VETIVER SYSTEM AND ITS RESEARCH AND APPICATIONS IN CHINA

CHINA VETIVER NETWORK

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Foreword

I am pleased to introduce this new photographic essay relating to vetiver grass technology in China. The Vetiver System, as it is now called, is used for many different applications from soil and water conservation to the reclamation of mine dumps and landfills, as well as stabilization of highways, canals and river-banks. This book is a testimony to initiatives taken in China to introduce this new technology and to the people and agencies who made it work.

Since 1987 much research has been undertaken in many different countries, the results of which confirm the value and success of the different vetiver applications. The Vetiver System continues to be one of the most cost effective and simple methods of conservation and stabilization of soils. Thus, the demand for its use continues to increase.

The development of the Vetiver System in China started in 1988 in Jiangxi and Fujian Provinces with, at that time, support from the World Bank. Subsequently, in 1996 the China Vetiver Network was established under the umbrella of the Chinese Academy of Soil Sciences in Nanjing. As a result, information about the Vetiver System has spread throughout southern China where it has been thoroughly tested and is now being applied for many different purposes. The results of this work have been shared with other vetiver users around the world and have helped accelerate its application in many other countries. Vetiver truly is a "network" linked technology where all participants have freely exchanged ideas and helped each other to further develop. The International Erosion Control Association with its prestigious international “Environmental Award of Distinction” presented to the China Vetiver Network in 2002 has acknowledged China’s strong contribution to this effort.

This book is primarily for farmers, soil conservation specialists, environmentalists, waste management and city planners, landscapers and bio-engineers. It would be good to see, as a result of this book, many more potential users applying the technology to protect their soil and land, to conserve moisture for better crop production, to stabilize engineering works, and to mitigate environmental degradation. Those who read this book can be assured that if they apply the technology correctly, the results will be extremely effective -- so READ, DO, SEE and BELIEVE.

Dick Grimshaw
Chairman
The Vetiver Network

Preface

Environmental protection must be considered a basic state policy to be adhered to for a long period as it is one of the most urgent missions faced by the contemporary world and also one of the basic tasks faced by the Chinese people in their economic construction and social development. To fulfill this mission, which in its broad sense consists of two fields: 1) soil and water conservation as well as 2) pollution control, various measures could be implemented. However, among the most popular measures, bio-engineering technology has become a favorite. It is frequently being adopted by an increasing number of people and has been applied in more and more situations in recent years.

A popular bio-engineering option currently is Vetiver (*Vetiveria zizanioides*) which is characterized by its strong stress tolerance, wide adaptability, quick growing vitality, huge biomass, highly developed root system with fantastic mechanical properties, and powerful soil binding capabilities. In addition, it is easy to plant, simple to manage and has very low costs. Consequently, Vetiver has been applied in a growing number of sectors and countries since the 1980's.

At the Second International Conference on Vetiver held in Thailand in 2000, the Vetiver System (VS) was defined as "a practical, low cost and easily managed vetiver bio-engineering technology to be applied in soil conservation, land stabilization and restoration." Nowadays, the Vetiver System is being applied in over 100 countries and territories. In China, it has been extended to all provinces and regions south of the northern limits of the subtropical zone. Vetiver Systems have been applied in fields of agriculture, forestry, highway construction, railway construction, mining, dam construction, and reservoir construction for soil and water conservation, land stabilization, slope protection, soil improvement, and eco-environmental enhancement. Moreover, VS is employed for pollution control in lakes and rivers as well as in landfills. Practice indicates that the Vetiver System is indeed a highly effective, practical and praiseworthy bio-engineering technology, that is worthy of being widely extended because of its suitability to the conditions in China.

In the past several years, on account of its own extraordinary contribution to the research, application, and extension of vetiver, the China Vetiver Network has received awards from the International Vetiver Network, the King of Thailand, and the International Erosion Control Association. At present, as a result of the leadership of the China Vetiver Network, a book titled "*Vetiver System and its Application in China,*" written and edited as a summary of Chinese research and applications of Vetiver Systems conducted by Chinese scientists and technicians over the past few decades, is about to be published. Publication of the book, which is written in a succinct, practical and objective style, and is supported by many actual cases and pictures that are designed to be a practical guide, is indeed a praiseworthy event. The book is the result of the hard and innovative work of leaders, scientists, technicians, workers and farmers in various sectors who devoted themselves to the research, experimentation and application of vetiver systems for decades, not to mention the contribution of its hard-working authors and editors. To facilitate international exchanges and cooperation, the book is to be published in both Chinese and English. It is hoped that its publication will assist in the promotion of wider and wider application of VS in China and throughout the world.

In the past few decades, Chinese people have put great efforts into controlling soil and water losses as well as pollution. Successes have resulted in worldwide renown. However, because China is a country that continues to suffer from severe soil and water losses, there is still a long way to go in the field of environmental protection. For example, recent figures show eroded land covered an area of 3.67 million km^2, which constituted 38.2% of China's territory. Of this 1.794 million km^2 was in the form of water erosion while the other 1.876 km^2 was from wind erosion. In addition, 5 billion tons of fertile soil were being washed away annually. Thus, the State Council of the People's Republic of China stressed the importance of erosion control in its document titled "*A Circular on the Soil and Water Conservation Program*" stating that soil and water conservation constituted the lifeblood of development in mountainous areas, an essential task for regional improvement and harnessing of river resources, and the basis of economic and social development.

Meanwhile, the *State Water and Soil Conservation Plan* has set a target for soil erosion control of 40,000 km^2 /year. This will not be an easy task. With the quickening pace of China's economic development in agriculture, industry and mining, the eroded and polluted areas will most likely continue to grow. Consequently, it is believed that the Vetiver System, as a new and emerging bio-engineering technology, will play a more active role in the aforementioned fields.

The publication and edition of the book got support from both Chinese and foreigners. The translation from Chinese into English was mainly completed by Mr Guoyan Xiong. Mr Shengluan Lu edited the Chinese version, while all the English articles were edited and corrected by Dr. Charles (Todd) Chirko. We hope to express our sincere thanks to them.

Liyu Xu
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Chapter 1

Vetiver System: Its Origin and Development

Vetiver, *Vetiveria zizanioides*, which now has a new scientific name: *Chrysopogon zizanioides* (L.) Roberty**,** is found the *Gramineae* family (as in the TVN Book the plant here will referred to as Vetiver, *Vetiveria zizanioides*). It is a perennial plant with a massive root system that is generally vertical and non-invasive to adjoining habitats. In addition, it has many other characteristics that have made it a favored plant for water and soil conservation as well as slope stabilization. Since the 1980's numerous countries in the world have introduced Vetiver Grass Technology (VGT) to control erosion and stabilize slopes.

During the Second International Vetiver Conference (ICV-2) held in Cha-am, Thailand in 2000 the phrase VGT was converted to Vetiver System (VS). VS is defined as a practical, inexpensive, low maintenance and effective method for soil erosion and sediment control, for water conservation, and for land stabilization and rehabilitation. It is environmentally friendly as well. There are 2 main components of VS. The first consists of live vetiver plants in agricultural and non-agricultural applications. The second is composed of dry vetiver plant parts, which are by-products of vetiver production grown for soil and water conservation, and are used for handicrafts, for roof thatching, for mushroom growing, for animal fodder and feed, for industrial products, for herbal products, etc.[1)]

Vetiver and vetiver grass technology was introduced to China by Mr. Richard Grimshaw through World Bank's China Red Soil Development Project in 1988. The project covered 5 provinces in southern China. With effort from numerous colleagues it was disseminated to many other southern provinces. Numerous universities and research institutes studied vetiver's biological and ecological characteristics; the establishment and management of vetiver hedges; and the effect of vetiver on soil fertility, soil moisture, soil erosion control, and crop yield. Tests showed that vetiver could play an important role in the remediation of red soils as well as in riverbank and coastal land stabilization.

Thus, to facilitate planting, scores of vetiver nurseries were established. Farmers then had access to vetiver to protect tea bushes and tea oil plants. They also fed animal stock and fish with vetiver prunings. In Fujian Province, people applied vetiver to fix coastal sand dunes, to control wind erosion, and to establish hedges for windbreaks. Research has shown that vetiver grass increased soil fertility with soil nutrients such as nitrogen, phosphorus, potassium, and exchangeable aluminum; and also improved soil pH and organic matter content (Chen K. et al. 1998). Another benefit was that vetiver hedges could reduce water runoff and water erosion (Tao 1998). When vetiver prunings were used to mulch the ground surface, soil temperature and moisture were improved (Chen and Li 1998).

To coordinate vetiver production in China the China Vetiver Network (CVN) was established in 1996 with the support of the Vetiver Network. To sum up experiences in the years since 1988, and to disseminate vetiver grass technology as rapidly as possible, the China Vetiver Network organized an International Vetiver Workshop in Fuzhou sponsored by the World Bank in 1997. During the post-conference tour, about 100 participants visited demonstrations on Pingtan Island, Fujian Province, that revealed vetiver grass applications to protect coastal areas and fish ponds, to fix sand dunes, and to protect high valued cash crops. The participants also visited a demonstration site that used vetiver to protect highway embankments in Nanping Prefecture again in Fujian Province.

[1)] Narong Chomchalow, personal communication, 10 March 2003.

At the workshop, Mr. Diti Hengchaovanich, an expert from Thailand, introduced some theory and recounted some successful experiences using vetiver grass technology for engineering protection focusing in particular on highway embankments. His presentation generated great interest among the Chinese participants. In China, since economic reforms began several decades ago, highway and railway construction has developed quite rapidly. It was noted that a great potential existed for using vetiver grass technology as a cheap and practical bio-engineering method to protect road embankments and preserve the ecological environment in the vicinity of the roads, especially in mountainous areas.

Unfortunately, few engineers participated in this workshop. Therefore, two years later, in 1999 in Nanchang, Jiangxi Province, the China Vetiver Network organized an International Conference on Vetiver Bio-Engineering Technology for Erosion and Sediment Control and Stabilizing Civil Engineering Construction Projects. A few recognized international experts were invited to introduce their experiences utilizing vetiver grass for protection in engineering construction projects. This time most of the participants came from engineering institutions throughout China and most were from highway institutions. Moreover, some landscape companies and interested individuals attended the conference. This conference had a huge impact on vetiver dissemination. Participants felt it was very successful because they found that vetiver technologies could bring them fast and considerable profits.

Since the close of the conference, vetiver systems have been rapidly employed for highway embankment protection, as well as with railway embankments, water reservoir preservation, mine tailings, land fills, etc. Universities and research institutes around China have also conducted research in various areas on topics such as the effect of vetiver grass on highway protection and on eutrophication; the result of insect pests on vetiver hedges; and the magnitude of vetiver root strength. Additionally, international scientists have studied the effect of termites on vetiver.

The number of vetiver organizations has grown tremendously in the last 15 years. In 1987 there were no vetiver networks. However, today in addition to The (International) Vetiver Network, there are 20 other vetiver networks throughout the world. These organizations are responsible for disseminating the well-known "Green Book" called: *Vetiver Grass: The Hedge Against Erosion*, which, in its fifth edition, has been distributed in over 100 countries. It was translated into Chinese in 1990 and again in 2002. In the future it is expected that vetiver systems will be disseminated more widely, and they will play a more important role in economic development in many parts of China and throughout the world.

Chapter 2

Basic Characteristics of Vetiver

1. BOTANICAL CHARACTERISTICS OF VETIVER

1.1. Roots

Vetiver has a highly developed, dense and net-like adventitious root system derived from the underground parts of Vetiver stems and tillers that can penetrate into very deep parts of the soil profile. Generally roots go 2-3m deep but can reach 5m in some cases with a record of 5.2m documented in Thailand. The root diameter can range from 0.6mm to 23.2mm with 33.3% found in the 0.6mm - 0.8mm range, 33.2% in the 0.8mm - 1.2mm range, and 24.9% in the 1.2mm - 2.2mm range (Cheng and Zhang, 2002). Although white colored in their early tender stage, Vetiver roots gradually turn pale-yellow to yellow-brown over time. Roots, fresh or dry, emit a special fragrance from the constituent vetiverol which is extracted for use in the perfume industry.

1.2. Leaves

Vetiver leaves are fairly thick and tough, sword-shaped, and look smooth and bright with some tiny saw-teeth like splinters along the upper part of the middle vein on the back side and around the leaf edges for about 1/3 of its total length. While the backside of the blade is green colored, the upper side looks pale-white as it is covered with light-colored grids consisting of tiny green and white colored lines except for the green-colored middle vein and 2-3mm at the edges. The blades are 0.4cm - 1.3cm wide, 30cm - 130cm long and appear V-shaped, when the length is viewed from the base, with the long axis curving downward. The middle and upper part of the leaf open smoothly; and then due to the force of wind and raindrops, the leaf droops to some extent for the last 20cm approaching the tip. The Vetiver plant generally has 16-20 blades that form in layers and is over 1.5m in height at its heading stage.

1.3. Stems

Mature stems stand straight and stiff and are 1.5m - 2.5m high at their heading stage. They generally have 16-20 nodes with a number of buds at each node that function as branch shoots, as well as sheathes wrapped between the nodes. They are cylindrical but somewhat flat shaped, with a smooth surface. These stems are of a hard texture being lignified, but they do have tiny cavities in their relatively loose cores. Neither underground stems nor stolons are found.

1.4. Flowers

Vetiver has an erect, purple-colored apical panicle with a strong rachis. Its spikes, usually 15-40 cm long, have numerous upward or erect, verticillate, fine and weak branches. One spikelet is sessile, hermaphrodite, and somewhat flattened laterally with short sharp spines. It has a glabrouscallus, three stamens, and two plumose stigmas. The other spikelet is pedicelled and staminate. Some cultivated forms rarely flower (Greenfield, 2000, pp.15). Vetiver flowers and heads in autumn, however there are no seeds due to its sterile nature. Thus, it reproduces by tillers.

2. PHYSIO-ECOLOGICAL CHARACTERISTICS OF VETIVER

Although it is a typical tropical and subtropical species, Vetiver has a fairly wide growing range and is very stress-tolerant. It is considered a climax plant surviving in various environments that has become a unique physiological and ecological specimen over its long history.

2.1. Adopted to a wide ecological range

2.1.1. Temperature. Being a tropical grass, Vetiver is capable of enduring not only a high temperature of 55°C, but also a low temperature of –15.9°C. With colder temperatures the above ground parts will perish, but the underground part will survive. It begins growth slowly when the mean daily temperature reaches 8°C, then quickens as the temperature increases. Vetiver attains its maximum growth rate when the mean daily temperature reaches 20°C - 30°C. During its peak growth period around June or July, it will grow at a rate of 2-3cm/day. Nonetheless, with temperatures over 30°C, its growth rate decreases.

2.1.2. Illumination. Being C4 plant, Vetiver has a strong capacity for photosynthesis, resulting in quick growth rates in times of abundant sunshine, moisture and nutrients. At the same time if illumination is deficient growth will be retarded (Xia *et al.*, 1994). Therefore, sufficient sunshine is needed for higher growth rates and plentiful tillers.

2.1.3. Moisture. *Vetiver will grow normally in areas that have from 200mm to 5,000mm of rainfall. Since it* is hydrophytic, it grows best in humid soil conditions and may survive in a totally inundated environment. It is reported that Vetiver can grow normally even when submerged by floodwater for up to 6 months. At the same time, Vetiver is fairly drought-tolerant and may survive through a drought period lasting several months.

2.1.4. Soils. Vetiver has been found growing in very wide range of soil conditions including clayey red earth, shifting sands, sandy soils without clay, strongly acid soils with a pH of 3, extremely alkaline soils with a pH of 11, saline soils, gravel soils with little loam on sloped land and infertile soils containing few N, P, or K nutrients. Vetiver grass has even become established on a residual plinthite layer with a severely eroded red earth profile after the A and B horizons have been totally washed away and where only small amounts of N and P were applied (Lu *et al.*, 1994).

2.2. Physiological characteristics

Vetiver's broad niche may be partially explained by its wide tolerance range to severe conditions.

2.2.1. Tolerance to low pH and manganese toxicity. A pH as low as 3, Mn content as high as 578mg/kg in the soil, or Mn as high as 890 mg/kg in plant parts has no negative impact on Vetiver growth (Truong and Baker, 1998).

2.2.2. Tolerance to aluminum toxicity. Vetiver grows well with a pH of 3.8 and Al saturation of 68% in soils where only moderate amounts of P and N were applied.

2.2.3. High saline tolerance. The growth rate of Vetiver decreases only 50% with a soil salinity of EC_{sc} = 16ms/cm. Studies by Xia *et al.* (1994) confirmed that Vetiver was capable of surviving in severely saline conditions of EC_{sc} = 16ms/cm. This high saline tolerance is partly due to Vetiver's deeply penetrating root system which enables it to take up nutrients from lower parts of the soil that have less saline toxicity and partly due to the fragrant components in its roots which may eliminate or mitigate the salt constituents.

2.2.4. Alkaline tolerance. N and P fertilizer application in strongly alkaline soils with an exchangeable Na percentage (ESP) = 33 may notably increase the growth rate of Vetiver.

2.2.5. Tolerance to heavy metal toxicity. Vetiver's extremely strong tolerance to heavy metals has been proven by a series of experiments. It can grow well in soils containing large quantities of heavy metals, such as where Cr =120mg/kg, Cu =100mg/kg, Cd =200-60 mg/kg or Ni =100mg/kg.

Data has shown that Vetiver both rejects and accumulates some heavy metal elements at the same time. To aid in purifying a polluted environment, Vetiver can be harvested when it has accumulated a pollutant so as to remove it from the environment. Using this technique, Vetiver has proven to be a good environmental purifier because it has a high growth rate and produces a huge amount of biomass.

3. MECHANICAL PROPERTIES OF VETIVER FOR SOIL STABILIZATION

Cheng and Zhang (2002) measured the tensile strength (P) of Vetiver using a method that was first introduced by Hengchaovanich (1999), where the maximum tensile force (F) at the moment the roots are broken is measured with a scaled spring tensiometer while the diameter (D) of a broken section of roots is measured with a Vernier caliper. Measurement and calculation of tensile strength ($P = 4F/\pi D^2$) and maximum tensile force (F) are shown in Table 2-1 with measurement of each sample repeated 10-28 times.

Table 2-1. Results of Vetiver Tensile Strength Measurements with $P = 4F/\pi D^2$.

Diameter of Broken Root Section (D)mm	Maximum Tensile Force (F)kg	Maximum Tensile Strength (P)MPa	Diameter of Broken Root Section (D)mm	Maximum Tensile Force (F)kg	Maximum Tensile Strength (P)MPa
0.20	0.60	186.69	0.62	2.63	85.10
0.35	1.20	121.90	0.62	2.63	85.20
0.38	1.50	129.20	0.62	2.80	71.40
0.40	1.33	103.40	0.63	2.66	83.40
0.40	1.50	116.70	0.63	2.73	85.60
0.45	1.38	97.10	0.65	2.56	75.40
0.48	1.75	93.50	0.65	2.70	76.70
0.55	2.23	91.70	0.65	2.73	63.30
0.57	2.62	100.30	0.66	2.74	78.20
0.60	2.15	74.30	0.67	2.68	74.30
0.60	2.61	90.20	0.70	2.95	74.90
0.61	2.30	76.90	1.30	4.90	36.10
0.62	2.48	79.00	1.50	5.10	28.20
0.62	2.53	81.90	1.70	5.30	22.90

At the same time, the maximum tensile force and maximum tensile strength of other grasses, including *Paspalum notatum* (Bahia grass), White clover, *Cyperus serotinus* (sometimes referred to as *Juncellus serotinus)* (Tidalmarsh flatsedge), *Paspalum dilatatum poir* (Dallis grass, Water grass, Large water grass, Mao hua que bai) and *Eremochloa ophiuroides* (centipede grass), were measured and calculated using the same method mentioned above. Comparison between these measurements and calculations and those for Vetiver are shown in Table 2-2 shows that, compared with the grasses mentioned above, the average tensile force (F) and the average tensile strength (P) of Vetiver are 0.92 - 8.34 and 2.11 - 5.33 times higher, respectively, than those of other grasses.

