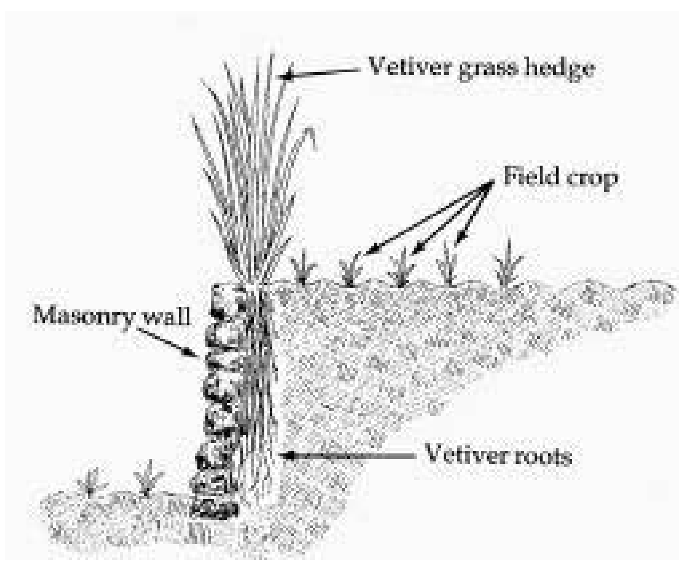

Figure 16-5a. This vetiver hedge is ideal for crop production. The farmer, using the hedge as a guideline, plowed on the contour. The combination of the hedge and plowing on the contour will give maximum moisture conservation, while preventing erosion.

Figure 16-5b. This constructed soil conservation bank, which cost a lot of money to install has burst and is useless. Now more money will be needed to restore it. Such constructed banks never work in the tropics, and the structures never last.

Figure 16-6. This photograph shows a "bare root" vetiver grass nursery in the state of Orissa in India.

Figure 16-7. Women at an Orissa, India, nursery prepare vetiver slips for planting. They break the clumps into three-tiller slips, trim the tops and roots, and bundle the slips, making them ready to transport to the field. Best result are obtained if the farmers then plant the slips within 24 hours of uprooting, although the slips will last for a week or more after uprooting.

Figure 16-8a. These vetiver plants are ready for transporting in Malaysia. They were grown in foam rubber pots and placed in boxes with a volume of one cubic meter, which holds a known number of slips. Selling vetiver plants by the cube is an easy way for commercially handling planting material

Figure 16-8b. Workers are planting a long vetiver hedge in Queensland, Australia. Although planting vetiver hedges may appear to be labor intensive, the hedge is planted only once, in a single line, and after three seasons of maintenance can be left to look after itself. Planting a vetiver hedge is much a less labor demanding task than is forestry and the effect is outstanding from the point of view of soil and moisture conservation.

Figure 16-8c. A finished hedge on black cotton soil is ready to withstand the rigors of the weather and to prevent soil from being lost again in this area. This simple, long-lasting hedge provides the only real way of sustaining production and retaining soil, fertility, and moisture.

Figure 16-9a. This vetiver hedge was planted on the Darling Downs, Queensland, Australia, to protect crops (in this case sorghum) from erosion and to ensure that crops receive maximum benefit from the rainfall and from conserved moisture that the hedge provides.

Figure 16-9b. This hedge (the same as the one in Figure 16-9a) is protecting its crop of sorghum.

Figure 16-10. This young vetiver hedge, only a few months old, effectively filters silt out of rainfall runoff and lays down the beginnings of a natural terrace. Where the footprint is in the photograph clearly shows a major runoff event, almost like a miniature "Laha" or mudslide stopped dead by an immature vetiver hedge that withstood the onslaught without even bending over under the pressure. Five similar flows in this photo stop at the vetiver hedge; on the other side, the soil remains undisturbed. This is soil conservation at its best, most economic, and safest. In the past, until the Vetiver System was introduced, the farmers were losing soils in their fields with no way of retaining it.

Figure 16-11. In Ethiopia, a vetiver hedge holds back silt on a steep slope planted in corn.

Figure 16-12. Vetiver grass hedges hold floodwater in field depressions. The water will drain away, leaving its silt to evenly fill the depression. Note how the hedge is unaffected by the depth of the water. In extreme conditions, vetiver hedges can remain submerged for six months without any damage to their effectiveness.