Table 2-2. Root Diameter, Tensile Force (F) and Tensile Strength (P) of Various Grasses.

Grasses	Average Root Diameter (mm)	Average Tensile Force (F) (kg)	Compared with Vetiver[a] (%)	Average Tensile Strength (P) (MPa)	Compared with Vetiver[a] (%)
Tidalmarsh flatsedge	0.38±0.43	2.66±0.47	10.7	24.50±4.20	28.8
Dallis grass	0.92±0.28	12.98±0.35	52.1	19.74±3.00	23.2
White clover	0.91±0.11	12.80±0.59	51.4	24.64±3.36	29.0
Vetiver	0.66±0.32	24.89±1.08	100.0	85.10±31.2	100.0
Common centipede grass	0.66±0.05	9.56±1.33	38.4	27.30±1.74	32.1
Bahia grass	0.73±0.07	8.99±1.99	36.1	19.23±3.59	22.6
Manila grass	0.77±0.67	8.84±1.25	35.5	17.55±2.85	20.6
Bermuda grass	0.99±0.17	10.49±2.65	42.1	13.45±2.18	15.8

[a]Compared to Vetiver with Vetiver as 100%.

Other reports indicated that the tensile strength (P) of Vetiver's root system (40-120 MPa with an average of 75 MPa) was about 1/6 of the ultimate tensile strength of steel, and notably higher than the mechanical tensile strength of many trees and bushes including *Alnus spp.* (alders) 4-74 MPa, *Pseudotsuga menziesii* (Douglas-fir) 19-61 MPa, *Populus spp.* (poplars) 5-38 MPa, *Salix spp.* (willows) 9-36 MPa, *Acer saccharinum* (silver maple) 15-30 MPa, *Tsuga heterophylla* (Western hemlock) 27 MPa, *Vaccinium spp.* (huckleberry types) 16 MPa, as well as *Hordeum vulgare* (common barley) 15-31 MPa, and non-*Gramineae* grasses 2-20 MPa (Hengchaovanich, 1999).

Consequently, Vetiver's root system with its powerful penetrative ability and "inborn" vitality is capable of penetrating through hardpans and even concrete. Vetiver roots are also found in very hard red plinthite layers and tiny cracks between rocks or gravel. This root system, consisting of an abundance of roots and forming a penetrating net which contacts almost every corner of the soil profile, functions as reinforcing bars to bind soil particles together. Its extraordinary soil-fixing power is derived from a combination of tensile force, friction and adherence.

4. GROWTH BEHAVIOR OF VETIVER

Vetiver is a perennial grass. Its growth characteristics in the subtropical zone as described from observations in Jiangxi, Zhejiang, and Hunan Provinces of China is as follows: Vetiver grasses begin to sprout on about 20 February, when the local mean temperature increases to a stable minimum of 8°C. After its winter dormancy the leaves are totally or partially withered and the winter buds and tillers are growing slowly. In late February new tiller buds sprout as the grasses are ready to be transplanted. Large scale transplanting is practiced from early to middle March. Then for about one month the roots of the transplanted slips begin to recover and extend while the leaves begin to turn green during a 15-20 day period. Later, the above ground part of the plant grows followed by tillering.

The first tillering peak takes place in April and early May. Then in June and early July the second peak occurs. During this time the most luxuriant growth and quickest tillering transpires with a maximum rate of growth of over 5cm/day. In addition, 50% - 60% of the annual tiller production happens at this time with the greatest biomass production, as there is abundant rainfall and favorable temperatures (20°C - 30°C). However, Vetiver growth declines

in August when there are droughts and intolerably high temperatures of over 35°C and even up to 40°C. Irrigation and fertilizer application, however, do alleviate the problem a little. The third peak of growth and tillering is found from September to early or middle October as temperatures cool and favorable climatic conditions return. Nevertheless, tillers that are produced in this period are not capable of attaining the jointing stage in the same year. As temperatures decrease, Vetiver growth slows which minimizes tiller production. Finally, the grass enters its winter dormancy stage, which usually comes in late December or early January.
Vetiver tillers are yellow-green at the 3-leaf stage, turning green as the leaves continue to emerge, grow and form a layer wrapped around the base of the tiller. At the same time, the tiller base becomes larger and larger having a flat, elliptical cross-section. At the 10-leaf stage the cross section has a width of 1.0cm - 2.0cm and a thickness of only 0.3cm - 0.4cm. Adventitious fibrous roots begin to emerge from the underground tiller base when there are 5-8 leaves. Then, new tillers gradually surface. This is the second phase of tillering. All tillers both old winter ones and new spring ones are jointing in late May and June. Heading and flowering occur from middle to late October. At this time over half will head with the non-headed ones being 1.0m - 2.0m in height. The shoots meanwhile, have young tillers or tiller buds with only 3 young leaves that are at various heights and in clumps, but all are less than 1.0m.

Leaves usually wither in winter. However, green leaves and tillers may still be found in the middle and bottom parts of some plant clumps. As long as cold temperatures are of short duration the plant will survive even though the temperature goes below 0°C. Therefore, in order to minimize damage by cold, it is suggested that Vetiver plants not be cut or pruned from late September through the winter season.

Generally speaking, the underground parts of Vetiver can safely survive a temperature of –8°C in a long and severe winter, though all surface parts will wither. Moreover, evidence shows that Vetiver roots in the deeper part of the soil may survive with air temperatures of -13°C to -15.9°C. Under these severe environmental conditions all surface parts and even the underground parts to depths of 1m - 2m will die. Yet, such a damaged plant is still capable of recovering and growing the following spring even though growth will be delayed about 20 days as the plant recovers.

Vetiver biomass production occurs quickly and hedges can form in a very short time. In the span of a year through tillering Vetiver can produce 10 to 15 new tillers and can reach 60 tillers with ideal moisture and nutrient conditions.

The biomass production is huge with a normal annual production of 50-60t/ha and can be as high as 100t/ha with adequate water and fertilizer.

Chapter 3

Vetiver Systems for Agriculture Production

Early in 1988, less than a year after it was introduced as a pilot experiment in the red earth area in South China, Vetiver had attracted wide attention for its “magical” characteristics, such as its wide adaptability and rapid growth. At that time, many agricultural officers, scientists and technicians not to mention some farmers were involved in research, experimentation, application and promotion of Vetiver. During the past 15 years, the Vetiver System (VS) has been applied widely in agricultural sectors including sustainable agriculture development; soil and water conservation in orchards, in tea gardens and on sloping farmland; ecological and environmental improvement of farmland; moisture retention by mulching with Vetiver leaves and stems to avoid drought; increased crop production; soil fertility by using leaves and straw for manure; environmental protection; windbreaks to prevent shifting sands from invading farmland; livestock production; fodder production by using the tender leaves and straw for cattle and sheep feed; and rural economic development by using Vetiver straw to culture edible fungi such as Jew’s ear (*Auricularia auricula-judae)*.

1. VETIVER SYSTEMS FOR SOIL AND WATER CONSERVATION IN ORCHARDS, IN TEA GARDENS, AND ON SLOPING FARMLAND

Vetiver Systems applications in agriculture for soil and water conservation with orchards, tea gardens and sloping farming fields is very important. Technicians in the experimental group of the First Phase of the Red Earth Development Program in Jiangxi and Fujian Provinces first introduced Vetiver plants as pilot experiments in agriculture development in 1989. At that time the Jiangxi Red Earth Program Office introduced 10,000 kg of Vetiver by planting on farmland in 6 counties (Guixi, Jinxi, Linchuan, Dongxiang, Chongren and Jinxian) and a research institute (Jiangxi Provincial Institute of Red Earth) within the Development Area. Altogether the Vetiver protected more than 200 ha of fields.

At the same time, the Fujian Red Earth Program introduced another 30,000 kg of Vetiver plants. These were planted in 29 tea gardens and orchards distributed in 7 counties in that province and protected more than 130 ha of fields as well. All experimental Vetiver plants were planted according to the technical rules listed in the *Green Book* (the Vetiver field handbook). In the fields involved, Vetiver was planted on the contour, with 2 m between contour lines. In addition, some farmers planted additional lines around their own fields to protect their crops with a Vetiver hedge.

Due to a shortage of Vetiver planting material, only 2-3 slips of Vetiver were planted in a clump at each hole with holes at 20 cm intervals. When planted, a small quantity of phosphorus or composite fertilizer was also applied. A year later, the plants had formed hedges with a 75% density. After the third year of establishment, these thick hedges provided excellent soil and water conservation conditions by intercepting runoff as well as trapping eroded silt and soil.

According to experimental results from standard runoff fields set up in Jiangxi and Guangdong Provinces (Table 3-1), silt interception increased with the Vetiver hedges compared to a control with no hedges revealing a decrease in surface runoff of 32.7%-59.7%, while soil erosion was reduced by 63.7%-92.7% (Hu, *et al.* 1997; Xia, *et al.* 1996).

Table 3-1. Effects of Vetiver Hedges on Water and Soil Conservation[a].

Field Sites	Annual Rainfall (mm)	Treat-ment	Surface Runoff			Eroded Soil		
			Total (mm)	Decrease (mm)	Decrease (%)	Total (kg/m^2)	Decrease (kg/m^2)	Decrease (%)
Yonghe Town, Xingning City, Guangdong Province	1931.8	Control	1015.8			14.53		
		Vetiver Hedge	409.1	606.7	59.7	1.06	13.47	92.7
Sixia Small Catchment, Chongren County, Jiangxi Province	1766.0	Control	223			3.36		
		Vetiver Hedge[b]	151	72	32.7	1.22	2.14	63.7
		Level Terrace	170	53	23.8	1.67	1.69	50.3

[a]Figures were averaged from measurements in 1993 and 1994. Vetiver was planted in 1992. Observation area for each treatment was 100 m^2.
[b]Vetiver hedges were established on 6^0 slopes.

A stationary observation in Renshou County, Sichuan Province, set up by the Soil and Fertilizer Division of the Agriculture and Animal Husbandry Department of that province, showed that 2 cm of silt was intercepted in front of the Vetiver hedge in the first year of its establishment, and 5 cm of silt was observed in the second year at the same site. Meanwhile, very evident eroded rills were seen at locations without Vetiver hedge protection. These observations showed Vetiver's excellent results in soil conservation.
In a different experiment in Yonghe Town, Xingning City, Guangdong Province, with Vetiver hedges present, soil moisture content during the rainy season increased 20.3% and 4.1% at soil depths of 0-20 cm and 20-40 cm, respectively, when compared to a control (Table 3-2) (Chen, L.J., 1998; Xia, H. P. et al 1996). More importantly, though, larger corresponding figures of 42.1% and 13.3% were recorded during the dry season. At the Soil Conservation Station in the same city, increases of 39.9% and 7.6% were recorded with Vetiver hedges in the dry season at 0-20 cm and 20-40 cm depths, respectively. This illustrated the positive effects of Vetiver grass on maintaining soil moisture during times of stress.

Table 3-2. Increase of Soil Moisture Content Due to Vetiver.

Experimental Sites[a]	Observation Season	Treatment	Depth: 0—20cm		Depth: 20—40cm	
			% Moisture	Increase (% Increase)	% Moisture	Increase (% Increase)
Yonghe Town	Dry	Control	15.74		19.29	
		Vetiver Area	22.37	6.63 (42.1%)	21.86	2.57 (13.3%)
	Rainy	Control	22.47		25.31	
		Vetiver Area	27.03	4.56 (20.3%)	26.36	1.05 (4.1%)
Soil Conservation Station	Dry	Control	16.3		14.50	
	Dry	Vetiver Area	22.8	6.5 (39.9%)	15.60	1.1 (7.6%)

[a]Both sites are located in Xingning City, Guangdong Province.

Since 1993, Vetiver technology has been further disseminated to counties and cities involved in the Second Phase of the Red Earth Development Program in Jiangxi, Fujian, Hunan and Zhejiang Provinces as well as Guangxi Autonomous Region. These areas are all found in South China's Soil and Water Conservation Program. For example, in Jiangxi Province alone, Vetiver contour hedges, with an accumulated area of over 20,000 ha, controlled all 43 small catchments on farms involved in the program distributed throughout 19 counties. These played an important role in controlling soil and water losses in the early stages of this phase of the Red Earth Development Program. Promoted by the China Vetiver Network (CVN), Vetiver Systems were disseminated to 16 provinces and regions in South China in 1998, with an estimated 200,000 ha planted.

Moreover, a Vetiver System, with an area of nearly 80 ha, was established during the implementation period of the "China Vetiver and Agroforestry Technology Project" led by Prof. Xu Liyu, of the Nanjing Institute of the Chinese Academy of Soil Sciences. On slopes in the Dabie Mountains, chestnuts, tea gardens, and mulberry farms located in Yuexi County, Anhui Province and Yingshan County, Hubei Province, were planted with Vetiver in 2002 and 2003. As the Vetiver hedges fill out, their effects on conserving soil and moisture as well as on ensuring continuous high yields of tea and fruits will become evident. Because of the favorable results to date, the project has been broadened through training and extension programs to include the whole of the Dabie Mountain region.

2. VETIVER MULCH TO IMPROVE SOIL MOISTURE AND THE FARM FIELD'S ECOLOGICAL ENVIRONMENT

In China Vetiver grasses (mainly hedges for soil conservation) planted between fruit trees, tea trees and other crop lines must be pruned several times every year. The first pruning occurs at the end of February when the dead leaves and stems that dried out during the winter are removed. Then, from the middle or latter part of June to the middle part of September another 3-4 prunings must take place. The pruned leaves and stems are usually used *in situ* as mulch materials to help resist drought or cold injury to fruit trees, tea bushes and other crops. The mulch is usually placed at the base of the tree, bush or crop or buried in the soil while fertilizing. Farmers have adopted this practice to increase yields as it helps retain soil moisture, lowers soil temperature and resists drought in the summer, while facilitating resistance to cold in the winter.

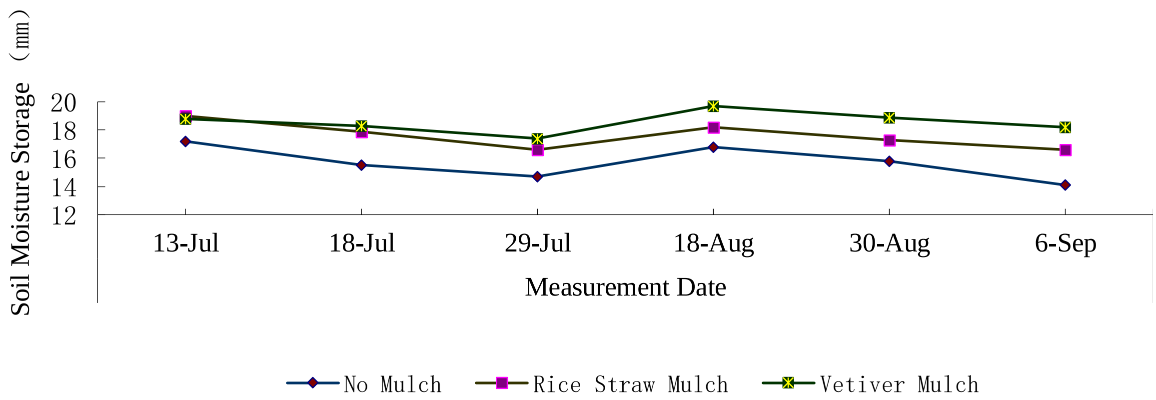
Chen K. *et al.* (1994), conducted a trial in an experimental citrus orchard located on Xiaohuashan Hill, a hill of red earth soils in Linchuan County, Jiangxi Province (28.0º N, 116.5º E, 50m above sea level). Orchard surface soils without Vetiver were compared to those with Vetiver planting and mulching. Results showed that the ecological environment of the orchard with Vetiver planting and mulching (the mulch consisted of pruned Vetiver leaves and stems placed on the soil surface at the base of and under the tree crowns) had greatly improved. On mid-summer days, the average temperature measured at the middle of the tree crowns (Table 3-3) decreased by 2.8ºC; relative humidity increased 4.3%; illumination intensity decreased 18.6 k lux; and daily mean temperature, daily maximum temperature, and diurnal temperature range on the surface soil at the base of the tree decreased by 5.1ºC, 19.1ºC and 20.8ºC, respectively. Meanwhile daily minimum temperature increased by 1.7ºC, daily inter root mean soil temperature decreased by 1.7ºC, and soil moisture increased by 2.8%. This illustrated that Vetiver improved the microclimate of the citrus orchard located on sloping red earth land. Especially during the mid-summer dry season with its high temperatures, the soil temperature was greatly lowered, while soil moisture maintained acceptable levels.

Table 3-3. Effects of Vetiver Planting on Microclimate Improvement in a Citrus Orchard on Red Earth Sloped Land.

Treatment	Daily Mean Temp. (in tree crown) °C	Daily Mean Relative Humidity %	Daily Illumination Intensity k lux	Temperature of Surface Soil at the Base of the Tree				Soil in Grass Roots	
				Daily Mean °C	Daily Max. °C	Daily Min. °C	Diurnal Range °C	Daily Mean Temp. °C	Moist. Content %
Control	29.3	59.2	57.2	33.8	58.6	22.5	36.1	29.2	17.4
Vetiver	26.5	63.5	38.6	28.7	39.5	24.2	15.3	27.5	20.2

Hu *et al*. (1997) conducted another experiment on a low hill in a citrus orchard, located at the Jiangxi Provincial Institute of Red Earth in which soil moisture capacities under different treatments were compared. The treatments were as follows: 1) the base of citrus trees were mulched with 12 kg of dry Vetiver grass; 2) the base of citrus trees were mulched with the same amount of dry rice straw; and 3) there was no mulch applied (control).
Results showed that, the daily mean soil moisture evapotranspiration from 0-60cm observed on the first treatment of dry Vetiver grass at the 5th day and 16th day during a continuous fine-weather period were 1.4 mm and 1.1 mm, respectively. That is to say, at the 16th day during a continuous fine-weather dry period in mid-summer, soil within 0-60 cm depth in the Vetiver mulch treatment contained 4.5% and 17.9% more moisture than that in the rice straw mulch treatment and the control treatment, respectively (Figure 3-1). Moreover, the differences were greater at the end of the Autumn-drought days. On 6 September, in the middle of the Autumn-drought period, there was 10.3% and 27.8% more moisture retained in soils with Vetiver mulch compared to the rice straw mulch treatment and the control treatment, respectively. As a result the Vetiver mulch increased the farmland's drought endurance capability by 6-10 days.

Figure 3-1. Dry Season Soil Moisture Change, Soil Depth 0-60 cm, in a Citrus Orchard Using Various Mulches.



3. USING VETIVER CLIPPINGS TO IMPROVE SOIL FERTILITY AND INCREASE CROP YIELD

Vetiver grass hedges established in orchards, in tea gardens and on sloped farmland have to be pruned 3-4 times per year and can yield 8-15 kg/m of fresh vegetation. Annual yields of fresh Vetiver plant material can reach 58-100 t/ha along with 24 t/ha of root material. According to the Jiangxi Provincial Institute of Red Earth, in 1 kg of dry Vetiver leaves and stems there are 422 g of C, 17.4 g of N, 0.5 g of P_2O_5, and 7.5 g of K_2O. Meanwhile, 1 kg of dry Vetiver roots contains 402 g of C, 2.1 g N, 0.6 g P_2O_5, and 5.8 g K_2O. Thus, Vetiver prunings used as mulch or manure can effectively improve soil fertility leading to increased crop production.

Lu and Zhong (1997) at the Jiangxi Provincial Institute of Red Earth conducted a 3-year stationary experiment in which cut Vetiver chips were applied to the soil as manure to improve fertility. In this experiment, 4.5 t and 2.25 t of dry Vetiver leaves and stems were applied on 2 farmland sites. Results (Table 3-4) showed that soil total porosity, organic C, total N, total P_2O_5, as well as available N and available P_2O_5 on treated farmland increased while soil specific weight decreased. This resulted in production of 2,790 kg/ha and 2,280 kg/ha of experimental corn seed, which was an increase of 34.8% and 10.1%, respectively, when compared with 2,070 kg/ha yield from a control.

Table 3-4. Effects of Vetiver Clippings on Soil Physical Features and Chemical Characteristics of Red Earth Farmland.

Treatment	Specific Weight[a] (mg/cm^3)	Total Porosity[a] (%)	Organic C[a] (g/kg)	Total Component[a] (g/kg)			Available Component[a] (g/kg)		
				N	P_2O_5	K_2O	N	P_2O_5	K_2O
Vetiver[b]	-0.03	+1.0	8.24	1.07	0.51	15.13	168	16.8	75.0
Vetiver[c]	-0.04	+1.3	8.26	1.08	0.51	15.12	173	15.3	77.5
Rice straw[c]	-0.09	+3.0	7.6	1.03	0.48	14.86	120	14.1	73.8
Control	+0.14	-5.0	7.97	1.05	0.50	15.26	163	13.5	75.0

[a]Values for specific weight and total porosity were derived by taking the differences between measurements before and after the experiment (i.e., after the third harvest), while other measurements were recorded at the end of the experiment.
[b]applied 4.5t/ha of dry straw
[c]applied 2.25 t/ha of dry straw

Similar results were found in an experiment conducted by Chen K. *et al.* (1994), at Nanjing University of Agriculture, in which Vetiver grass was planted in a citrus orchard on red earth sloped land and then applied as a mulch material at the base of the trees. In this experiment, when compared to an untreated case, soil physical features and chemical characteristics in the treated cases improved. As shown in Table 3.5 the soil specific weight dropped by 0.09 mg/cm^3, soil porosity increased by 3.8%, and the pH value went up 0.65 (meaning acidity decreased). In addition, there were increases in the following: organic matter (OM) 4.60 g/kg, total N 0.29 g/kg, hydrolytic N 17 mg/kg, available P 2.4 mg/kg and available K 51 mg/kg. Meanwhile micronutrients also increased by the following amounts: Ca 274 mg/kg, Mg 21.85 mg/kg, Fe 18.27 mg/kg, Mn 1.59 mg/kg, Zn 1.90 mg/kg, Cu 0.32 mg/kg, B 0.04 mg/kg and Mo 0.01 mg/kg. Finally, total soil amino acid content increased by 57.44 mg/kg. The experiment indicated that Vetiver planted in a citrus orchard on red earth sloped land could help increase citrus yields due to improvement of the soil physical features and chemical composition. It was also noted that conditions for citrus flowering and fruiting were enhanced. For example, the increase in pH and OM meant an increase in soil nutrient availability and an improvement in ability of the citrus root system to assimilate them.

Table 3-5. Effects of Vetiver Clippings on Improvement of Soil Physical and Chemical Properties for Red Earth Soils in a Citrus Orchard.

Treatment	Specific Weight mg/cm^2	Porosity %	pH	OM	Total N	Hydrolytic N	Available P	Available K	
				g/kg		mg/kg			
Control	1.35	48.6	4.70	10.30	0.54	47	7.0	24	
Vetiver	1.26	52.4	5.35	14.90	0.83	64	9.4	75	
	Total Amino Acid	**Ca**	**Mg**	**Fe**	**Mn**	**Zn**	**Cu**	**B**	**Mo**
	mg/kg	**mg/kg**							
Control	254.75	252	70.36	14.37	3.85	1.15	0.75	0.10	0.04
Vetiver	312.19	526	92.21	32.64	5.44	3.05	1.07	0.14	0.05

4. APPLICATIONS AS WINDBREAKS, TO FIX SHIFTING SAND AND TO STABILIZE EMBANKMENTS ON SEACOASTS, RIVERS AND PONDS

Key attributes of Vetiver grass are its drought resistance, its ability to grow on infertile soils and its deep and thick root system allowing wide adaptability. Therefore, technicians in Fujian and Jiangxi Provinces planted Vetiver as a fast growing windbreak hedge to fix shifting sands and to stabilize seacoast embankments, riverbanks and pond dikes, with beneficial results.

In March 1994 the Soil Conservation Office of Fuzhou City, Fujian Province established Vetiver hedge windbreaks for their Jojoba (pronounced hohoba) oil crop garden in Daping Village, Zhonglou Township, Pingtan County. The 0.44 ha garden of sandy soil, comprised of mainly shifting sands (90%), had an annual mean wind velocity of 8.4 m/s with a prevailing northerly wind. In total the hedges were over 800 m long and arranged at 6-8 m intervals. This was parallel to the Jojoba lines and perpendicular to the prevailing wind direction. These hedges filled out the same year the Vetiver was planted and after 1 year had long, thick leaves and stems. By the end of the second year, these lush hedges which were over 2 m high, had already become powerful natural windbreaks arresting the shifting sands and protecting the Jojoba garden. The result was a high yield of oil. Measurements on the sheltered (leeward) side of the hedges showed that wind speed was greatly diminished by the hedges (Zhang, 1996). The closer the measurement was to the hedges the greater the decrease in wind speed. For example, 5 m from the hedge, the wind speed decreased 58.8% while 2 m away from the hedge the wind speed decreased 79.4%.

In March 1995, over 2000 m of Vetiver hedges were set up along the banks of the Pan River, the Liushui seacoast and a few ponds. These hedges also had positive effects on soil conservation and minimization of silt in the runoff in the same year as planting. Measurements indicated that, in the winter of the first year of hedge planting, up to 7.5 kg of silt was intercepted by a 1 m long section of the hedge; while in the second year the figure increased to 17.0 kg. Moreover, embankments were tightly bound and stabilized by the powerful Vetiver root system, preventing collapse from strong winds and waves. As an example, there were over 200 cases of collapsed embankments without the Vetiver hedge protection after a powerful typhoon hit on 31 July 1996. By contrast, in the same storm the embankments stabilized by Vetiver hedges were not destroyed at all. As a result, in the spring of 1997 local fishermen planted 1740 m of Vetiver hedges on a voluntary basis around all of their ponds.

5. FRESH VETIVER CLIPPINGS AS FODDER FOR CATTLE AND SHEEP

Both the Soil and Fertilizer Division of the Agriculture and Animal Husbandry Department in Sichuan Province and the Jiangxi Provincial Red Earth Development General Company conducted an analysis of nutrient values on Vetiver as a fodder. Nutrient levels were compared for Vetiver at 65 days and then again at 215 days (Table 3-6, Soil and Fertilizer Department of the Agricultural Bureau of Sichuan Province, 1992).

Table 3-6. Protein and Amino Acid Content in Vetiver Leaves and Stems.

Number of Growing Days / Content of Vetiver Leaves and Stems (%)	215	65
Water	60.4	69.7
Lignin (Dry)	9.33	10.07
Lignin (Fresh)	3.69	3.05
Raw Protein (Dry)	8.94	11.0
Raw Protein (Fresh)	2.75	3.33
Asparaginie Acid	0.32	1.00
Threonine	0.17	0.19
Serine	0.13	0.32
Glutamic Acid	0.55	2.61
Blycine	0.22	5.13
Alanine	0.35	2.64
Cystine	0.06	0.21
Valine	0.27	0.70
Methionine	0.04	0.04
Iso Leucine	0.19	0.27
Leucine	0.30	0.73
Tyrosine	0.11	0.06
Phenylalanine	0.21	0.45
Lysine	0.22	0.59
Amonia	0.16	0.17
Histidine	0.07	0.14
Arginine	0.18	1.23
Proline	0.12	3.25

In addition, a comparison of protein content (Table 3-7) showed that fresh and tender Vetiver stems and leaves (at 65 days) was higher than alfalfa, clover, sweet potato vine and rice straw but slightly lower than that of Chinese milk vetch (*Astragalus sinicus*). Although protein content in dry Vetiver (at 65 and 215 days) was lower than alfalfa, it was higher than that in corn silage and other common winter fodders such as rice straw and wild oat straw. Moreover, the methionine content of Vetiver was almost the same as other fodders, while the lysine content was much higher (Soil and Fertilizer Department of the Agricultural Bureau of Sichuan Province, 1992). These measurements indicated that tender Vetiver grass clippings were suitable as fodder for cattle, sheep, pigs, rabbits, and fish. Also with cattle and sheep Vetiver seemed very palatable.

Table 3-7. Nutrient Content of Vetiver and Some Common Fodder Types.

Component / Fodder Type	Protein (Fresh) (%)	Protein (Dry) (%)	Lysine (%)	Methionine (%)
Vetiver grass (65 Days)	3.30	11.00	0.59	0.04
Vetiver grass (215 Days)	2.75	6.94	0.23	0.04
Alfalfa	3.20	12.00	0.25	0.07
Comfrey (start of flowering)	3.10	22.30	0.15	0.04
Clover	2.30	13.30	0.18	0.06
Sweet Potato Vine	2.10	18.30	--	0.22
Chinese Milk Vetch	3.50	17.00	--	--
Rice Straw	2.90	3.40	--	--
Corn Stem Silage (Mature)	--	5.31	--	--
Corn Stem Silage (Waxen Mature)	--	6.32	--	--
Wild Oat Straw	--	4.50	--	--

Hu *et al*. (1997) found that different sources and tenderness of Vetiver grass revealed differences in content (Table 3-8). The degree of tenderness was important as experiments at the Jiangxi Provincial Institute of Red Earth showed that cattle could be fed entirely on tender Vetiver grass when it was a half-month old, but only 90.9% when it was one-month old. Meanwhile, large numbers of fish could eat feed that was 59-71% Vetiver if the grass was a half-month old, but with one-month old grass this was reduced to 44-56%. This meant that the more tender the Vetiver clippings the better the feed. The older grass with joints was not as suitable as the younger shoots when used as fodder.

Table 3-8. Content of Vetiver Grass with Different Sources and Tenderness.

Sources of Vetiver	Tenderness	Water (%)	Raw Protein (%)	Raw Fat (%)	Raw Fiber (%)	Raw Ash (%)	N-free Extract (%)
Indian	Tender	3.25	7.31	1.97	34.53	4.76	48.18
	Less tender	3.19	6.00	1.86	35.76	4.79	48.40
Fujianese	Tender	3.24	6.76	1.28	36.24	4.07	48.41
	Less tender	3.14	5.89	1.19	18.36	3.83	47.60
Rice straw	Old	3.25	4.59	1.46	32.37	17.14	41.33

Thus Vetiver's advantages of fast growth, drought-resistance, and ability to grow on infertile soils renders it useful for soil conservation, and for developing animal husbandry by stall feeding animals when the young and tender shoots are used.

6. USING VETIVER POWDER FOR CULTURING EDIBLE FUNGI

An experiment conducted by Lin Zhanxi of the Fungi-Grass Research Center at Fujian Agricultural University, indicated that Vetiver was a high quality grass material for culturing edible fungi (Zhang, 1996). They successfully used Vetiver leaves and stems as a raw material to raise many kinds of edible fungi, including *Lentinula edodes* (Shiitake, Black forest, Black, Oak Shiitake, Black forest mushroom), *Auricularia polytricha* (Cloud ear, Tree ear, Wood ear, hairy Jew's ear), *Auricularia auricula* (Black ear, Wood ear, Jew's ear, *Pleurotus ostreatus* (Tree Oyster, Oyster, White oyster, Gray oyster, Oyster mushroom), *Pleurotus abalones* (Abalone, Abalone mushroom), *Pleurotus pulmonarius (sajor-caju)* (Phoenix oyster, phoenix-tail mushroom), *Pleurotus spp.*, *Flammulina velutipes* (Enoki, Winter, Velvet stem, Golden, Snow puff, Winter mushroom), G*anoderma lucidum* (Ling-Zhi, Reishi, Glossy ganoderma), *Hericium erinaceus* (Lion’s mane, Monkeyhead, Bear's head), *(Dictyophora indusiata* (Bamboo sprouts, Collared stinkhorn, Stinkhorn mushroom), (*Pholiota nameko* (Nameko, Nameko mushroom) and others. In cultivating edible fungi, Vetiver presented high biotransformation rates of about 80% for *Lentinula edodes* and up to 100% for both *Pleurotus ostreatus* and *Auricularia polytricha*.

Information summarized from various sources showed that, in the second year of planting, Vetiver planted as a net on soils of medium or higher fertility could produce 60-100 t/ha of dry grass. That is to say, with a biotransformation rate of 80%, a single hectare of Vetiver was able to raise 48-80 t of fresh mushrooms, valued at 19,000-32,000 RMB Yuan[1] at the present market price. At the same time, the hyphal rich waste material remaining after fungi raising qualified as feed that was good for livestock, poultry, and pond fish. In addition, Vetiver hedges could be pruned 2-3 times and their clippings could still be used for edible fungi production. This meant not only more biomass for fodder, but also a thicker hedge for soil conservation. Therefore, Vetiver grass with its multiple uses was ideal in helping to increase farmer’s income and for promoting rural economic development.

Chapter 4

Vetiver Systems for Highway Embankment Protection

1. INITIATION OF VETIVER SYSTEMS APPLICATION FOR HIGHWAY EMBANKMENT PROTECTION

Supported by The World Bank and various institutions from both China and abroad, an International Vetiver Workshop was organized by the China Vetiver Network in Fuzhou, the capital of Fujian Province, from 20-26 October 1997. One of the first Vetiver System (VS) applications visited was for highway embankment stabilization in Jianyang County in northern Fujian Province. The demonstration site showed participants that Vetiver grass could prevent highway embankments from landslides and at the same time could efficiently protect paddy fields from silt deposits. The demonstration was warmly welcomed not only by engineers but also by farmers.

At the demonstration site, Vetiver grass was planted two ways. One was Vetiver hedges planted along the contour, and the other was planting like a square mesh, which combined vertical and horizontal hedges like a honeycomb. After a few months' growth, it seemed that the latter worked more efficiently.

During the Fuzhou workshop in addition to participants visiting demonstration plots, Thai expert Mr. Diti Hengchaovanich introduced his expertise in using VS for highway protection in Malaysia. He pointed out that Vetiver had a strong fibrous root system that penetrated and bound the earth to a depth of up to 3 m and could withstand the effects of tunneling and cracking. Thus, the grass was more effective than hardwood roots in stabilizing slopes.

Later on 8 July 1998, an official document was prepared and released by the Highway Bureau of Fujian Province in southern China. The document fully approved utilization of Vetiver for stabilizing highway embankments and asked all highway institutions, offices, and departments at the county and prefecture levels throughout the province to study Vetiver technologies and implement them for highway stabilization and erosion control. The document further requested that all institutions strengthen their exchange of ideas and experiences in order to extend the grass throughout the entire province more rapidly.

There are 3 prefectures, 16 cities, and 54 counties in Fujian Province with a total area of over 120,000 km^2. The Province has many mountains and hills accounting for more than 90% of its area, and recently there has been rapid development in highway construction. For example, in Fujian Province 4,000 km of highways were built from 1992 to 1996. The highways were usually constructed on deeply weathered granite, which was a few meters to several dozens of meters deep. Their embankments were subject to soil erosion and landslides on both the cut (upper) side of the slope and the fill (lower) side of the slope. This led to damaged highways with newly formed pockets where the soil had eroded and the road caved in, especially along the fill (lower) side of the highways. To protect these highways, engineers had to use rock and concrete as reinforcement for the embankments in critical sections of the road. There were 2.6 million m^2 of road embankment slopes that needed to be protected in Fujian Province. However due to financial constraints, only a very small percentage of these slopes were protected. Thus, extension of VS played an important role in highway protection throughout the province.

2. THE HISTORIC NANCHANG CONFERENCE

Although the Fuzhou Workshop introduced Vetiver applications to the engineering field, most of the participants were involved in agriculture and few engineers attended. The workshop organizer, the China Vetiver Network, realized that there was a huge potential for VS to be used in highway and railway construction as embankment protection. For example, the total length of highways in China increased from 1,118,000 km in 1994 to 1,186,000 km in 1996. This was an annual increase of 34,000 km. However, due to financial limitations many highway embankments were not properly protected resulting in serious erosion.

To speed up VS extension in the engineering sector, the International Conference on Vetiver using Bio-Engineering Technology for Erosion and Sediment Control and Civil Construction Stabilization was held in Nanchang, Jiangxi Province in October 1999. The conference was a breakthrough for highway protection. It was co-organized by the China Vetiver Network and The Highway Administrative Bureau of Jiangxi Province so that more highway engineers could attend the conference.

For the conference field trip, the first large demonstration of Vetiver for highway embankment protection was established on Wuyi Mountain through joint efforts of The Highway Administrative Bureau of Jiangxi Province and the Nanchang Water Conservation and Hydropower College. In March 1999 a total of 10,000 m^2 of highway embankment was protected with VS. The slopes ranged from 30° to 60° with elevations of 280 m to 750 m above sea level. The embankments consisted of coarse materials of granite and were subject to frequent landslides. Although the area's high elevation affected growth, Vetiver fully protected the embankment four months after planting and landslides ceased. The demonstration showed participants: (1) Vetiver could grow well on infertile parent materials and still stabilize embankments and (2) Vetiver was very successful and economical using only 20 tillers/m^2. This meant the cost of Vetiver was only 1/9 – 1/10 of the cost of the other two hard measures.

The Nanchang Conference played an extremely important role in VS application for engineering in China and acted as a historical milestone in the sense that:

1) The demonstration showed engineers and government officers the fact that Vetiver could be widely used for highway embankment stabilization (especially on slide areas on the cut side or upper part of a slope) and could reduce costs.
2) The conference transferred VS applications in China from the previous decade's focus on use for agriculture purposes to engineering applications.
3) VS was fully approved by provincial and national highway experts, and the demonstration and project received a third place award from the National Highway Society in 2002. It was also introduced in the *China Communication Newspaper* and on the Human Resources of China Communications web site.
4) The conference generated interest among private individuals because they found that VS could bring them high profits. From this time on, the private sector began to actively and positively promote VS.

3. COMPREHENSIVE DEVELOPMENT IN SOUTHERN CHINA

3.1. Initiation and development in Zhejiang Province

Just following the Nanchang Conference, Zhejiang Province initiated a VS program. Mr. Zhao Zhaoqing who worked with the Highway Administration Bureau of Zhejiang Province participated in Nanchang Conference in 1999. This was an opportunity for him to learn some of the fundamentals of Vetiver from foreign experts and Chinese scientists. Later he visited Vetiver nurseries and demonstrations in Fujian Province and learned even more. When he returned to his office in Hangzhou he launched the Zhijiang Vetiver Engineering Co. Ltd. of Hangzhou City.

Then, a high quality nursery was established in Hangzhou. In cooperation with Madam Pan Biying, the first demonstration followed on the newly constructed National Highway No. 330 in April 2000 on 10,600 m^2 of slopes to prevent the frequent landslides that occurred in the mountainous areas of Lishui City. Later, Vetiver Systems were introduced for protection on Provincial Highway No.52. These demonstrations were quite successful.

In November 2000 the Zhejiang Communication Bureau organized an appraisal conference on Vetiver, the first conference of this kind in China. Provincial and national experts attended the conference and toured the demonstrations. As a result, Vetiver Systems were fully approved and thus, disseminated throughout the province. As of December 2002, by using Vetiver to stabilize a total of 318,000 m^2 of slopes, costs of around US$ 1.44 million had been saved. These highway embankments planted with Vetiver were along national, provincial, and county highways as well as expressways.

Mr. Zhao's experiences were introduced at Zhejiang Provincial Highway Society's annual conferences in both 2000 and 2002. In June 2001, the Zhejiang Provincial Communications Bureau released an official document to introduce Vetiver Systems as a new technology so that it could be disseminated more easily and rapidly. Because Mr. Zhao's Vetiver company had established a good relationship with the government as well as the Highway and Communications Bureau, further development and a favorable reputation for VS was ensured. It is worth mentioning that Mr. Zhao was the first man in China to cultivate Vetiver planting materials using the bridge technique and the high (raised) bed technique to produce high quality planting materials. In addition, the first demonstration in Zhejiang Province was implemented in the She Minority Group's area. Through information dissemination and field practice the government officers and technicians of the She people came to learn of this inexpensive but very effective method of utilizing Vetiver to fix slopes.