Figure 16-13a. The vetiver hedge has floodwater on either side, yet it remains erect and functional.

Figure 16-13b. The upper side of the same hedge (see Figure 16-13a) after the floodwater has receded. This photo shows sediment that is trapped, filling and leveling a low spot in the field. This area will be plowed and planted next crop. This "low spot" flooding will never be a problem again. Eventually rainfall will be spread evenly over the entire field, giving much better yields without soil loss.

Figure 16-14. Vetiver hedges protect and enhance cotton and sorghum crops.

Figure 16-15. Vetiver hedges, which have grown to their full height, protect and enhance a sorghum crop. The crop was produced after the flood shown in Figure 16-13a. Constructed terraces would have drowned the crop; vetiver hedges do not. Vetiver hedges retain the fertility and moisture.

Figure 16-16a. In Queensland, Australia, farmers burn vetiver hedges to prepare them for the next cropping season. These hedges will recover within 10 days.

Figure 16-16b.This close-up photograph shows green leaves that resisted the fire; green vetiver is fireproof. Vetiver seems to thrive on being burnt, and the hedge immediately regrows to protect the bare ground from any intense summer storms that could lead to severe erosion.

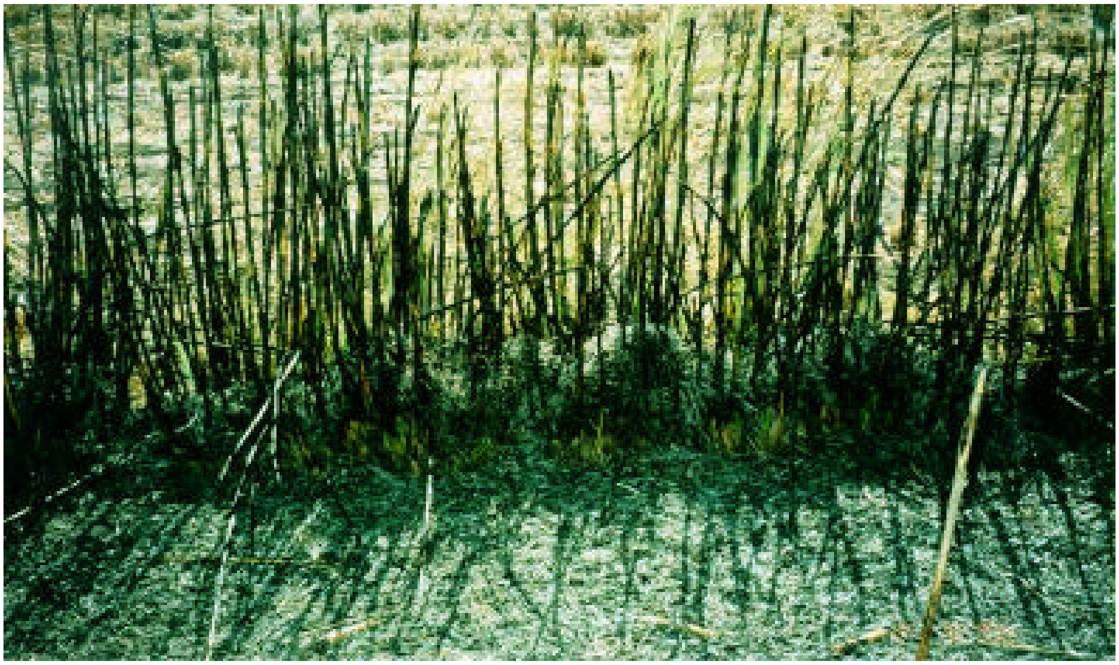

Figure 16-17.a. On this vetiver hedge, one week after it was burned, rapid green regrowth emanates from the base of the plant despite no extra care such as irrigation or even rainfall.