3.2. Progress in Jiangxi Province

Since the Nanchang Conference, there have been many developments in VS applications in Jiangxi Province. These included (see Table 4-1):

1) In March 1999 the first project was launched in the Wuyi Mountains. Altogether 10,000 m^2 of highway embankments were protected with Vetiver. The slopes ranged from 30° to 60° with elevations of 280 m to 750 m above sea level. The embankments consisted of coarse granite materials and were subject to frequent slides. Although the area had a high elevation that affected growth, Vetiver fully protected the embankments four months after planting and landslides no longer occurred saving 300,000 Yuan RMB (US $36,300). This demonstration was shown to the participants of the Nanchang Conference.
2) In March 2000, over 20,000 m^2 of slopes were planted with Vetiver in XingGuo County. The project saved 600,000 Yuan RMB (US $72,500).

3) Also in March 2000, over 10,000 m^2 of highway embankments were planted with Vetiver to protect against heavy flooding of Poyang Lake in the Duchang Section of Jiujiang City. The results showed that VS not only protected the highway, but also protected the farmland along the road. Vetiver withstood long term flooding (about 3 months/year) along Poyang Lake and saved 300,000 Yuan RMB (US $36,300).
4) In April 2000, about 10,000 m^2 of slopes were stabilized by Vetiver in the YuShui Section of Xinyu City to prevent the road from landslides and sinking. This saved 300,000 Yuan RMB (US $36,300).
5) In April 2001, Vetiver was planted on 20,000 m^2 of highway embankments to protect against river flooding and erosion at the XinGan Section of JiAn City. The project saved 600,000 Yuan RMB (US $72,500).
6) In March 2001, a total of 300,000 m^2 of highway embankments with steep fills was planted with Vetiver to protect the highway from lake water flooding and landslides. The project was located in the Tianpo section's first grade highway in Poyang County. This project saved 10 million Yuan RMB (US $1.2 million).
7) In AnYuan County, Vetiver was planted on 15,000 m^2 of steep embankments to protect the highway from erosion in March 2002. This saved 450,000 Yuan RMB (US $54,400).
8) In Yingtan City, about 30,000 m^2 of embankments on National Highway No. 206 was planted with Vetiver during the highway upgrade project. This saved 1 million Yuan RMB (US $121,000).
9) During FengLe's upgrade project in Yichun City, 60,000 m^2 of embankments on a second grade highway was planted with Vetiver to protect the road from erosion. This saved 1.8 million Yuan RMB (US $218,000).
10) In May 2002, Vetiver was planted on 10,000 m^2 of embankments on the highway from Xunwu County to Fujian. This saved expenses of 300,000 Yuan RMB (US $36,300).

Table 4-1. Highway embankment protection in Jiangxi Province (1999-2002)[a].

Year	Location	Slope Area (m^2)	Amount Saved (RMB Yuan)	Amount in US $[b]
1999	Wuyi Mountain	10,000	300,000	36,300
2000	XingGuo County	20,000	600,000	72,500
2000	Duchang Section	10,000	300,000	36,300
2000	Xinyu City	10,000	300,000	36,300
2001	JiAn City	20,000	600,000	72,500
2001	Poyang County.	300,000	10,000,000	1,200,000
2002	AnYuan County	15,000	450,000	54,400
2002	Yingtan City	30,000	1,000,000	121,000
2002	Yichun City	60,000	1,800,000	218,000
2002	Xunwu County	10,000	300,000	36,300
Total	(1999-2002)	485,000	15,650,000	1,900,000

[a]Wang M., 2003, personal communication.
[b]US$1.00 = 8.27 RMB Yuan (amounts rounded off).

It is evident that VS has been used for highway embankment protection in many cities and counties in China. Embankment establishment varied from high mountain areas such as the Wuyi Mountains to lowlands where Vetiver was used to protect highways from floods and waves of Poyang Lake. Altogether 485,000 m^2 of slopes were protected in Jiangxi Province over the 4 years from 1999 to 2002. In Jiangxi Province the rock and cement used for embankment protection was usually 35-40 Yuan/m^2, while the cost was only 5-10 Yuan/m^2 with Vetiver. On the average this saved about 30 Yuan/m^2. In addition, Vetiver protected the environment, reduced noise, and decreased the use of rock that came from quarries.

There were 10 counties or cities involved in VS applications in Jiangxi Province, which is a relatively underdeveloped province in China. The application of Vetiver Systems saved the province over 15 million Yuan RMB (almost US $1.9 million). Thus, VS made a great contribution to the province's economic development.

3.3. Further developments in Fujian Province

Since the Fuzhou Conference in 1997, VS has been extended very rapidly. All cities and counties in the province were actively involved in Vetiver System applications for highway protection. In 1999 along the Fuquan Expressway, a large demonstration was established on a huge landslide totaling 20,000 m^2 with soils consisting of coarse parent materials. This successful application indicated that Vetiver could not only protect the fill side below the road but also the cut side above the road from larger landslides.

Other huge landslides were protected by Vetiver in Qingliu County of Sanming City. Here between the county proper and a mountain there was a river and a highway. When the road was widened in 1996, the slope of the mountain became very unstable. In August 1997, tons of rock and earth slid down the slope blocking the highway and the river thereby threatening the safety of the townspeople. To control the huge cut above the road from further slides, the highway bureau tried constructing armored concrete walls using a matrix design. However, the cut was too large to be completely stabilized, as many places were still subject to further movement. To fully stabilize the slope and to protect the environment, the highway bureau planted Vetiver in 1999 and again later in 2000 forming contour hedges. Some Vetiver was planted in a "V" pattern to lead runoff into the concrete ditches. This proved to be very successful, and the grass grew very well. In some places the grass even grew on the rocky parent materials; and even though it looked yellow, three months after planting it was impossible to pull the grass out. To date, this slide area has been stable without further landslide incidents.

The Highway Bureau of Fuzhou City conducted a study of three different sites for a comparison and labeled them A, B, and C. At each site, 3 sections of the same slope area were protected by 1) Vetiver, 2) rock, and 3) rock plus cement. The rock and rock plus cement were an average of 30cm thick. The cost for the Vetiver protected slopes was 6 and 8 times less (Table 4-2) than the rock and rock and cement, respectively (Highway Society of Fujian Province, 2003).

Table 4-2. Comparison of Vetiver and rock protected slopes.

Material	Unit Price (RMB Yuan)[a]	A		B		C	
		Comparable Area for the Study[b]	Cost in RMB Yuan[a]	Comparable Area for the Study[c]	Cost in RMB Yuan[a]	Comparable Area for the Study[d]	Cost in RMB Yuan[a]
Vetiver	4.5/m^2	1,100/m^2	4,950	2,450/m^2	11,025	1,850/m^2	8,325
Rock	90.0/m^3	330/m^3	29,700	735/m^3	66,150	555/m^3	49,950
Rock and Cement	120.0/m^3	330/m^3	39,600	735/m^3	88,200	555/m^3	66,600

[a]US$1 = 8.27 RMB Yuan.
[b]1,100m^2 x 0.3m = 330m^3.
[c]2,450m^2 x 0.3m = 735m^3.
[d]1,850m^2 x 0.3m = 555m^3.

As of June 2001, Fujian Province had 44 sections planted with Vetiver grass from 15 different highway bureaus. In addition, the Fujian Provincial Communications Bureau designated Vetiver for highway embankment stabilization as a Science and Technology Development Planning Program and requested all cities and counties to establish their own Vetiver production bases.

3.4. Utilizing visits, conferences, and publications

According to incomplete data over one million square meters of highway embankments have been protected by Vetiver in China. This includes Guangxi and Yunnan Provinces, in addition to Zhejiang, Jiangxi, and Fujian Provinces mentioned above. As a result, tens of millions of Yuan RMB have been saved. The key to success of this outstanding achievement was encouraging various sectors including government officers, institutions, and private companies, to promote Vetiver System dissemination. This was accomplished by visits to demonstration sites, conferences, and publications. As long as participants found Vetiver useful, they did their best to make use of the grass. In many cases "seeing was believing." So visiting demonstrations had a profound effect.

Conferences were also excellent tools in the process of disseminating Vetiver Systems. These conferences included the Fuzhou Workshop, the Nanchang Conference, the 1998 Expressway Construction and Development Conference in Kunming, and the 1998 East China Highway Information Conference in Xiamen to name a few.

Since 1998, many articles have been published on Vetiver in many highway and communications journals. The China Vetiver Network and many highway engineers helped prepared these articles. These publications moreover, played an important role in VS dissemination for highway construction and field maintenance in China.

Chapter 5

The Vetiver System for Railway Embankment Protection

There has been great progress in Vetiver System (VS) applications for highway construction since the Vetiver Bio-Engineering Technology for Erosion and Sediment Control and Civil Engineering Construction Stabilization Conference, which was held in Nanchang, Jiangxi Province, China in 1999 and organized by the China Vetiver Network (CVN). One example was the large number of demonstrations established in several provinces in southern China. Another case in point was the many Vetiver companies established by soil conservation institutions, highway bureaus, and companies in the private sector. In some provinces the application of VS has became an official policy and a regular activity adopted for highway embankment protection. For instance, the Fujian Provincial Highway Bureau released an official document requesting all highway institutions to use VS. Meanwhile, the Zhejiang Provincial Highway Association established an Official Vetiver Company for extension of VS. The National Highway Research Institute also incorporated VS into its national highway greening regulation, which is awaiting final approval by the Communications Ministry.

A procedural difference arose when trying to implement VS with highways and railways in China. Each highway division whether at the national, provincial, county, or township level was entitled to apply VS so long as it agreed to use Vetiver technology. However, no railway institution was allowed to start Vetiver planting until they received permission from the top railway organization via the Railway Survey and Design Academies. This meant that if an organization wanted to use VS it had to pass through various doors for permission. With great effort, the Xinchang Railway Company located in Nanjing, the capital of Jiangsu Province, became the first railway to form a Vetiver company. It was launched in 2001 and at that time began to use VS.

Later, The First Railway Vetiver Technology Identification and Evaluation Conference of China was held in Nanjing from 18-20 October 2001. Around 40 participants attended the conference, including experts from the Engineering Design and Identification Center of the National Railway Ministry, the First Survey and Design Academy of the Railway Ministry, the Second Survey and Design Academy of the Railway Ministry, the Fourth Survey and Design Academy of the Railway Ministry, the Shanghai Railway Bureau, the Railway Office of Jiangsu Province, the Director of the headquarters of the Xinchang Railway, Managers of the Xinchang Railway Co. Ltd., and the Directors of the Xinchang Vetiver Slope Stabilization Co. Ltd. At the conference, the coordinator of the China Vetiver Network was invited to introduce some characteristics of Vetiver and to discuss Vetiver research and development in China as well as the rest of the world. During the conference all the participants went to Huangqiao to inspect the demonstration site.

On 20 October 2001, the manager of the Xinchang Vetiver Slope Stabilization Co. Ltd. introduced the background and the process used to establish the demonstrations. An enthusiastic discussion followed. Then a leading group was formed to summarize the comments. The participants agreed that the demonstration was a success and suggested that this technology be tested in more locations and on different railway slopes in order that the Vetiver technology could be disseminated wider and faster. In 2002 and 2003 the Vetiver System was applied to an increasing number of railways in Jiangsu and Fujian Provinces. This paper, then, introduces the first application of VS for use in railway embankment protection in China.

1. BACKGROUND OF THE XINCHANG RAILWAY

The Xinchang Railway Company was responsible for construction of the Xinchang Railway totaling 638 km. It was started in 1998 and completed in 2001 with a total budget of 6.23 Billion Yuan RMB[2] (over $750 million). The railway is located in eastern China from Xinyi in Jiangsu Province to Changxing in Zhejiang Province. Most of the land the railway passed through was plains or lowlands. The embankment was constructed with fine sand and silts of alluvial materials.

To introduce VS to the Xinchang Railway and to other prospective railway lines, the first large demonstration was arranged in the Huangqiao section (around N32° 20', E120° 30'). Road construction material came from deep soils derived from the Yangtze River Basin which in this area had a northern sub-tropical climate (Table 5-1).

Table 5-1. Average Monthly Air and Soil Temperatures.

Depth (cm)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
0	2.9	4.9	10.1	17.2	23.3	28.1	31.9	32.0	25.8	19.3	11.7	5.1	17.7
5	3.2	4.7	9.0	15.5	21.1	25.7	29.8	29.9	24.6	18.5	11.6	5.5	16.6
10	3.6	5.0	9.0	15.0	20.4	25.0	29.1	29.4	24.5	18.6	12.0	6.0	16.5
15	4.0	5.1	8.9	14.8	20.1	24.6	28.6	29.1	24.6	18.8	12.5	6.4	16.5
Air	1.9	3.8	8.0	14.9	19.2	23.9	27.7	27.5	22.5	16.8	10.6	4.4	15.0

The absolute maximum temperature was 38.8°C, and the lowest temperature was –12.5°C. The annual rainfall was 1021.9 mm of which 55.8% was distributed from June to September. The soil primarily consisted of fine sand (Table 5-2) that was easily eroded by both water and wind.

Table 5-2. Soil Particle Size Analysis of a Nearby Field.

Depth (cm)	Particle size (%)			
	>0.05(mm)	0.01-0.05(mm)	0.001-0.01(mm)	<0.001(mm)
0-12	29	43	28	15
12-49	31	45	24	13
49-71	31	47	22	13
71-100	26	45	29	17

For construction of non-Vetiver embankments the Railway Institute had to use plastic sheets to cover the entire slope to guard against erosion. To protect this embankment the railway company then used rocks to make a stone lattice forming a skeleton on the embankment in which they sprayed grass seeds in the openings. The seed spray usually cost 9 Yuan/m^2 and had to be maintained for one year. This meant watering every 3 days the first month after seeding if there was insufficient rainfall. Meanwhile the rocks cost around 60 Yuan/m^3. By way of comparison and to save money and promote a quick vegetative cover, a section of over 5000 m^2 was designed to use Vetiver.

[2] US $1.00 = ~8.3 RMB

2. VETIVER PLANTING AND MANAGEMENT

On 20 April 2001, 120,000 tillers of Vetiver planting material were transported from a village in the Dabie Mountains where farmers had been producing planting materials for contracted Vetiver projects since 1998 as part of a poverty alleviation program and an environmental protection scheme. When transported to the railway construction site the clumps of planting material had stems about 50 cm long with the roots about 15cm in length, and there were 15–100 tillers per clump. The tillers were packed together in bundles with a loamy soil. To increase the survival rate and reduce water loss the tillers were to be cut at the site to 20 cm and then separated into small clumps each containing 3-6 tillers. Unfortunately some tillers were left at around 40 cm because the local farmers wanted to save time and energy by reducing the number of necessary cuts to the seedlings.

As the soil contained a preponderance of silt particles and very little clay, it lacked the desired water storage capacity. So to moisten the roots and maintain soil moisture for a longer time period, the roots were dipped and thoroughly coated with a loamy-clay paste just before planting. At the same time ditches 20 cm deep were prepared along contour lines. To avoid disturbing the slope too much the width of the ditches was limited to around 10 cm by using a specially designed digging tool. Vetiver was planted at a spacing of around 10 cm within a row with 140 cm between rows (Figure 5-1). Because soil nutrients measured from samples in a nearby field were insufficient (Table 5-3), an NPK chemical starter fertilizer (N-15%, P_2O_5 - 15%, K_2O-15%) was applied at 25g/10m ditch. After the application of fertilizer, 3cm of soil was to be placed in the ditch to cover the fertilizer, thus avoiding direct contact with the roots.

Figure 5-1. The Planting Pattern.

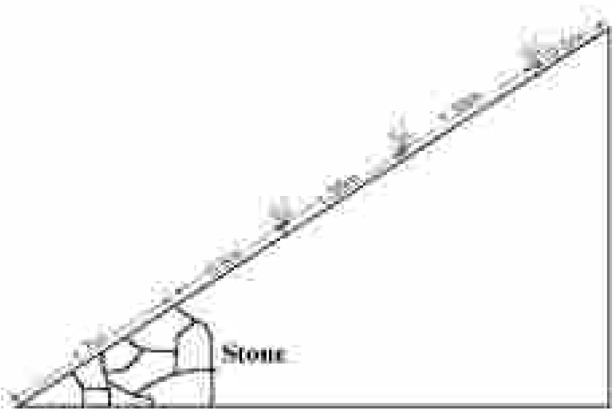


Table 5-3. Soil Nutrient Analysis of a Nearby Farm Field.

Depth (cm)	O.M. (g/kg)	T-N (g/kg)	T-P_2O_5 (g/kg)	S-N (mg/kg)	S-P_2O_5 (mg/kg)	S-K_2O (mg/kg)	$CaCO_3$ (g/kg)	CEC (Me/100g soil)	pH (water)
0 - 12	10.0	0.87	1.66	100	7	97	6.9	9.4	8.1
12 - 49	8.3	0.67	1.51	79	1	51	9.2	9.3	7.7
49 - 71	4.5	0.38	1.57	70	1	73	16.3	10.3	7.8
71 - 100	2.0	0.25	1.25	57	2	61	58.8	6.1	8.1

O.M. = organic matter, T- = total, S- = soluble

Since there was a little rainfall before planting and soil moisture was insufficient, irrigation was provided on 22 April just as the planting finished. The whole planting process lasted 2 days. Then it rained the following day with two cloudy days afterward.

One month later on 25 May 2001 an inspection revealed that only 40% of the planting materials had survived. On 30 May, about 30,000 new tillers were transported from Suzhou, Jiangsu Province to the demonstration site and planted a second time. The re-planting was conducted on 31 May 2001. The weather was cloudy and watering followed the planting on the same day.

For the second planting, the tillers came from the nursery in clumps of clay soil. It was quite difficult to separate tillers even when the clumps were soaked in water. So the tillers were separated by slicing the clumps vertically with a knife. The stems of the tillers were cut to 20 cm and cutting was monitored for accuracy. Watering was also provided once the planting was finished. Later, a third planting was implemented on 26-27 June 2001 to insure Vetiver hedges would form successfully without openings. The planting materials for the third planting came from the Dabie Mountains as did the first planting.

In addition to irrigating three times just after planting and re-planting, a further two irrigations were conducted. On top of this, diluted pig manure was applied on 28-29 July. Then 15 kg of carbamide (urea) was applied on 17 August. It is worth noting that when checked on 21 June, two months after planting, Vetiver grew well and weeds also thrived as the Vetiver had improved the microclimate. To avoid any adverse effects, weeding was undertaken on 26 July, however the weed roots remained in the soil to help control erosion.

3. SURVIVAL RATE AND GROWTH BEHAVIOR

3.1. Survival rate

The survival rate of the first planting was poor when scrutinized on 25 May 2001 possibly due to several factors:

- The chemical starter fertilizer should have been covered by 3 cm of soil before planting to avoid direct contact with the roots. Nevertheless, as the plants grew the roots might have come in contact with the fertilizer resulting in poor growth.
- The tillers had stems and leaves that were not pruned back thereby increasing transpiration. Although the stems of the tillers were to be pruned to 20 cm at most, some of them were 30 cm or even 40 cm because farmers wanted to reduce their workload.
- Since the tillers were too long, some of them were planted too deep (some tillers had about 20 cm of their stem buried). This may also have influenced the survival rate.
- The survival rate was higher when planting 6 tillers/clump rather than 3 tillers/clump. Therefore, it is recommended that more tillers/clump should be planted for engineering construction protection projects.
- Regarding the planting material planted on 31 May, the survival rate when checked on 21 June, about 20 days after planting was around 40%. However, it increased to 70% when checked on 26 June (just 5 days later) and to 85% and 2 July (six days after the second check). This was probably due to an increase in the soil and air moisture during the plum-raining season[3], which had just begun during this time. Furthermore, there was a large rice field along the railway at this spot. At this time the rice seedlings in the field were irrigated and the relative humidity increased over the area.
- The new Vetiver leaves appeared very late because most of the roots were damaged or destroyed when being separated from the clumps. Thus, only a few roots remained and these were bound tightly by the clay. It would take a longer time for these few tightly bound roots recover in their new environment and grow.

[3] Around The Yangtze River Basin, there is a rainy period of about 20 days in June, when the plums ripen.