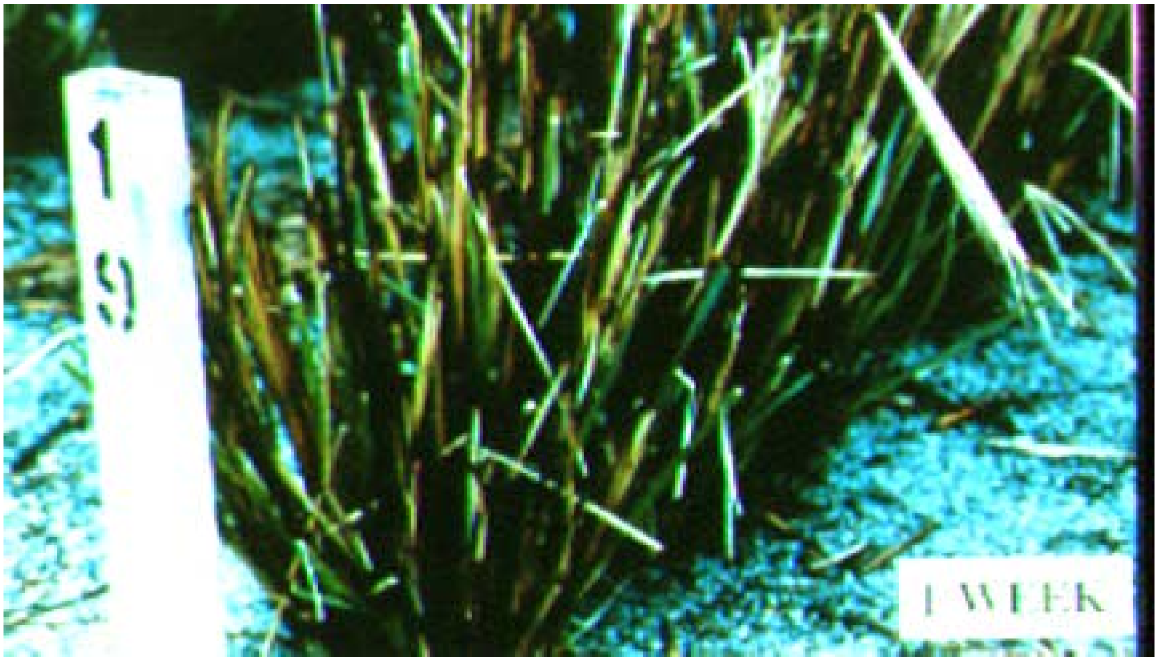

Figure 16-17b. Four weeks later, the same hedge as in Figure 16-17a, with no special treatment, flourishes.