3.2. Growth differentiation

Generally speaking, the demonstration section of the railroad embankment ran in an east-west direction. Vetiver grass with a southern exposure did not grow as well as that with a northern exposure, possibly because of less moisture associated with the southern aspect. However, even on slopes with the same aspect Vetiver growth differed especially in the first 2 months. In addition, tillering varied from 5 to 45 tillers/clump. Analysis showed that soil nutrients also differed from location to location (Table 5-4). This was due to soil materials from farmland derived from Yangtze River sediment with different layers having a different nutrient content. Moreover, the surface soil of the farmland should have had higher nutrient levels which would promote Vetiver growth. Table 4 shows that a high nitrogen content may promote Vetiver growth at the early stage.

Table 5-4. Soil Nutrient Analysis of Surface Soil from Different Sections of the Road Embankment.

SS	Description	O.M.	T-N	T-P	T-K	S-N	S-P	S-K	pH (water)
		(g/kg)				(mg/kg)			
1	Vetiver-grew very well, southern aspect	**5.9**	**0.33**	**1.70**	**19.8**	**78.16**	**3.7**	**34**	**8.70**
2	Vetiver-died after the first planting, southern aspect	**4.7**	**0.29**	**1.72**	**20.8**	**63.95**	**39.3**	**90**	**8.51**
3	Vetiver-grew well, northern aspect	**5.5**	**0.32**	**1.22**	**21.8**	**71.05**	**2.4**	**32**	**8.86**
4	Landslide area-northern aspect	**7.1**	**0.37**	**1.87**	**19.6**	**93.79**	**4.1**	**37**	**8.79**

SS = soil sample number, O.M. = organic matter, T- = total, S- = soluble,

3.3. Insect control

At the beginning of August, a rice borer was found on some of the Vetiver. The insect was at the end of its first generation and the beginning of its second generation. To control the insect, three applications of Tamaron were used on 6 August, 28 September, and 15 October.

4. EROSION CONTROL RESULTS

Generally, the grass that was originally planted on 20 April was about 80 cm high two months after planting. This formed a preliminary hedge that started to exert some of its protection function. Inspection at the end of July, 3 months after planting, revealed that the whole embankment was fully protected with Vetiver grass that was over 2 m high, and the roots were 80 cm – 110 cm in length. The embankments that had passed the rainy season safely were well protected by Vetiver's dense and massive root system that had a high shear strength per unit fiber concentration. This offered a better chance for continued survival.

Nevertheless, examination on 27 June turned up a small landslide of about 4 m^3. Repair and replanting were immediately undertaken. Soil sampling and analysis showed that although particle size distribution seemed to be similar in the different samples (Table 5-5), the fourth soil sample (SS 4) had a texture of sand and loamy sand attributed to fewer clay particles (<0.002mm), which explained why this section of the slope had a small slide. Nonetheless, the slide happened two months after planting when the Vetiver hedges were not fully formed, and it was caused by continuous rainfall during the plum-raining season. Once this season passed and the Vetiver was established the embankment no longer collapsed.

Table 5-5. Mechanical Analysis of Surface Soil from Different Sections of the Road Embankment.

SS.	Description	Particle size (%)				Texture
		2 - 0.2 (mm)	0.2 – 0.02 (mm)	0.02– 0.002 (mm)	< 0.002 (mm)	
1	Vetiver-grew very well, southern aspect	0.8	74.8	16.0	8.4	Sandy loam
2	Vetiver-died after the first planting, southern aspect	0.5	84.0	9.8	5.7	Sandy loam
3	Vetiver grew well, northern aspect	0.5	69.5	20.5	9.5	Sandy loam
4	Landslide area-northern aspect	0.5	84.8	9.5	5.2	Sand and loamy sand

SS = soil sample number

According to farmers' experiences, slopes had to be protected by rocks otherwise the embankments would collapse and bury the nearby rice field. Thus, the railway engineers usually had to use huge plastic sheets covering the whole embankment to guard against erosion. This demonstration showed that Vetiver hedges could act like a concrete wall or rock lattice to prevent erosion.

5. CONCLUSION

The first application of Vetiver for railway embankment protection was quite successful, which indicated that Vetiver could be used to protect slopes composed of sandy soils. This was quite different from numerous embankments on other highways in the mountainous areas of China that usually contained rock fragments, some clay particles and mixed forest soils containing organic matter. Although the best planting season in this area was March during the dormant season, Vetiver took only 3 months to become fully established even when planted at the end of April.

To ensure survival of Vetiver the following should be seriously considered:

- Initially, planting may be considered strictly a technical issue in which planting precision is unimportant. This could lead to complacency and therefore to planting failure. As a result, planting and management procedures should be prepared and followed throughout the entire process.
- Planting materials should not come from the nursery in soils with a high clay content so as to avoid difficulty in separating the tillers.
- Organic manure as a starter fertilizer is recommended. If chemical fertilizer is used calcium-magnesium-phosphate might be a good selection to avoid possible root damage.
- Planting materials should be carefully prepared (not longer than 20 cm in length).
- Select the most suitable planting dates to ensure success with less effort and to prevent possible landslides during the rainy season. This is especially important for embankments with sand or loamy sand textures. In addition, a soil analysis should be conducted prior to planting in order to design different techniques for different soil textures.

Chapter 6

Vetiver for Revegetation on Mine Tailings

Vetiver can withstand a wide range of pH values and grows well under different soil and ecological conditions. Thus, it is ideal for use with revegetation on mine tailings. For instance Vetiver can grow well on copper mine tailings with a pH of 4.0 and aluminum mine tailings with a pH of over 10.0. In another example, since the 1999 Nanchang Conference, Vetiver has been used for quarry revegetation and stabilization (Xu, 2002a). In a different case, Nanjing people drilled holes in rocky parent material and inserted Vetiver slips to green the surroundings. A further application of Vetiver is revegetation on dolomite mine tailings such as in the Mufu Mountains, which are situated to the north of Nanjing City along China's Yangtze River. After being mined for decades its highest peak stands at 199.3 m above sea level. The mountains protect Nanjing City from the northern sandstorms and cold snaps that can occur. Since the 1950's there have been over ten companies involved in dolomite mining, which has caused 2,000,000 m^2 of barren and unusable mountain area that is very difficult to revegetate. Following economic development the Mufu Mountains became part of Nanjing City, and they have become an eyesore affecting the local scenery.
In 1998 the Nanjing Horticulture Bureau began to plant trees to revegetate the mountain area. However, due to the poor ecological environment the survival rate was low and large areas remained barren. In 2002, the city mayor heard of Vetiver's potential and suggested that the Horticulture Bureau contact the China Vetiver Network to see if the grass could be employed to assist in quickly revegetating the mountains. This paper, then, describes some of the research conducted on the general properties of different mine tailing types and the role Vetiver has played in revegetating these mountains.

1. MATERIALS AND METHODS

1.1. Soils

There were 4 treatments with soils coming from mine tailings or other materials. They included: 1) coarse materials from carbonized shale, 2) dolomite slag, 3) Xiashu Loess, and 4) lake bottom sediments.

1.2. Field tests

Vetiver clumps were planted along contours at spacings of 150 cm x 10 cm from 26-29 May 2002. Each clump contained 3-5 tillers. Before planting all tillers were dipped in a clay paste to cover their roots, and were watered after planting. Altogether 4,000 m^2 of slopes were planted. On 14 July 200 kg/ha of urea was applied, and the grass was pruned to a height of 40 cm above the ground.
1.2.1. The effect of different treatments on Vetiver growth. Three plots (each 200 m^2) were designed for each of the four treatments: 1) carbonized shale, 2) dolomite slag, 3) Xiashu Loess, and 4) lake bottom sediments. Three tillers were selected at random from each plot every 16 days to determine Vetiver's growth.
1.2.2. Effect of Vetiver on the microclimate. Small plots of 1 m x 1 m were chosen at random to determine the effect of Vetiver grass on vegetation recovery after Vetiver planting.

2. RESULTS AND ANALYSIS

2.1. Chemical and physical properties of different treatments (mine tailing types)

The mechanical analysis is shown in Table 6-1. Of the 4 treatments, the carbonized shale contained the highest number of fragments (over 49%) in the over 2 mm diameter size class and also the highest content in the coarse sand size class with over 70%. Thus, the shale contained little in the fine sand and sandy silt categories, and the least clay content with only 3.0% to 3.8%. This meant that the carbonized shale material could retain very little moisture for plant use. On the contrary, the Xiashu Loess contained the highest clay content, at 35%, with no fragments. Therefore, it could retain much more moisture. The dolomite slag contained about 25% fragments with much higher fine sand and sandy silt. Meanwhile, the lake bottom sediments contained the highest amount of fine sand. Since the carbonized shale had a high fragment content and therefore could retain little moisture, about 1 kg Xiashu Loess was added to each Vetiver planting hole for this treatment.

Table 6-1. Mechanical Analysis of the Different Treatments.

Treatments	Particle Content (%)					Soil Texture
	Fragments (>2 mm)	Coarse Sand (2-0.2 mm)	Fine Sand (0.2-0.02 mm)	Silt (0.02-0.002 mm)	Clay (<0.002 mm)	
Carbonized	49.1	73.4	16.9	5.9	3.8	sand
shale	49.9	70.5	20.2	6.3	3.0	
Dolomite	24.5	18.0	35.4	29.0	17.6	loam
slag	22.7	16.3	32.3	35.9	15.5	
Xiashu Loess	0	0.5	32.8	32.1	34.6	clay loam
	0	0.7	29.5	34.6	35.2	
Lake bottom	3.8	1.5	79.5	10.3	8.7	loamy sand
sediment	1.6	1.9	77.3	11.5	9.3	

Table 6-2 shows the basic chemical properties of the different treatments. This indicates that carbonized shale contained the highest content of organic matter, total N, available P and available N. This was due to its mineral origin. However, because it contained the highest content of fragments, the plants may not be able use these elements. Similarly the dolomite slag had a high percentage of fragments. Table 6-2 also showed that dissimilar treatments had different pH values ranging from 4.13 with carbonized shale to 8.85 for lake bottom sediments. In addition, the dolomite slag had high levels of $CaCO_3$ (328.3 g/kg). All of these factors could affect plant growth.

Table 6-2. Chemical Properties of the Different Treatments.

Mine Tailings	Organic Matter (g/kg)	Total N (g/kg)	Available K (mg/kg)	Available P (mg/kg)	Available N (mg/kg)	pH (water) (1:2.5)	$CaCO_3$ (g/kg)	CEC $\{C_{mol}(+)/kg\}$
Carbonized	57.0	1.43	22.8	121.3	148.3	4.13	0	8.04
shale	62.1	1.50	38.4	104.8	153.2	5.30	0	8.65
Dolomite	22.7	0.92	97.5	8.7	32.4	7.90	314.9	4.98
slag	13.9	0.64	77.8	5.2	29.3	7.84	328.3	4.95
Xiashu	5.7	0.47	89.2	16.3	36.1	7.42	6.4	11.82
Loess	5.2	0.44	78.8	19.1	26.2	7.09	3.9	11.72
Lake bottom	6.4	0.28	60.2	13.2	22.5	8.45	54.4	3.46
sediment	6.1	0.31	54.9	14.6	23.7	8.85	56.9	3.30

2.2. Vetiver growth on different treatments (mine tailing types)

About 95% of the Vetiver grass survived. Following an initial establishment phase after planting, Vetiver on the 4 different treatments grew rapidly but at different rates. The grass grew faster on the lake bottom sediments and reached almost 32 cm in 16 days (Figure 6-1), which was a daily growth rate of about 2.0 cm/day. The Vetiver on the other 3 mine tailing types did not grow as fast.

Figure 6-1. Vetiver Growth on Different Mine Tailing Types.

Starting from 15 July, Vetiver grew slowly because of hot weather and high evaporation rates (Figure 6-2) as growth depended on temperature and soil moisture.

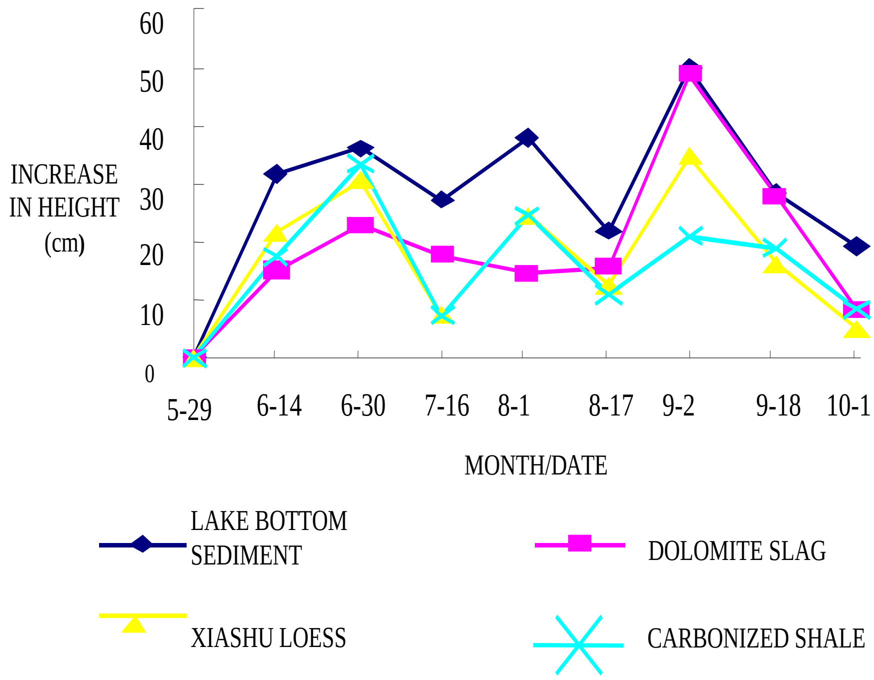
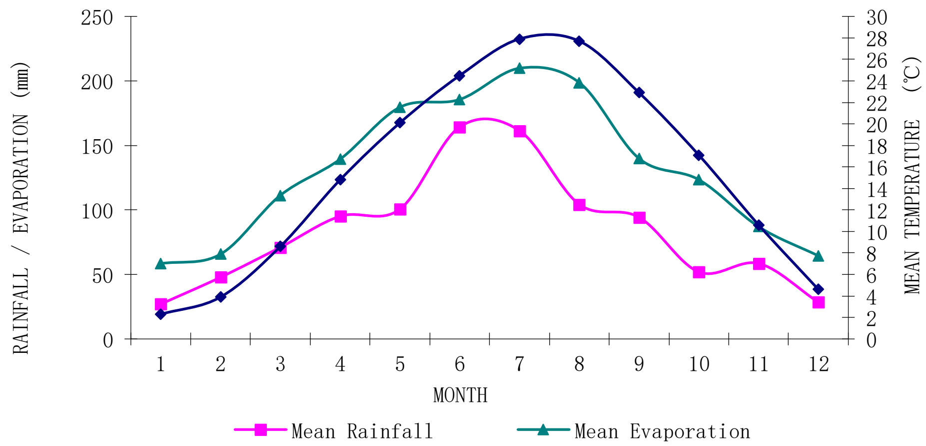


Figure 6-2. Mean Monthly Rainfall, Evaporation, and Temperature.



When irrigation facilities were lacking, growth was dependent on rainfall and soil properties including the soil structure. Since the lake bottom sediment had large amounts of fine sand (77.3% - 79.5%, see Table 6-1), better soil structure that could hold more moisture, and possibly more available nutrients, the grass grew better.
Table 6-3 indicates that the lake bottom sediments contained 9.3% and 10.4% water at soil depths of 0-20 cm and 20-40 cm, respectively. The 3 carbonized shale type treatments contained less water because they contained so many fragments. Moisture in these 3 treatments also differed possibly due to different locations on the slopes. Carbonized shale (c) contained only 2.1% water at the 0-20 cm depth, and here Vetiver appeared to wilt under the high temperatures.

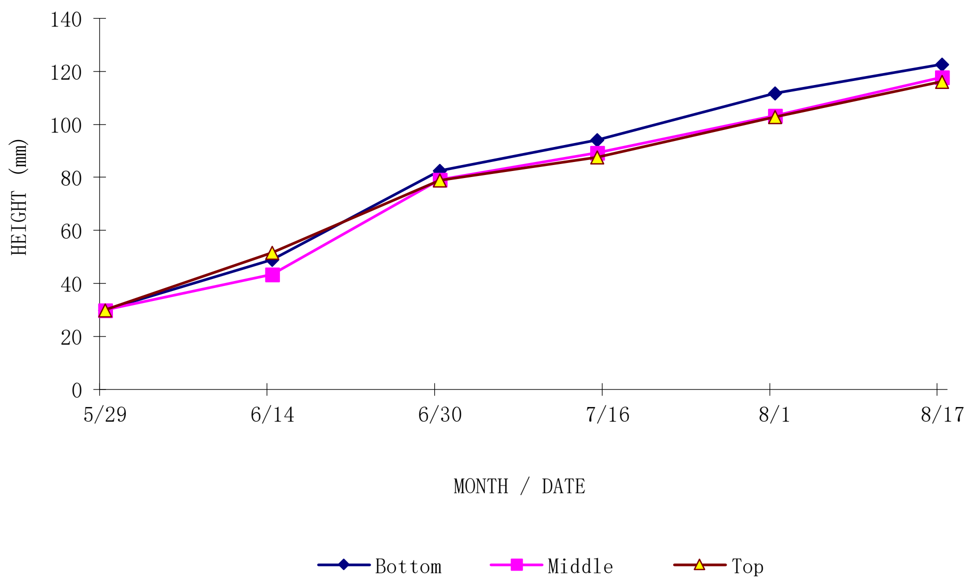
Table 6-3. Soil Moisture Content in the Summer[a].

Treatments	Depth (cm)	Wet Weight (g)	Water Content (g)	Water Content (%)
Lake bottom sediments	0-20	25.59	2.38	9.3
	20-40	57.58	5.99	10.4
Carbonized shale (a)	0-20	36.84	2.26	6.1
(no Vetiver wilt)	20-40	33.04	2.48	7.5
Carbonized shale (b)	0-20	49.40	1.98	4.0
(no Vetiver wilt)	20-40	42.70	3.02	7.1
Carbonized shale (c)	0-20	71.78	1.50	2.1
(some Vetiver wilt)	20-40	59.41	3.86	6.5

[a]Samples collected on 5 August 2002

Field investigation showed that the growth of Vetiver differed with different positions on the slope. It grew slightly better at the foot of the mountain possibly because soil there was thicker than on the middle and the upper part (Figure 6-3). Nevertheless, when compared to other plants Vetiver generally grew much better. From 11-17 July when air temperatures reached 39ºC (the highest temperature in the most recent 10 years), only part of the Vetiver shoots appeared yellow and wilted, while some of the native *Jasminum mesnyi* (primrose jasmine or Chinese jasmine) and *Photinia serratifolia* (also known as *Photinia serrulata*) (sawtooth *Photinia*) plants were totally yellow or had withered away.

Figure 6-3. Vetiver Growth at Different Positions of the Slope.



2.3. Effect of Vetiver on the microclimate.

Many studies have shown that a Vetiver hedge can improve the microclimate and therefore enable plants to develop where they normally wouldn't (Xu, 2002b). This study reconfirmed this point. On the carbonized shale slope four, 2 m x 2 m plots both with and without Vetiver hedges were selected at random to measure the vegetation coverage. With Vetiver hedges the vegetation coverage was 92%, while without Vetiver hedges it was only 45%. In addition, multiple plant species were found with the Vetiver, but without Vetiver only *Artemisia absinthium* (wormwood) grew. This was due to the Vetiver hedge's ability to trap fine soil material and runoff, thereby improving soil moisture and other properties that were beneficial to plants.