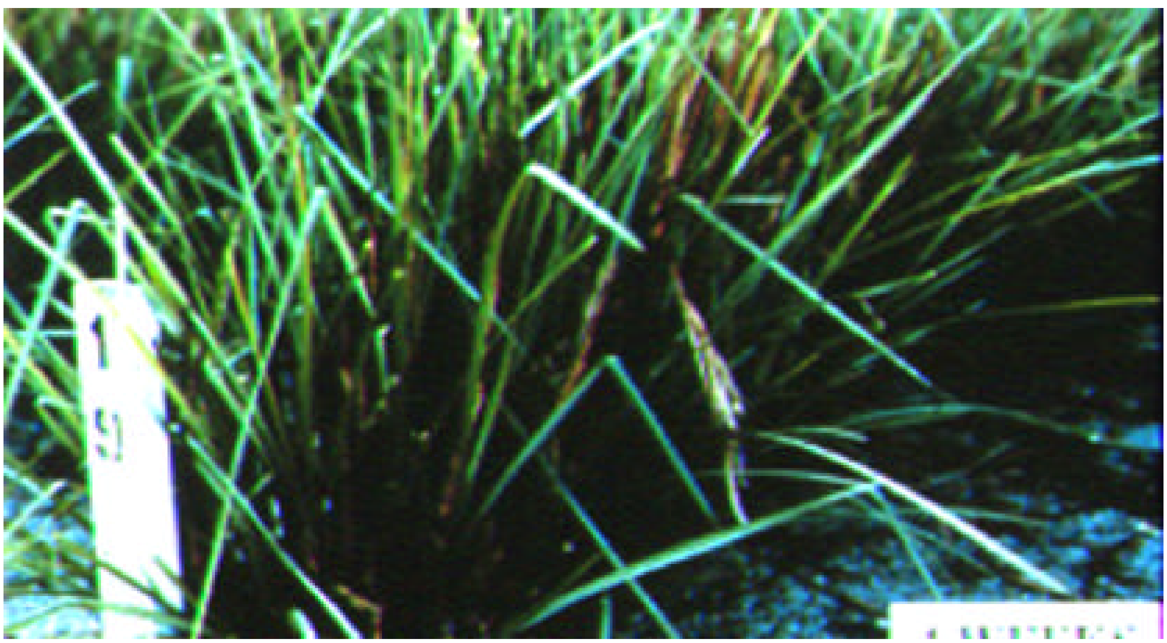

Figure 16-18. In Costa Rica, this farmer shows off an excellent crop of tobacco that is protected from erosion by one of his vetiver hedges.

Figure 16-19. Preventing the loss of runoff moisture ensures a good crop on these hill slopes. Without the vetiver hedges, which do not compete with the crops, the farmer has no way of retaining moisture.

Figure 16-20a. In the Philippines this major highway presented serious problems in stabilizing the highway cut under extreme rainfall conditions and earthquake damage. Complete stability was achieved through vetiver grass.

Figure 16-20b. This road in Malaysia, that suffered severe collapse was eventually stabilized using vetiver hedges, and no further problems have occurred where the hedges were well-established. Nonetheless, engineers were still skeptical, asking for proof.

Figure 16-21.Engineers, who doubted that vetiver roots would penetrate a steep fill, dug and sluiced away the soil on the side of the fill slope to expose the roots. The roots had penetrated to nearly 4 meters through this rough profile and have now stabilized the fill and "nailed" the soil to the slope. The engineers are now satisfied that the Vetiver System works.

Figure 16-22a. Nothing would survive in the rocky "soil" of this waste outlet in tropical Queensland, Australia.

Figure 16-22b. Now, in the same location as in Figure 16-22a, vetiver hedges protect, rehabilitate, and stabilize the land, making it useful for more productive purposes.

Figure 16-23a. In Queensland, Australia's outback, workers plant a vetiver hedge at the water line (green ink line) to prevent lap erosion from destroying this vital source of water storage and to prevent further silting.

Figure 16-23b. At the same Queensland site (as in Figure 16-23a), the vetiver hedge grows despite dry weather, protecting the dam from erosion and preventing silt from entering the dam.

Figure 16-23c. At the same Queensland site (as in Figure 16-23a), the vetiver hedge becomes established.

Figure 16-23d. Clean water at the same Queensland site (as in Figure 16-23a) has resulted from the vetiver hedge's ability to filter out silt and debris that would have entered the dam as products of normal runoff.

Figure 16-24a. On China's Pintang Island, vetiver hedges protect the sea wall around a fish farm. This hedge has protected the wall from the effects of a typhoon that wrecked the unprotected walls in other parts of the farm. The roots of the vetiver extend down to the wall's base and protect it from the internal runoff from the land behind.

Figure 16-24b. The vetiver hedge (the same as in Figure 16-24a) is not affected by seawater.

Figure 16-25. In Panama, a vetiver hedge protects a farmer's vegetable garden from the damage of intense runoff above his field. The hedge will slow down the runoff, spread it out, and prevent it from concentrating in any area, thus preventing erosion, or worse still, slipping.

Figure 16-26. In Natal, South Africa, vetiver hedges, strategically placed down the slope, protect this construction site by preventing rilling from even starting. Over time, native plants will germinate between the hedges, voluntarily stabilizing the whole area, although the vetiver hedges, as they are planted, could do the job alone. The natural regrowth fostered by the hedges prevents wind erosion from blowing noxious dust into the townships.

Figure 16-27a. Vetiver hedges are used in urban areas to protect hotel grounds, airports, residential houses, and parking areas from soil loss runoff, slumping, and sediment buildup.

Figure 16-27b. In this same area (as in Figure 16-27a), once a year the hedge can be cut back to a height of 40 centimeters, and the trash can be used as mulch around the trees or can be sold to organic farmers as pesticidal/fungicidal mulch for their truck crop farms.

Figure 16-28a. In Australia, at old coal mine tailings that had never been properly stabilized, serious rilling has occurred over the years.