3. CONCLUSION

1) Although it was very difficult for plants to become established on dolomite mine tailings that had different mechanical and chemical properties, Vetiver grew quite well. There was little difference in Vetiver growth on different mine tailing types except where the lake bottom sediment had been added to the mine tailings. Just like on highway and railway embankments, Vetiver hedges formed in three months. Due to its many advantageous characteristics (Hengchaovanich, 1998), Vetiver has proven to be an excellent pioneer plant for revegetating and stabilizing barren slopes.
2) Vetiver had a wide range of tolerance to soil types and pH and could improve the ecological environment in a short time. This enabled other plants to grow thereby promoting ground surface coverage.
3) Vetiver had high adaptability and could grow well on different parent materials. It was unnecessary to add soil when planting on mine tailings. Although it grew better with lake bottom sediment added, Vetiver was superior to other plants when only grown on mine tailings. Vetiver had a well-developed root system just two months after planting and could fix the soil solum.
4) Although Vetiver is photophilous it grows well in the shade under young popular trees.
5) Based on this study and many other studies, Vetiver can be planted in March, April, May, June, and September. The best time is in March and April because within this period there is ample rainfall; the solar radiation is not too strong; and evaporation is low. Once the grass is established it can enter a fast growing period under higher temperatures. However, it grows slowly when the temperature nears 40^{o} C in July and possibly August. It also can be planted without watering and still have high survival rates.

Chapter 7

Vetiver Systems Applications for Construction in the Hydroelectric Power Industry

1. INTRODUCTION

Vetiver's biological characteristics and function have been understood or mastered by many people. The International Vetiver Network and Vetiver experts have promoted Vetiver since the ninth decade of the last century. Nevertheless, the fact that Vetiver is an interdisciplinary subject it cannot be placed in a simple botanical category. There are many variable factors in its practical application. This is especially evident considering the different professions and engineering applications that are involved with Vetiver Systems applications.

The Vetiver System is a comprehensive and complex scientific technology encompassing many branches of learning. It possesses not only rich knowledge for the botanical field, but also knowledge for engineering mechanics, geology, atmospheric phenomena and so on. Disseminating and utilizing this technology to replace or partially replace traditional hard engineering technologies such as concrete or masonry protective coverings, anti-landslide piles etc. can be economically practical for reinforcing engineering structures, beautifying the environment, and increasing ecological diversity.

2. APPLICATION PRINCIPLES

Vetiver contains a vigorous underground root system with numerous roots that penetrate into the soil layer. This produces a binding effect that increases the shear strength of the soil in a short period of time, which then can prevent soil erosion and surface soil slips. The space between Vetiver hedges can be interplanted with supplementary plants (other grasses, vines, bushes or even trees). Vetiver roots extend 30 cm to 50 cm underground and can be likened to a three-dimensional root network that is capable of consolidating the soil. At the ground level, a Vetiver hedge's stiff stems and dense leaves combined with any supplementary plants can reduce soil moisture, slow runoff speeds, reduce runoff quantity, trap eroded sediments, and generally assist in promoting water and soil conservation, preventing landslides, and protecting slopes.

The stiff stem and leaves along with the strong root system can withstand water 0.6 m - 0.8 m deep and a 3.5 m/s velocity water flow. This makes it very difficult to dislodge Vetiver by water flow once it is established. Thus, it can reduce the potentially destructive force of strong wind and wave action, thereby protecting dikes or riverbanks.

3. APPLICATION CHARACTERISTICS OF VETIVER SYSTEMS FOR HYDROELECTRIC POWER CONSTRUCTION PROJECTS

Supplementary vegetation, planting design, planting techniques and nutrient requirements are different when applying Vetiver Systems in different locations. For hydroelectric power construction projects important characteristics for Vetiver or supplementary plants include not only resistance to water logging and the ability to withstand submersion for periods of time, but also resistance to drought. Planting design must consider flood discharges as well as provide protection from wind and wave action. If the planting occurs during the winter season, the planting technique must be adjusted so that the seedlings form "belts" or "strips" or are planted densely. This will require “professional maintenance” and application of “special Vetiver nutrition.” By applying “special Vetiver nutrition” the survivability and success rate of the Vetiver System will be increased. Thus, the Vetiver System will form a comprehensive soil and water erosion protective system. By fulfilling the above requirements, the success rate for Vetiver Systems with hydroelectric power plant construction projects is presently near 100%.

4. APPLICATION EXAMPLES

There are many successful application examples of the Vetiver System in China’s hydroelectric power construction projects. Since the beginning of 2000, the Vetiver System has been applied in southern China with excellent results. Some hydroelectric power departments in northern China have also started to study and test Vetiver by introducing this technology into northern China.

In China it is mainly the Guangzhou City Vetiver Industry Science Co. LTD that conducts dissemination and application of Vetiver Systems for hydroelectric power construction projects. To date, this enterprise has completed many hydroelectric power projects in provinces and regions around China, such as Hunan, Hubei, Guangdong, Guangxi and Guizhou. Some of these projects have even been key national level projects conducted by noted experts and scholars in engineering circles.

Some examples of hydroelectric power projects that have incorporated Vetiver Systems include: The Slope Stabilization Project for the Hydroelectric Power Station in Yutan, Zhangjiajie, Hunan; The Anti-scouring and Slope Protection Project for the Golden Congkou Section of the Hanjiang Dike in Wuhan; Steep Slope Stabilization for the Qinglongshan Reservoir, in Jiangxia, Wuhan; The Slope Stabilization and Anti-scouring River Hub Water Conservation Project at the Leading Campsite on the Left Bank of the Youjiang River, in Baise, Guangxi; The Slope Stabilization and Anti-scouring Spillway of Yanshan Reservoir in Luocheng, Guangxi; Slope Stabilization for the #2 Highway at the Longtan Hydroelectric Power Station in Guangxi; The Slope Stabilization Project at the Shitang Hydroelectric Power Station in Guangdong; The Slope Stabilization and Anti-scouring Spillway for Tangxi Reservoir in Raoping, Guangdong; The Protection Bank for the Xinfengjiang Reservoir in Heyuan City, Guangdong; and so on. Several representative construction project examples are found in Table 7-1.

Table 7-1. Selected hydroelectric power construction projects utilizing Vetiver.

Projects / Item	**Slope Stabilization at the Yutan Hydroelectric Power Station, Hunan**	**Anti-scouring and Slope Protection at the Hanjiang Dike, Wuhan**	**Slope Stabilization and Anti-scouring on the Left Bank of the Youjiang River, in Baise, Guangxi**	**Slope Stabilization and Anti-scouring at the Yanshan Reservoir Spillway in Guangxi**
Establishment phase	15Sep to 10Oct 2000	20Apr to 1May 2001	25May to 11Jun 2002	18Dec to 25Dec 2002
Professional maintenance period	11Oct to 10Dec 2000	2May to 30 Jun 2001	12 Jun to 11 Aug 2002	26Dec2002 to 25Feb2003
Geographical coordinates	N latitude 29^{0}17’, E longitude 110^{0}35’	N latitude 30^{0}56’ E longitude 114^{0}23’	N latitude 23^{0}55’ E longitude 106^{0}32’	N latitude 24^{0}47’ E longitude 109^{0}05’
(Continued below)				
Table 7-1. Selected hydroelectric power construction projects utilizing Vetiver (continued).				
Projects	**Slope Stabilization at the Yutan Hydroelectric**	**Anti-scouring and Slope Protection at the Hanjiang Dike,**	**Slope Stabilization and Anti-scouring on the Left Bank of**	**Slope Stabilization and Anti-scouring at the Yanshan**

Item	Power Station, Hunan	Wuhan	the Youjiang River, in Baise, Guangxi	Reservoir Spillway in Guangxi
Weather conditions	Average annual rainfall 1600mm; Mean annual temperature 16.3°C, highest temperature 40.7°C, lowest temperature -13.7°C	Average annual rainfall 1170mm; Mean annual temperature 16.3°C, highest temperature 40°C, lowest temperature -12.6°C	Average annual rainfall 1077.1mm; Mean annual temperature 22.2°C, highest temperature 42.5°C, lowest temperature-5.6°C.	Average annual rainfall 1760mm; Mean annual temperature 18.9°C, highest temperature 38°C, lowest temperature -4.0°C.
Topographic and geological conditions	1.Topography: steep, average slope 65° 2.Geologic structure: crush zone not too developed, cracks in sedimen-tary rock joints 3.Rock properties: Quaternary macadam; block stone; conglomerate, shale and sandstone.	Beach strand is regular, Quaternary built terrace, sandy loam. Nutrient content is above average.	1.Waste solid, mainly shale, sandstone, partially yellow loam; acidic soils, impoverished soils, water holding capacity is very low. 2.Design slope is 1:1.5.	Spillway was cut in a natural hill. Masonry covering. Slope is 1:0.8~1.0. Soil quality: yellow and red loam, partially strong weathered shale.
Vetiver planting design	Distance between rows on contour is 120cm, clump distance is 10cm	1.Planting along the direction of flow, distance between rows is 100cm, clump distance is 15cm; 2.For other rows distance is 300cm, their direction is 45^0 to original row crossing contours. The rows form a diamond structure.	1.Row distance along slope is 100 cm; clump distance is 10 cm. 2.Established 7 boxes near the construction site for observation at same steps. Filled boxes with same soil as construction site, planted same batch of Vetiver, same method of planting and maintaining.	Row distance along slope is 100 cm, clump distance is 20 cm.
Companion vegetation	*Paspalum notatum* (Bahia grass), and *Rauvolfia perakensis*, (thunderbolt bush)	*P. notatum*, and St. Augustine grass (*Stenotaphrum* helferi).	*P. notatum*, *Oxalis pes-caprae* (Bermuda buttercup or Soursob), and *Wedelia chinensis* (Chinese wedelia)	*P. notatum*, O. pes-caprae, and *Lolium perenne* (perennial rye-grass)
Choice of construction technique	1.Planting Vetiver and *R. perakensis* with a nutrition bag; 2.Planting asexual *P. notatum* and sowing seeds.	1.Using bare root Vetiver slips; 2.Using asexual *P. notatum* and *S. helferi.*	1.Bare root planting for most Vetiver; 2.Asexual planting for *P. notatum* and *W. chinensis*, sowing seeds for *O. pes-caprae.*	1.Planting Vetiver with a nutrition bag and in planting strips from nursery; 2.Asexual planting for *P. notatum*; sowing seeds *for O. pes-caprae and L. perenne.*
(Continued below)				

Table 7-1. Selected hydroelectric power construction projects utilizing Vetiver (continued).

Projects	Slope Stabilization at the Yutan	Anti-scouring and Slope Protection at	Slope Stabilization and Anti-scouring	Slope Stabilization and Anti-scouring

Item	Hydroelectric Power Station, Hunan	the Hanjiang Dike, Wuhan	on the Left Bank of the Youjiang River, in Baise, Guangxi	at the Yanshan Reservoir Spillway in Guangxi
System nutrient supply (different soils have different special Vetiver nutrient prescriptions)	Basic nutrients are organic fertilizer and #1 special Vetiver fertilizer; #2 special Vetiver fertilizer was used during maintenance period.	Basic nutrients are organic fertilizer and #1 special Vetiver fertilizer; #2 special Vetiver fertilizer was used during maintenance period.	Basic nutrients are organic fertilizer and #1 special Vetiver fertilizer; #2 special Vetiver fertilizer was used during maintenance period.	Basic nutrients are organic fertilizer and #1 special Vetiver fertilizer; #2 special Vetiver fertilizer was used during maintenance period.
Hydro-meteorology and weather effects during maintenance period	Planted in winter; all plants were in winter dormancy.	Planted in summer; temperatures near 40°C, but no heavy rainfall or floodwater.	Planted in summer; temperatures near 41°C; 4 flood peaks and plants submerged 10 days.	Temperature was below 0°C a week after planting. Plants were covered by 20 cm of snow nearly 10 days. The lowest temperature was -2°C for 5 days
Observation results during professional maintenance period	1. 10Nov2000; 30 days after establishment: the Vetiver leaf tips became red, *P. notatum* did not change, *R. perakensis* became green; 2. 15Dec2000; 65 days after establishment: all plants entered winter dormancy. Plant cover only 65%; 3. 10Apr2001; 160 days after establishment: all plants became green, sprouting. Vetiver was 120cm high; *P. notatum* cover 70%; *R. perakensis* was the best.	1. 20May2001; 20 days after establishment: Vetiver 80% green, *P. notatum* and *S. helferi*, 90% green, bare beach basically covered. 2. 22Jun2001; 52 days after establishment: Vetiver survival rate reached 98%, others 100%. Vetiver root system reached 70cm; *P. notatum* 45cm; 3. 27Jul2001; 87 days after establishment: Vetiver stems and leaves 150cm high, root system 120cm deep. Parts of Vetiver were submerged, but they were still luxuriant.	1. 5Jul2002; 25 days after establishment: floods washed away plants below 124 m elevation. Others became green. 2. 25Jul2002; 45 days after establishment: Vetiver 80cm high, more than 6 tillers; roots of other plants 10 cm long, 3-4 cm high. 3. 20Aug2002; 60 days after establishment: Vetiver 100cm high, most tillers/slip were 21, others growing very well, basically bare ground surface covered.	1. 28Jan2003; 34 days after establishment: snow had melted. Vetiver 15% mortality, *L. perenne* growing well. 2. 18Feb2003; 55 days after establishment: Vetiver, *P. notatum*, *O. pes-caprae* no change, *L. perenne* covering most of the soil surface; 3. 29Mar2003; 96 days after establishment: all plants became green, sprouting. Vetiver 50cm high; *P. notatum* and *O. pes-caprae* coverage reached 65%.
Reexamina-tion and results	20Jul2001; 280 days after establishment: Vetiver mean height 185cm, *P. notatum* and *R. perakensis* completely covered bare hillside. The slide area controlled.	9Jun2002; 404 days after establishment: Vetiver re-tillering and growing. Effectively fixing beach. Some parts of *P. notatum* and *S. helferi* were washed away by river water.	5Apr2003; 296 days after establishment: opened box 7 and observed: root system was 210 cm deep, average diameter of main roots was Φ1.5 mm, crown of root system was 40 cm.	30Apr2003; 127 days after establishment: Vetiver mean height 90cm; *P. notatum* and *O. pes-caprae* completely covered surface soil. *L. perenne* beginning to die.

5. RESULTS AND EXISTING PROBLEMS

Comparing the four representative engineering examples in Table 7-1, there were some important characteristics for application of Vetiver Systems in the construction of hydroelectric power projects. These included:

11) From 100°E to 120°E longitude and below 30° N latitude, Vetiver Systems can be applied successfully. When planting in the winter, suitable seedlings and establishment techniques must be selected.
12) Companion plants should be from local resources. Also geological conditions and soil nutrition at the project site must be known. If necessary the soil quality must be improved by supplying the appropriate nutrients.
13) Establishment technique, professional maintenance and application of special nutrients are the keys to success.
14) A reasonable design and standard establishment procedures can ensure that a Vetiver System is functioning in 30 days with a maximum protection capacity by 60 days and it can henceforth withstand a flow velocity 2 m/s. (See the example of the Baise water and power project above.)

Of course, there are still other items that must be considered when applying a Vetiver System in projects:

1) If the establishment time is during the winter, the costs will increase nearly 3 times compared to the costs in the spring and the summer seasons. Unfortunately it is easy to doubt the beneficial results of a Vetiver System since they do not show until half a year after planting.
2) The aesthetic value of local companion plants is not always the most desirable. So it may be difficult to select an appropriate mix
3) Vetiver can prevent landslides and protect slopes and dikes. However, it may cause problems when discharging floodwater since it grows too high and is dense.

6. FUTURE PROSPECTS

The study of Vetiver in China and many countries around the world has a long history, but comprehensive application has only recently been undertaken. There is still a need to improve the establishment techniques. Gradually engineers are learning the possibilities and advantages of Vetiver, so its application is becoming more and more popular. Vetiver's ability to protect the environment at a lower price will have an important affect on its use in future civil engineering projects. Nevertheless, application techniques go beyond the scope of botany. Thus, a multidisciplinary approach is needed to strengthen the links and cooperation among the different branches of learning where the Vetiver System may be useful.

Chapter 8

Research and Utilization of Vetiver for Wastewater Treatment Ponds

Vetiver grass is a high-biomass hydrophytic plant that can be considered a principal candidate for a constructed wetland. Vetiver Constructed Wetlands (VCW's) possess many advantages for cleaning wastewater, however the techniques are still in the trial stage in China and need to be further improved. In this article, recent research and application of VCW's for wastewater treatment in China are reviewed.

1. INTRODUCTION

Vetiver grass (*Vetiveria zizanioides* (L.) Nash) is a high-biomass, hydrophytic plant that is sometimes called a "miracle grass." It has a strong tolerance to environmental stresses such as acidity, alkalinity, high salt content, heavy metals, eutrophication, flooding etc. (Chen *et al.*, 2000; Jing *et al.,* 2001; Shu *et al.*, 2000; Truong and Baker, 1998; Xia and Li, 1998; Xia *et al.,* 1998; and Xia *et al.,* 2000). Truong and Hart (2001) reviewed the research, development, and application of Vetiver grass in helping to clean wastewater in Australia, China, and Thailand to name a few countries and showed that the Vetiver System was a very effective method of helping to purify polluted water, domestic effluent, industrial wastewater and landfill leachates. Vetiver's ability to help cleanse wastewater could be due to some of the following characteristics (Truong and Hart, 2001):

- It has a higher evapotranspiration rate than most wetland plants;
- It has a very high and fast absorption rate of nutrients, particularly ammonia, nitrogen and phosphorus;
- It is normally sterile and non invasive;
- It is highly tolerant to soil acidity, alkalinity, salinity, and sodicity;
- It is highly tolerant to water logging and inundation;
- It is highly tolerant to concentrated leachates.

Vetiver grass was first recognized in 1995 as having a strong absorbent capacity suitable for sewage modification in Australia. Chinese scientists also confirmed this in 1997. Since then the Vetiver System has been increasingly used to assist in cleaning wastewater in China (Truong and Hart, 2001; Xia, 2001; Zheng *et al*., 1997).

2. THE VETIVER CONSTRUCTED WETLAND (VCW)

Vetiver grass has shown strong potential as a suitable dominant plant for constructing a wetland system. It is a robust plant, structurally strong, and tolerant of high effluent loadings. In fact, it has been demonstrated that Vetiver can survive in and aid in cleansing most non-diluted domestic effluents. Thus, its greatest large-scale application may be in wetlands (Truong and Hart, 2001). Natural and constructed wetlands have shown to be effective in purifying agricultural and industrial wastewater. The use of wetlands for the removal of pollutants

involves a complex variety of biological, physical, and chemical processes, such as microbiological transformations, adsorption, precipitation and sedimentation.
Vetiver is also suitable for constructing a vegetative buffer or wetland due to the following morphological and physiological features mentioned by Cull *et al.*, (2000) and Truong and Hart (2001):

- Its ability to tolerate flooded soil conditions make it ideal for use in ephemeral or permanent wetlands;
- Its dense stands of stiff, erect stems can reduce flow velocity, increase detention time and enhance deposition of sediment and sediment-bound contaminants (e.g. heavy metals or pesticide residues);
- Its dense, finely structured root system can improve soil bed stability and nutrient uptake, as well as provide an environment that stimulates microbiological processes in the rhizosphere;
- Most importantly, its sterility minimizes its potential for becoming an aquatic weed.

In addition, Vetiver is highly resistant to pests and diseases. These features may eliminate some operational problems that exist in other wetlands, may decrease some maintenance costs, and may promote the application of VCW's for wastewater management.

3. BASIC RESEARCH

3.1. Vetiver tolerance to domestic leachate phytotoxicity and purification effectiveness

Xia *et al.* (1999) investigated the response of cultivation with Vetiver and three other species using domestic leachates. The domestic leachates were taken from the wastewater treatment station at the Likeng Domestic Landfill in Guangzhou, Guangdong Province, China. The two kinds of leachate used in this trial were collected from the inflow and outflow points of the station; they consisted of a high concentration leachate (HCL) that came out of the landfill prior to purification, and a low concentration leachate (LCL) that had been physically cleansed and ready for discharge to the oxidation pond. The content of COD (Chemical Oxygen Demand), total N, ammoniac N, Total P, and Cl^{-1} (chloride) in the HCL (Table 8-1) were considerably high. In fact, these were as much as several dozens of times higher than the highest allowable discharge concentration for industrial sewage or irrigation water for farmland. After the usual purification process the concentrations of these "pollutants" in the LCL remained above the effluent standard.

Table 8-1. Water quality of 2 types of leachate from the Likeng Domestic Landfill in Guangzhou and the purifying effects of the treatment station (all values are in mg/L with the exception of pH).