Figure 16-28b. At this same site (as in Figure 16-28a), after the Vetiver System was introduced, vetiver plants grow in the larger rills, and hedges thrive on the easier slopes at the bottom of the tailing.

Figure 16-29a. On a sugarcane field in Natal, South Africa, vetiver hedges protect drainage lines and waterways.

Figure 16-29b. The contrast between the constructed and vegetative methods of soil conservation is evident in these photographs of sugarcane fields in Natal, South Africa. In the foreground, the traditional system of contour banks and channels, constructed to prevent soil erosion, takes a strip of land 5 meters wide out of production. In the valley, vetiver hedges are now replacing the constructed banks and take only 1 meter's width of land.

Figures 16-30a and 16-30b. Alongside this newly built low-cost, farm-to-market road in the mountains of northern Madagascar, vetiver protects the cut and fill slopes. It is estimated that by using vetiver, maintenance costs are reduced by 30 percent, and the road is now open year round to market traffic.

Figure 16-31a. Vetiver grass, which forms a stiff grass hedge, is permanent and will grow only where someone plants it. In this photograph, a good, well-established vetiver hedge protects a field from erosion. It also prevents runoff from concentrating and causing damage by spreading it out and giving it time to be absorbed.

Figure 16-31b. The stiff nature of the vetiver hedge enables it to withstand flooding, while the native grasses have collapsed.

Figure 16-31c. The density of vetiver grass enables it to hold back gravel.

Figure 16-32. To avail yourself of the Vetiver System of soil and moisture conservation, you need just three things: (1) some planting slips of vetiver grass, (2) some loose or plowed soil, and (3) a pair of bare hands. Simply plant the vetiver across slopes or across gullies or rills, look after it for a couple of seasons until is establishes, and you will have protection from erosion for life. You do not need surveyors, engineers, or bulldozers. You do not need help from the government. As long as you can get some planting material, you can plant and maintain a vegetative system of soil and moisture control that will enable you to develop a sustainable system of farming.

Annex 1. Vetiver Development Costs

Table A1-1. Hectare Budget for Developing a Vetiver Grass Nursery India, 1988

Labor and Machinery	Units	Cost per Unit (Rupees)	Number of Units	Total per Hectare Cost (Rupees)
Plowing	Oxen	45	10	450
Breaking clods	Man days	12	50	600
Spreading FYM	Man days	12	10	120
Forming ridges and furrows	Oxen	45	5	225
Loading and unloading slips	Man days	12	10	120
Slip treatment	Man days	12	15	180
Pruning and sorting slips	Man days	12	20	240
Planting	Man days	12	75	900
Weeding	Oxen	45	15	675
Weeding and topping	Man days	2	150	1,800
Uprooting clumps	Man days	12	25	300
			Subtotal	**5,610**
Input	**Unit**	**Cost per Unit**	**Number of Units**	**Total per Hectare Cost**
Purchase of slips	’000	10.0	62.5	625
FYM	Tonnes	50.0	25.0	1250
Di-ammonium phosphate (DAP)	kg	3.5	250.0	875
Urea	kg	2.6	375.0	975
Atrazine (ai)	kg	167	1.5	250
BHC (10%)	kg	2.0	25.0	50
Irrigation			1	250
			Subtotal	**4,275**

			Base Costs	**9,885**
Contingencies and losses	%	25.0		2,471
			TOTAL COSTS	**12,356**

FYM=farmyard manure
Note: Basing information on the actual costs of a government nursery, a farmer could do the work much more cheaply using less labor and fewer inputs. The costs in this table are for a commercial nursery, which will be “harvested” (for slips) two to three times per year and possibly over several years. (Once farmers have planting material, they do not need the services of the nursery again.)

Table A1-2. Output from the Nursery

At a planting rate of 62,500 slips per hectare—		
20 slips/clump	would yield	1,250,000 slips
30 slips/clump	would yield	1,875,000 slips
40 slips/clump	would yield	2,500,000 slips
60 slips/clump	would yield	3,750,000 slips

Assumed sale price per slip: One paise per slip (1/1500 US$); therefore, at 60 slips per clump, the nursery farmer would make a return of US$2,500 per hectare on each harvest.
NB. Cost in Rupees per hectare—15 Rupees = US$1.00.