Leachates	pH	COD[1]	BOD[2]	Alkalinity	Total N	Ammoniac N	Nitrate N
HCL	7.4	1120	121	1882	1125	314	314
LCL	6.5	246	43	396	294	87	64
Purifying rate (%)	--	78.0	64.5	79.0	73.9	72.3	79.6
Leachates	**Total P**	**Cl**	**Fe**	**Zn**	**Pb**	**Cd**	**Ni**
HCL	4.4	1406	6.94	0.25	0.013	0.0005	0.06
LCL	2.6	812	0.54	0.14	0.009	0.0003	0.04
Purifying rate (%)	40.9	42.2	92.2	44.0	30.8	40.0	33.3

[1]Chemical Oxygen Demand
[2]Biological Oxygen Demand

In their work Xia *et al.* (1999) compared 4 types of plant materials: *V. zizanioides* and *Paspalum notatum* (Bahia grass), were sampled form the nursery in the South China Institute of Botany, and *Alternanthera philoxeroides* (Alligator weed) and *Eichhornia crassipes* (Water hyacinth or Million dollar weed) from local ditches and ponds. All 4 species selected exhibited characteristics of rapid growth, large biomass, and somewhat or strong tolerance to a polluted or poor environment. The research results showed that:

1) Of the four plant species investigated in this study, *E. crassipes* was poisoned to death in the two types of wastewater tested (HCL and LCL); *P. notatum* could not survive in the high concentration leachate (HCL) and was severely damaged in the low concentration leachate (LCL); and *A. philoxeroides* was impaired in the HCL, but formed a considerably large biomass in the LCL (which was possibly due to the LCL having a high efficiency of eutrophication). *V. zizanioides* was also hurt by the leachates, but was the least affected of the 4 species. The rank tolerance to domestic leachate for the 4 species was *V. zizanioides* > *A. philoxeroides* > *P. notatum* > *E. crassipes*.
2) Of the two species that grew relatively better in the wastewater, *A. philoxeroides* on the whole was superior to *V. zizanioides* in purifying the LCL, especially in regards to Total N and nitrate N; nevertheless, *V. zizanioides* was able to purify seven kinds of "pollutants" in the HCL better than *A. philoxeroides*. Of the seven items measured in the study ammoniac N showed the best results with a purification rate between 77%-91%. *V. zizanioides* also showed a high purification rate for P (>74%).
3) The leachates discharged from Guangzhou's Likeng Domestic Landfill contained high concentrations of pollutants that did not reach the effluent standard. This effluent displayed strong phytotoxicity that could be harmful to plants and the surrounding areas. Therefore, the landfill leachates needed further purification. Both *V. zizanioides* and *A. philoxeroides* could act as purifying agents to assist in reducing the high and low concentration domestic leachates.

3.2. Testing Vetiver wetlands in microcosm for treatment of domestic leachates

Lin (2002) constructed Vetiver wetlands of different substrates in microcosm to investigate the effects of treating domestic leachates. Eight batches of wetland microcosms comprised of 24 tanks with high COD and $N\text{-}NH_4$ concentrations were set up in a greenhouse to treat the landfill leachate. Every batch consisted of 3 replicated tanks. Five batches with Vetiver (15 tanks) were established to test the performance of 5 different substrates (coal refuse, fly ash, cinders, soil, and gravel) on the wetland microcosms when treating the landfill leachate.

Three additional batches (9 tanks) were set up to test the treatment efficiency when sawdust (as a carbon source for the nitrogen) was added to the wetland microcosm. Two of these batches (6 tanks) were established to determine the function of Vetiver grass in the wetland microcosms' treatment of landfill leachate while 1 batch (3 tanks) had no Vetiver. Thus, altogether there were 21 tanks with Vetiver grass seedlings and 3 tanks without. The experiment lasted 35 days with a 5 day Hydraulic Retention Time (HRT), and 40 days with a 10 day HRT. The results were as follows:

4) When the sawdust was added, the pH of the landfill leachate increased while the electrical conductivity (EC), Total Suspended Solids (TSS), color and volume decreased. The COD removal efficiency of every batch ranged from 33% to 73%, $N\text{-}NH_4$ from 46% to 74%, $N\text{-}NO_3$ from –72% to 94%, Total Kjeldahl N or total soluble N (TKN) from 46% to 73%, Total Phosphorus (TP) from –127% to 90%, and Total Soluble Phosphorus (TSP) from –1714% to 92%.

5) Wetlands microcosms with coal refuse as a substrate had the best performance in removing EC, N-NH_4, TKN, TP, TSP and TSS, while the batch of wetland microcosms using cinders as a substrate had the best performance in removing color, COD, N-NO_3 and TSS. The wetland microcosm with fly ash showed the poorest performance in removing all items except TP and TSP.
6) With the addition of sawdust, the pH of the effluent from the wetland microcosms increased while the EC and color values decreased. The removal efficiency of N-NH_4, TKN and TSS decreased significantly, while the removal efficiency of N-NO_3 increased significantly. Although the removal efficiency of COD, TP and TSP decreased, changes were not significant. The addition of sawdust also led to a reduction in above ground and total biomass of the Vetiver grass, as well as the number of tillers and height. Thus, with the addition of sawdust as a carbon supply, the process of denitrification was greatly enhanced. Meanwhile, the removal of all pollutants except N-NO_3 was inhibited with the growth of Vetiver grass being significantly inhibited.
7) The concentration of N-NH_4 in the leachate greatly influenced the performance of Vetiver grass in the wetland microcosms. Excessive concentrations of N-NH_4 in the leachate were harmful to the Vetiver grass. Thus, before the landfill leachate was put into the wetland microcosm, it needed to be pretreated such that the concentration of N-NH_4 in landfill leachate was less than 200mg/L.
8) Prolonging the HRT of the treatment significantly enhanced the N-NO_3 removal efficiency.
9) Vetiver grass played a great role in purification of the landfill leachate in a wetland microcosm. Wetland microcosms with Vetiver grass had a greater removal efficiency, 9.1%, 12.9%, 15.7%, 104.8%, 17.4%, 57.0% and 1.6% for COD, N-NH_4, TKN, N-NO_3, TP, TSP and TSS, respectively, than the wetland microcosms without Vetiver grass. The total removal efficiency with Vetiver grass, as a percentage of uptake, was greater for TP than for Total Nitrogen (TN).

4. CASE STUDY I: VCW'S IN TREATING PIGGERY WASTEWATER

4.1. *V. zizanioides* and *Cyperus alternifolius* showed a high decontamination capacity

Wetlands were considered to be the most efficient means of reducing both the volume and the high nutrient load of piggery effluent. Liao (2000) found that from among twelve species in a comprehensive evaluation, the two wetland plants, *C. alternifolius* (Umbrella plant) and *V. zizanioides,* were most suitable as vegetation in a constructed wetlands for treatment of pig farm effluent in South China. Both plants were better in terms of pollution resistance, biomass accumulation, root growth, landscape beauty and management costs. This showed that *C. alternifolius* and *V. zizanioides* could grow in pig farm wastewater with a COD of 825mg/L, a BOD of 500mg/L, NH_4-N of 130mg/L and TP of 23 mg/L. They reduced these indices to 64%, 68%, 20%, and 18%, respectively, with a HRT of 4 days. Results of a statistical analysis showed that there were significant differences existing in the COD, BOD and TP between treatments with plants and without plants.

4.2. Nitrogen, phosphorus and organic matter removal

Liao and Luo (2002a, 2002b) used *Vetiveria zizanioides* to make a Vetiver Constructed Wetlands (VCW) and *Cyperus alternifolius* to build a Cyperus Constructed Wetlands (CCW). The two constructed wetlands (CW) were 1.0m×0.5m×0.8m. The purifying role with seasonal pattern changes, varying influent concentrations, and differing hydraulic retention times of the

CW's were studied to determine the effects on nitrogen and phosphorus in wastewater from a piggery. The results showed:

1) The effects of the HRT and wastewater concentration on the removal rate of NH_3-N and $S^{-1}(PO_4)^{-3}$ were obvious in both VCW's and CCW's. High removal rates of NH_3-N and $S^{-1}(PO_4)^{-3}$ were obtained in CCW's and VCW's in the spring. Significant removal of TN in wastewater existed in CCW's and VCW's in the autumn, while significant removal of TP in wastewater existed only in VCW's. The removal of TP or $S^{-1}(PO_4)^{-3}$ versus the HRT in CW's followed an exponential function. The P removal rates in winter and summer changed with the influent concentrations. With the same HRT, the change of $S^{-1}(PO_4)^{-3}$ concentrations in the effluent versus that of the influent followed a linear relationship (Liao and Luo, 2002b).
2) The two CW's had very stable effects on the removal of COD and BOD, while the organic matter in the wastewater changed. The removal of the COD and BOD was 70% and 80%, respectively, with a 1-2 day Hydraulic Retention Time (HRT) in autumn. The removal rate of the COD reached 70% with an influent COD of 1003 mg/L in winter. There was no significant difference between the two CW's for the removal of COD, BOD or Suspended Sediment (SS). Liao and Luo (2002b) found that the contaminant decrease for the HRT in the CW's followed an exponential function:

$$Y_t = Y_0 \cdot e^{-kt}$$

while the relationship between the concentration of contaminants in influent (x) and effluent (y) for the same HRT followed the linear relation:

$$y = a + bx$$

5. CASE STUDY II: OIL REFINERY WASTEWATER TREATMENT

Xia, *et al.* (2002) initiated Vetiver use with treatment of wastewater from an oil refinery. In their trials, they found that wastewater produced from the Maoming Petro-Chemical Company oil refinery (part of the China Petro-Chemical Corporation) contained high concentrations of organic and inorganic pollutants. Therefore, this sewage could not be discharged directly into rivers or seas unless it was treated first. Four plant species, *V. zizanioides*, *Phragmites australis* (Common reed), *Typha latifolia* (Common cattail), and *Lepironia articulata* (Twigrush or Giant sedge) were planted in large containers to test their efficiencies in purifying sewage that came from an oil refinery and to check their growth characteristics in these wetlands.

The purifying rates of the oil refinery wastewater constructed wetlands were all very high in the beginning. It was found that 97.7% of the ammoniac N, 78.2% of the COD, 91.4% of the BOD, and 95.3% of the oil were removed with the first batch of high concentration wastewater (HCW) and low concentration wastewater (LCW), but that this performance decreased as time passed. Even though performance decreased with time, the wetland's pollutant removal efficiency was always in the order of ammoniac N > oil > BOD > COD. It was also found that when the plants were very young their purifying function was quite weak and as plant growth and biomass increased this gradually increased. Nonetheless, in comparison, there was very little difference in the removal efficiencies among the four species.

The four tested species produced better growth in wetlands with an HCW or a LCW compared to clean water. In addition, there were fewer tillers with *V. zizanioides*, *P. australis*, and *T. latifolia* in the HCW compared to the LCW inferring that the HCW might be damaging these

three species. Meanwhile, growth seemed to be better for *L. articulata*, with the HCW.
When clean water was used for cultivation, the production rate of new *V. zizanioides* tillers was the lowest among the four species. Yet when wastewater was applied, tiller production gradually increased with *V. zizanioides*, while with the other three species it was distinctly lower. This suggested that *V. zizanioides* might have a stronger adaptation than *P. australis*, *T. latifolia* and *L. articulata* to the harsher environment.

6. SUMMARY

Vetiver constructed wetlands have shown a strong potential for purifying “polluted water.” Thus, it is gaining increasing interest from scientists for pollution control. Previous research has laid a solid foundation for applying this technique in China, but it is still in the trial stage. So far, only a few constructed wetlands have been used for cleansing wastewater in the field. The Longdong constructed wetland is one case. It is located in Longdong Village of Guangzhou City and was constructed in October 2000, to help purify domestic effluent.
In other areas, constructing a wetland may be detrimental due to unsuitable climatic factors. In addition, as found in other wetland systems, a VCW may be limited by factors similar to those that Kivaisi (2001) noted:

- Construction, operation and maintenance costs;
- Type of wastewater and target water quality;
- Ability to control disease vectors;
- Ability to control invading animal pests;
- Control of effects from bad odors.

Although, these factors may restrict the development of a Vetiver wetland, the VCW, which is a promising green wastewater cleaning technology, could be popularized in China if these problems were overcome.

Chapter 9

The China Vetiver Network—
Its Role in Vetiver Systems Development and Dissemination

Since Mr. Richard Grimshaw introduced the Vetiver System for soil conservation by implementing World Bank's 1988, Red Soil Development Project in China, a great deal of research has been conducted by Chinese scientists on Vetiver's biological and ecological characteristics, soil amelioration properties, and role in agricultural production. In order to coordinate Vetiver research, development, and extension, the China Vetiver Network (CVN) was established in 1996 with financial support from the (international) Vetiver Network. This was an extension of the already existing China Agroforestry Network, which was launched in 1993. Both networks were affiliated with the Soil Science Institute of the Chinese Academy of Sciences.

1. INFORMATION COLLECTION AND ANALYSIS

As a network, one of the most important tasks was to disseminate information. So the first step in information dissemination was to find the institutions and people who were most interested in the Vetiver System, in other words, in which areas or fields the Vetiver System might be applicable. The network office in this regard expended a great deal of effort. They collected information on institutions and personnel involved in agriculture, forestry, water and soil conservation, ecology, the environment, land management, highways, railways, mining, and excavation. Their list also included universities, technical schools, research institutes, extension stations (centers), and government units. Through information analysis a ranking of the most interested institutions and people was prepared in which to disseminate facts about Vetiver.

2. EXTENSION AIDS FOR PROMOTING VETIVER SYSTEMS

The first task for the China Vetiver Network was to disseminate the Vetiver System. Therefore multiple publications were produced to attract different groups of people. These publications included:

- The *Vetiver Newsletter* was a quarterly journal introducing new achievements, new developments, and new technologies from China and abroad. It was printed in Chinese, with occasional publications distributed in English.
- *Vetiver for Water and Soil Conservatio*n was a FACT sheet. These were printed on different colored paper in order to attract people's attention. They introduced practical technology and were mainly for use with farmers and extension workers.
- *Agroforestry Today* was a quarterly journal in Chinese. It primarily introduced Vetiver based agroforestry systems and was mostly distributed to agroforesters.
- *Vetiver Research and Development* was a book published in 1998. It was written for scientists, university professors, and government officials.
- *Vetiver New Year's Greeting Cards* were produced in large quantities in 2001 and distributed to many different people during the Chinese New Year holiday called Spring Festival. These cards briefly introduced Vetiver Systems and encouraged interested farmers or others to contact the China Vetiver Network for more information.
- *Vetiver Grass: The Hedge against Erosion* in its new edition of the Green Book was re-translated into Chinese as part of the Salvation Army supported China Vetiver and Agroforestry Technology Project in 2002. It was widely distributed nationwide. In addition, three other booklets were produced that told farmers how to use Vetiver to protect chestnut trees, tea bushes, and mulberry trees for silkworm production..
- *Vetiver Grass for Slope Stabilization and Erosion Control* was written by Thai expert Mr. Diti Hengchaovanich and was translated into Chinese in 2001. This book introduced his successful experiences in using Vetiver for engineering purposes. It was widely distributed to engineering institutions.
- *Color photo sheets* were produced for special situations to show certain characteristics of Vetiver grass. For example, some wondered whether Vetiver could tolerate waterlogging. To illustrate that Vetiver could withstand long periods in water, photo sheets showing the whole plant submerged in water were produced. Others were concerned about Vetiver's tolerance to seawater. Thus, photos showing the grass growing on the coast next to the ocean helped to assuage their worries.

3. VETIVER SYSTEMS DISSEMINATION VIA PUBLIC CHANNELS

To disseminate Vetiver Systems more widely, numerous public agencies and channels introducing the grass from different points of view were utilized through joint efforts of network members. These included the central television station, *Informal Reference Information*, the *Science Times*, the *Communication Times*, the *Nanjing Daily*, the *Jinling Evening Paper*, the *Lishui Daily*, the *Farmers Daily*, the *Yuexi Newspaper*, the *Anhui Economy Paper*, and others. Some of these papers printed articles more than once. At same time, many research articles were published in different journals, such as the *Water and Soil Conservation Research*, *China Water and Soil Research*, *World Agriculture*, *Ecology Science*, *Journal of Ecology*, *Journal of Biology*, *Science and Technology of Tropical Crops*, *Red Soil Research of Jiangxi Province*, the *Bulletin of Water and Soil Conservation*, *Jiangxi Science*, the *Highway Journal*, *East China Highway*, *Mountain Research*, *Agricultural Science and Technology of Guangdong Province*, *Water and Soil Conservation of Fujian Province*, *Science and Technology of Water Conservation in Jiangxi Province*, *Acta Agriculturae Jiangxi*, the *Highway Survey and Design of Guangdong*, *Communication Survey and Design of Fujian*, the *Jiangsu Highway Society Newsletter*, and so on. It is worth noting that many articles were co-authored by scientists from different disciplines, for example from agriculture and engineering. This played an important role in Vetiver Systems dissemination among different institutions and promoted application within differing divisions. According to an incomplete list there were over a dozen articles published in different highway journals promoting Vetiver applications with highway construction.

4. ORGANIZING CONFERENCES AND TRAINING COURSES

Holding a conference was an effective way to spread and develop Vetiver Systems. As mentioned in Chapter 1, the China Vetiver Network organized the “Fuzhou Conference” and the “Nanchang Conference” in 1997 and 1999, respectively. Both conferences played an important role in summing up experiences and introducing Vetiver Systems for engineering protection. International experts, Mr. Dick (Richard) Grimshaw and Mr. Diti Hengchaovanich, were invited to expound on their experiences. Thai expert Mr. Diti Hengchaovanich presented a lecture on using Vetiver Systems for engineering protection, which covered two main disciplines--agriculture and engineering. Therefore, the China Vetiver Network invited The Highway Administrative Bureau of Jiangxi Province to co-organize the Nanchang Conference to insure that more engineers would participate in the conference. In addition, private companies and individuals were invited to participate in the conference, which ushered in the involvement of the private sector in utilizing Vetiver Systems in China.

The China Vetiver Network also introduced Vetiver Systems at conferences organized by other organizations, such as water and soil conservation institutes and regional or national highway institutes. In addition, the network helped highway and railway institutes to co-organize evaluation and identification meetings so that Vetiver Systems could be extended smoothly in these fields.

Although it has been over one decade since Vetiver Systems were first introduced to China, there were still many people who were unfamiliar with the grass. This situation was quite common in the countryside. Therefore, the China Vetiver Network sponsored different training courses through the China Vetiver and Agroforestry Technology Project that was supported by the Voluntary Agencies Support Scheme (VASS) of New Zealand, the New Zealand Salvation Army, AusAid, the Australian Salvation Army, and the Hong Kong and Macao Salvation Army. The training course content included an introduction to Vetiver Systems, Vetiver propagation, and Vetiver hedges for cash crop tree production. Before the training courses began, multiple training materials were prepared. The training itself combined classroom lectures with hands on field practice. To guarantee success the CVN arranged for specialists to attend the field practice sessions to provide guidance and on-the-spot instructions. Not only that but the network also took this opportunity to train governmental officials and encouraged these officials to help train farmers.

During the training process the network distributed many colored posters that were produced by The Vetiver Network (international) and Taiwan University. Because these materials had plenty of color pictures, farmers were very enthused about reading them. In 2002 alone, over 600 farmers directly received training of which women comprised 50%. Moreover, farmers were encouraged to produce their own wall posters in their villages so that they could refresh their memory and teach others who had not attended the training sessions. Some farmers and business minded individuals then established their own nurseries and Vetiver companies, which in turn promoted further development.

5. DEMONSTRATIONS AND VISITS

A good demonstration is better than a classroom lecture. During extension of the Vetiver System, it was found that acceptance and application of Vetiver knowledge differed depending on the different educational levels and experience of the trainees. The CVN selected project officers to identify and evaluate farmers’ fields and choose the best as demonstration models.