Table A1-3. Field Costs for Establishing Vetiver Hedges
(circa 1990)
(Indian Rupees)

Item	**Unit**	**Cost per Unit**	**Number of Units per Year**		**Cost per Year of Establishment**		
			Year 1	**Year 2**	**Year 1**	**Year 2**	**Total**
Operation							
Opening furrows[1]	2 oxen	45	0.5	0	--	--	22.5
Forming V ditch[2]	Man days	12	5.0	60	--	--	60.0
Digging/separating/ loading/unloading	Man days	12	2.0	0.4	24.0	4.8	28.8
Planting/fertilizing	Man days	12	4.0	0.8	48.0	9.6	57.6
Weeding	Man days	12	2.0	24.0	0	0	24.0
						Subtotal	**193**
Input	**Unit**	**Number**	**Number of Units per Year**		**Cost per Year of Establishment**		
			Year 1	**Year 2**	**Year 1**	**Year 2**	**Total**
Purchase slips[3]	000	10	40	8	400.0	80.0	480.0
Transport/slips[4]	%	10	4		40.0		40.0
DAP	kg	3.5	20		70.0		70.0
Urea/3 splits[5]	kg	2.5	60		150.0		150.0
BHC (10%)[6]	kg	2.0	40	4	80.0	8.0	88.0
Contingencies	%	10	10		74.0	8.8	82.8
				Total (rounded)	**814**	**97**	**911**
Treatment (Cost per hectare)							
Labor					45	4	49
Input					204	24	228
				Total (rounded)	**250**	**28**	**277**

Notes:
1. Costs entered as oxen-pair days.
2. Opening "V" ditches, necessary in semi-arid and arid areas to accumulate water to plant slips to ensure their survival.
3. 1Rp/100 slips.
4. From nursery to field site.
5. Use of fertilizers is optional, although the plants will form a hedge faster if they are fertilized; but it is not essential.

6. BHC was used to protect the young slips from white ant attack, it is not essential.

These budgets are based on a 40-meter horizontal interval (HI) between hedges, equivalent to 250 meters of hedge per hectare. No hard and fast rules about HI exist; this is a natural system and is not governed by formulae. The HI is determined by observation—the point at which rilling would start again down from the protection of the hedge. For more information about slope, intervals, and so on, see Chapter 7.

Table A1-4. Hectare Budget—China (1989)
Farmer-owned nursery
Cost of production of vetiver slips per Mu*

		Yuan 6/day	Yuan 3/day
Labor	22 man days	132	66
Fertilizer	Urea 25 kg @ Y 1.4/kg	35	35
Fertilizer	Phosphate 25 kg @ Y 0.4/kg	10	10
Water charges		30	30
Planting slips	4000 @ 100/Y	40	40
Chemicals		20	20
Packing		100	50
Total Cost	**Yuan**	**367**	**251**
Average cost of slips/Mu at 30/clump (30 x 3,900) = 117,000 at 100slips/ Yuan = Y 1,170/Mu.			
Gross Margin	**Yuan**	**803**	**919**

***Mu** = 1/15ha • 1 Yuan = approx 25 ¢ US

Table A1-5. Field Planting of Vetiver Grass
(Cost per Mu on 20º slope)

Planting material[7] 2,000 slips/Mu at 1 Fen/slip = Y 20
Manure, fertilizer = 10
Planting labor, 3 days at Y 6/day = Y 18
Transport = Y 2
Yuan 50/Mu8 (US$14)

Annex 2. Pests and Diseases

Those working in the field with vetiver have reported that the plant has been attacked by, but not affected by, the following pest and diseases:

Fusarium spp. This fungus, commonly known as root rot, attacks particularly during the rains. It is controlled by 0.1 percent Ceresan.

Curvularia trifolii. This pathogen attacks vetiver, causing leaf spot—tan to dark spots that later turn black. It can be controlled by copper spray.

Gloeocercospora sorghi. This fungal disease shows as diffuse brown spots with irregular margins, but it causes no problem.

Holotrichia serrata. These bugs, commonly known as white grubs, have been found in the roots of vetiver, but do not seem to affect it.

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