The network presented them with awards and asked officers to organize farmer visits to these demonstration plots. Additionally, the CVN organized project officer exchanges in different areas and different provinces so they could visit and learn from each other. At the same time many institutions and private individuals arranged for their own study tours, which further promoted learning and dissemination. For example, in September 2000, the Highway Society of Fujian Province arranged for 11 people to travel to Zhejiang Province to study Vetiver Systems applications in the mountain areas of Zhejiang Province.

To introduce foreign experiences, in addition to translating Vetiver materials, the China Vetiver Network arranged for 17 Chinese experts and representatives of private companies to participate in the 2nd International Vetiver Conference in Thailand. This included a special technical post conference tour for Chinese participants. Some provincial Vetiver networks also organized similar visits. Meanwhile, the China Vetiver Network invited foreign experts to China to visit different Vetiver System applications, to offer their advice, and to share some of the successful Chinese experiences.

6. DISTRIBUTION OF VETIVER PLANTING MATERIALS AND MINI-GRANTS

To enable more people to test and utilize Vetiver, the China Vetiver Network released mini-grants via support from The Vetiver Network (international). A total of US$10,375 in mini-grants was distributed to 17 recipients in 7 provinces in 1998. In addition, CVN arranged to distribute one million pieces of planting material during the spring of 1998 and had it transported to 14 institutions in 9 provinces free of charge. All of these events encouraged more scientists and technicians to test and use the grass. Most of the recipients provided feedback and used the mini-grants and/or planting materials very effectively and successfully. As most of the recipients were those who did not know about or had not seen the grass before, the first thing they did when they received the planting materials was to establish nurseries for further propagation. Also, there were some recipients who conducted various tests or experiments with their limited and valuable planting materials. Some even re-distributed planting materials to neighboring institutions.

7. COORDINATION OF NEW TRIALS AND RESEARCH

The China Vetiver Network has collected huge amounts of data on Vetiver applications and research throughout China; and it has encouraged different institutions to cooperate in further study. Based on data collection and analysis, the network has evaluated the status of Vetiver development and proposed new topics of study and areas for application. It has given instructions as to where Vetiver Systems could be tested and where Vetiver could not grow. According to field surveys and data collection, the China Vetiver Network, in cooperation with local governments and institutions, has launched new Vetiver projects to promote further development. In addition, the network has placed emphasis on Vetiver applications for cash crop tree production and poverty alleviation in the poor mountainous areas. These poor farmers readily welcomed Vetiver expertise.

Through several years of hard work, along with the efficient development policy of the China Vetiver Network, Vetiver Systems have been disseminated widely throughout the southern part of China. These systems have played an important role in erosion control and slope stabilization and have promoted economic development. Based on its outstanding achievements, the China Vetiver Network was granted awards by The Vetiver Network (international) in 1998, The King of Thailand in 2000, and the International Erosion Control Association in 2002

Chapter 10

Introduction to the China Vetiver and Agroforestry Technology Project

The China Vetiver and Agroforestry Technology Project was launched in the Dabie Mountains to increase food production, to assist in poverty alleviation and to protect the natural resources. In this project both the Vetiver System and Agroforestry were introduced and demonstrated, 8.416 million cash crop trees or bushes were planted, and 5 pumping stations were constructed in 2 villages of 2 provinces in neighboring counties. A series of training courses were organized, and 944 people were directly trained. Project experiences and technical information were very widely distributed by means of in-direct training, information dissemination, visits, and national and international networking. Because the project combined extension of the Vetiver System with cash crop trees and food production, local governments and farmers warmly welcomed it.

1. INTRODUCTION

1.1. Soil erosion and natural disasters

Soil erosion has been a problem ever since man started to cultivate land. It became more critical with an increasing population. In the most recent decades, forests have decreased dramatically in China and soil erosion has become ever more serious. Statistics of relevant data have shown that in the past decade, soil fertility has declined on over 2 million hectares, and crop yield has decreased by 30% due to soil degradation. Thus, the area with soil erosion problems in China has expanded to 1.5 million square kilometers.

Due to soil erosion, the riverbed level has risen dramatically. For example, the riverbed in the mainstream sections of the Yangtze River has risen 1 meter every 10 years. As a result, during the flood season the water level has become much higher than that of the surrounding land surface. For lakes such as Dongtinghu Lake, the water level during the flood season has also become higher than the land surface (usually 10 m higher), which has seriously threatened people’s lives and led to disastrous consequences.

In 1998, based on statistics provided by the authorities, the heavy flooding of the Yangtze caused 4,150 deaths and a direct economic loss of over 255.1 billion Yuan RMB (about US$30.8 billion[4]). There were also 6.85 million houses destroyed, and 18.393 million people had to be evacuated to safer places.

1.2. The Dabie Mountains

The Dabie Mountains, which range from 90 m to 1,700 m above sea level with a total area near 100,000 km^2, are found in the border region of three provinces, namely Anhui, Hubei, and Henan. Due to various factors, the Dabie Mountain area remains underdeveloped and forms one of the poorest regions of the country with a mean annual per capita income of around 800 Yuan RMB (US$96.7). In the Dabie Mountains there are more than a dozen counties identified as Poverty Counties by the central government.

Because of an increasing population and a multitude of other reasons, the original forests in these mountains have been almost completely destroyed. Especially in recent years following the national economic reform, farmers and government officials have been increasingly interested in clearing forests for commercial tree (cash crop forests) production calling this a

[4] US$ 1.00 = ~8.27 RMB Yuan

"forestry revolution." They have cleared vegetation, built earthen terraces and planted tea, mulberry trees, and chestnut trees on a large scale. Because of this rapid, large-scale cultivation program, a lack of protection measures were included which meant more soil erosion followed by a decline in soil fertility. Consequently, the cash crop trees did not grow well. In addition, the soil usually eroded before these trees and other new vegetation grew. Meanwhile, soil erosion aggravated sediment deposition in the reservoirs and the lower parts of the river basin causing disastrous consequences. In August 1975, for example, on two of the largest reservoirs, flooding destroyed the Banqiao and Simantang Reservoir dams. Due to sediment deposition the bed of the reservoirs and the riverbeds had risen as high as the dams in 40 places in Jinzhai County. This further deteriorated the environment and aggravated poverty.

1.3. Vetiver and agroforestry technologies

To control water and soil erosion, increase farming benefits and relieve natural disasters, soil and land use (including agroforestry systems) have been introduced in the Dabie Mountains since 1995. This was accomplished in over 10 counties or cities. In addition, the Vetiver System was first introduced in this area in 1998.
Field trials for Vetiver in Yuexi County of Anhui Province, and Huanggang Prefecture of Hubei Province showed that:

- Vetiver grass could grow well in the proposed project area. These new plantings of Vetiver could grow 3 m high on terraces after one growing season (5-6 months).
- Vetiver successfully protected newly constructed terraces in Hubei Province from erosion within 3-5 months after planting.
- The output of well-protected Vetiver based agroforestry orchards on terraces i.e. the Vetiver-chestnut-wheat system, could bring in more than 80,000 Yuan (US$9,674)/ha/yr in the 8th year after planting, while a control forest would earn only 102 Yuan (US$12.3)/ha/yr.

The project launched in the Dabie Mountain area was to apply the Vetiver System with agroforestry and other technologies. This was begun in the southern part of the mountain area in particular, in order to protect cash crop trees, to reduce the risk of natural disasters caused by the poor ecological and environmental conditions, and to increase farmers' income so as to help alleviate poverty in the area. At the same time food production for the people here was emphasized.

2. BACKGROUND OF THE PROJECT SITES

2.1. A brief description of the project sites

Yuexi and Yingshan are two of the poorest counties in China and were among the first designated as poverty counties by the state. They are both located in the hinterland of the Dabie Mountains of Anhui and Hubei Provinces, respectively. The two villages of Zhangfan in Changpu Township, Yuexi County and Zhengfang in Shitouzui Township, Yingshan County were selected as key project sites. Both villages were typical examples of the whole mountain area in natural and social-economic conditions. Medium-high mountains with only scattered river valleys dominated the topography of both counties.

2.2. Analysis of the causes for poverty

2.2.1. Little arable land and low production levels. In both villages, the average per capita cultivated land was around 0.025 ha - 0.034 ha (0.38 mu - 0.51 mu with 1 mu = 1/15 ha). The soil layer was shallow and the fertility due to erosion was low. In particular, the water conservation facilities were few (only 2 pumping stations irrigating 5.7 ha {85 mu} of land). Thus, the villagers had to rely on rain-fed agriculture. On the average, each hectare of land could only produce 5,550 kg of grain, which was not enough grain in a year to meet local needs. This meant serious food shortages at times. In addition, a lack of funds has resulted in extremely limited investments in land improvement.

2.2.2. Low productivity of forestry. Although in both villages the average per capita area of mountain holdings was 0.33 ha – 0.60 ha (5 mu -9 mu), the forests have suffered from severe destruction in the most recent 60 years. Today, there are merely scattered Masson pines (*Pinus massoniana*), bamboo, bushes and weeds, most of which can only be used for fuel. Statistical data over the past years has shown that the output value of forestry for both villages only occupied 0.28-18% of their total agricultural output value. This meant the average income from every hectare of mountain land was only US$1.81 – US$77.99 (1 - 43 Yuan RMB/mu), and that the average per capita income from the forests was US$0.60 – US$44.74 (5 - 370 Yuan RMB)/year. Thus, failure to make full use of the extensive mountain lands was another important reason for poverty.

2.2.3. Fragile ecological environment. Most soils in the Dabie Mountains were derived from granite and subject to water erosion. With increasing population pressures, farmers have had to cultivate new sloping lands for food, fuel and cash crops. This in turn has destroyed the existing vegetative cover and further aggravated soil and water erosion due to a lack of soil conservation practices.

2.2.4. Poor education and health-care facilities. A poor transportation system and few contacts with outside world meant many of villagers were illiterate or semi-illiterate. They commonly adhered to past practices and showed indifference towards scientific farming, natural resources protection and commodity production. This made it quite difficult for some advanced agricultural techniques to be introduced and accepted.

2.2.5. Lack of scientific planning. For years, local authorities and farmers cleared large areas of forest for planting timber trees (Chinese fir—*Cunninghamia lanceolata*, for example) or cash crop trees, however this kind of development lacked scientific planning and market analysis. Consequently it not only failed, but it also caused new ecological and environmental problems.

3. THE GOAL OF THE CHINA VETIVER AND AGROFORESTRY TECHNOLOGY PROJECT

Supported by the Voluntary Agencies Support Scheme (VASS) of New Zealand, the New Zealand Salvation Army, AusAid, the Australia Salvation Army, the Hong Kong and Macao Salvation Army as well as local governments and farmers, the China Vetiver and Agroforestry Technology Project (CVAT Project) was launched in 2001 with a total budget of over US$ 181,000 (1.5 million Yuan RMB). The objectives of the project were to help farmers get rid of poverty and at the same time to protect natural resources from damage. This was accomplished by:

- Introducing and raising awareness among policy makers, farmers, extension workers and technicians in the Dabie Mountains of soil and natural resources protection including the importance of Vetiver in soil erosion control, sustainable agriculture, soil stabilization, disaster prevention, sustainable farming and other numerous multiple uses.
- Introducing and extending proper agroforestry technologies, such as hedgerow intercropping of the Vetiver-chestnut-wheat system; nitrogen fixing trees, shrubs, and plants; contour planting technology; crop diversity for erosion control; etc.

- Generating income by establishing Vetiver-protected, high quality cash crop trees and vegetables on terraces, raising silkworms, providing for animal husbandry projects with small animals, cultivating mushrooms, making handicrafts, etc.
- Increasing food production by promoting electrical pumping systems for irrigation, intercropping cash crop trees with crops, and applying fertilizers based on soil and crop sample analyses.
- Helping women improve their social and economic conditions through training and demonstration of silkworm raising techniques, tea production, handicraft production with Vetiver prunings, etc.
- Extending the above technologies and experiences to the whole Dabie Mountain area utilizing multiple activities.

4. REMEDIAL MEASURES TAKEN IN THE PROJECT

Through on-the-spot checks and studies, wide-ranging discussions with national Vetiver and agroforestry network experts and technicians, visits to different types of farming households, studying models of typical examples in the surrounding areas, and discussions with farmers at their homes and in the field, the following measures were implemented, which contributed to high productivity, sustainability, and adaptability:

4.1. Income generation

Mountain land was the main resource in the two villages. Commercial trees (cash crop forests) with regional priority and high quality products such as mulberry, chestnut and tea were planted on different kinds of land. In addition, silkworm production was introduced, which could dramatically generate profits. Altogether 16,000 chestnut trees, 400,000 mulberry trees, and 8 million tea bushes were planted. All cash crop trees and bushes were planted and managed according to scientific standards so that they would grow well, produce high profits, and not cause new soil erosion problems. Training courses were implemented on different topics such as tree management, mushroom production and making handicrafts with Vetiver prunings.

4.2. Vetiver and agroforestry technologies for high quality cash crop tree yields and to increase food production

Sloping land with newly planted cash crop trees could cause serious soil erosion in ecologically fragile areas derived from granite parent material if necessary protection measures were not adopted. Vetiver technology was introduced and contour-planted on terraced and sloped farmland for erosion control. In all about 5 million Vetiver tillers were planted. To accomplish this, Vetiver nurseries were established on individual smallholder farms. In addition, the Vetiver prunings were used as fodder for small animals and as mulch to help maintain soil moisture. Also proper agroforestry technologies were introduced, demonstrated, and extended including: the A-Frame method for planting crops and trees on the contour, living hedges of Vetiver and multipurpose nitrogen-fixing shrubs for soil erosion control and soil reclamation, intercropping crops among newly established cash crop trees, etc.

4.3. Increasing food production and food self-sufficiency

In Zhangfan and Zhengfang Villages, high-yielding fields only constituted 15% of the total farmland. Therefore, the plan called for building and installing 5 electric pumping stations that would irrigate 39.3 ha (590 mu) of rice fields and increase their yield by 59,000 kg.

Wheat was intercropped in newly developed chestnut terraces in order to provide more grain for farmers and increase the ground vegetative cover to reduce erosion.

Vetiver prunings were used as fodder for animals and mulch to improve soil moisture and

fertility in order to enhance food production.
Rational fertilization schemes were developed and implemented based on different soil types of granite and gneiss parent materials as well as soil and plant sample analyses. Estimates were that this could increase yields by 10%. Organic manure also increased through animal husbandry improvement, which in turn increased yields and promoted the benefits of sustainable agriculture.

4.4. Extension and training

Observations and discussions revealed that there was high enthusiasm among farmers who realized that extension and training could bring income generating opportunities. Because the implementation area of the proposed project was limited, while the Dabie Mountains covered a large area, extension and training would be critical in spreading the experiences obtained from the project to other locations. Thus, this became a key component of the project, especially since the existing extension system met with funding and personnel cuts as part of national economic reforms.

4.4.1. Subject matter. Consultations were conducted with farmers at both project sites and non-project sites. These resulted in extension and training topics that included:

- Soil and water conservation and reconstruction of eroded slopes and terraces,
- Vetiver and its characteristics, growth behavior, applications, reproduction technologies, and benefits,
- Agroforestry technologies and crop diversity for income generation, erosion control and food security,
- Nitrogen-fixing trees, shrubs, and plants for soil fertility maintenance and sustainable farming,
- Contour-planting techniques,
- Commercial tree production and management (including chestnuts, tea, and mulberry trees),
- Handicraft production utilizing Vetiver prunings.

In addition, other pertinent topics were included in the training; for example, woman's health care and environmental protection.

4.4.2. Methods.

- ***Formal training:*** Training courses were conducted at two levels. The first was the township level for middle school graduates and the second at the village or group (smaller than a village) level for less educated farmers. The middle school graduates who were trained then became the trainers for the less educated farmers. The training combined practical exercises with field demonstrations whenever possible.
- ***Self-study:*** Supervision and multiple types of training materials supplemented formal training. Self-study printed materials were a very cost-effective training method. Also small, supervised groups were organized to spread technologies and to answer farmers' questions.
- ***Farmer-to-farmer visits:*** One of the challenges in this project was to create opportunities for participants at the field level to learn from each other. Thus, "Model" farmers were selected and awarded. Then farmers were organized to visit these demonstration sites and discuss what they saw.

4.4.3. Materials:

- ***Printed materials*:** Special training materials were prepared based on local natural conditions. Famous development institutions at home and abroad refereed training materials. These materials included: the re-published Green Book (*Vetiver Grass—The Hedge against Erosion*) in Chinese, and brochures on chestnut tree, tea, and mulberry tree cultivation that described not only the cultivation of these cash crops, but also the application of Vetiver systems for cash crop/tree promotion. The printed extension and training materials all had adequate illustrations, diagrams and pictures to communicate field practices and were sent to farmers living within the entire Dabie Mountain area both inside and outside of the project sites.

- ***Posters*:** As a large number of poor farmers in the proposed project area had relatively low levels of education, The (International) Vetiver Network (TVN) and Taiwan University prepared printed posters with numerous photos and vivid drawings. These were sent to farmers to be placed on walls both inside and outside their homes so they could be reminded how to utilize the new technologies.
- ***Newsletters and fact sheets:*** These were produced to introduce practical technologies and report on the project's progress. They were distributed to the whole Dabie Mountain region and surrounding areas. Distribution included not only the local governments at the county and township levels, but also various bureaus and extension stations involved in agriculture, forestry, soils and fertilizers, livestock and the environment.
- **National and international impact:** The progress and experiences of the project were also distributed throughout China and the world via national and international Vetiver newsletters and home pages as well as the Asia and Pacific Agroforestry Network News (APAN News).

***4.4.4. Personnel*:**

- ***Trainers:*** These consisted of experts, qualified technicians and master farmers depending on the subject matter. The experts were responsible for preparing training materials, while local technicians mainly gave lectures to farmers under the guidance of the experts. This helped relieve the problem caused by local languages. The trainers formed supervisory teams to give guidance in the field. Visiting experts were invited to present lectures on technical matters.
- ***Trainees:*** These consisted of farmers both from the project and non-project counties. Local governmental officials were also included. Altogether over 944 people received direct training and most of these were women, while tens of thousands were estimated to have received in-direct training.

4.4.5. Farmers' participation. Throughout the project, including the preparation stage, farmer participation was crucial. Since farmers were beneficiaries as well as implementers, their participation was key to the project's success. Examples of farmer participation included:

- Design and preparation of the project,
- Comments, suggestions, and decision-making on land tenure as well as contract methods and conditions,
- Design, selection, and improvement of crop systems and their components,
- Evaluation of trees, shrubs, grasses, and food crops,
- Tests and/or experiments with the selected new technologies,
- Project improvement during different stages,
- Content of the training courses,
- Policies to promote project development including those that benefited both the farmer's livelihood and the environment.

4.4.6. Widespread extension of Vetiver technologies. In comparison to the whole Dabie Mountain area containing dozens of counties or cities, the project sites covered a very small area. To extend Vetiver and related technologies, the China Vetiver Network distributed huge amounts of printed matter, such as Vetiver Newsletters, Fact Sheets, Posters, and the Green Book. In total tens of thousands of copies were distributed. In addition, when farmers heard about Vetiver information referring to the project sites, they enthusiastically requested printed matter and/or Vetiver planting materials from their neighbors or the China Vetiver Network. Neighboring counties, townships and villages also contacted the China Vetiver Network and requested similar projects in their area. What's more, local newspapers in the two project counties discussed the project's progress and helped to disseminate Vetiver technology. In addition, the national network sent training materials by mail to agriculture stations and water conservation stations in south China, outside the Dabie Mountains, to introduce project experiences and basic Vetiver knowledge.

5. CONCLUSION

Since the China Vetiver and Agroforestry Technology Project was based on many years of investigation and scientific trials as well as on the local social and economic situation, local government and farmers warmly welcomed it. The project made erosion control using the Vetiver System as a key component. Meanwhile, emphasis was also placed on cash crop tree and bush production as well as water conservation so that farmers could get more direct benefits. Presently the China Vetiver Network is seeking more benefits for farmers through Vetiver handicraft production. They are looking into providing Vetiver prunings or crudely processed materials to handicraft factories that have close cooperation with export agencies.

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Vetiver System and Its Research and Applications in China

（Color plates，Photographing by Liyu Xu except for specified)

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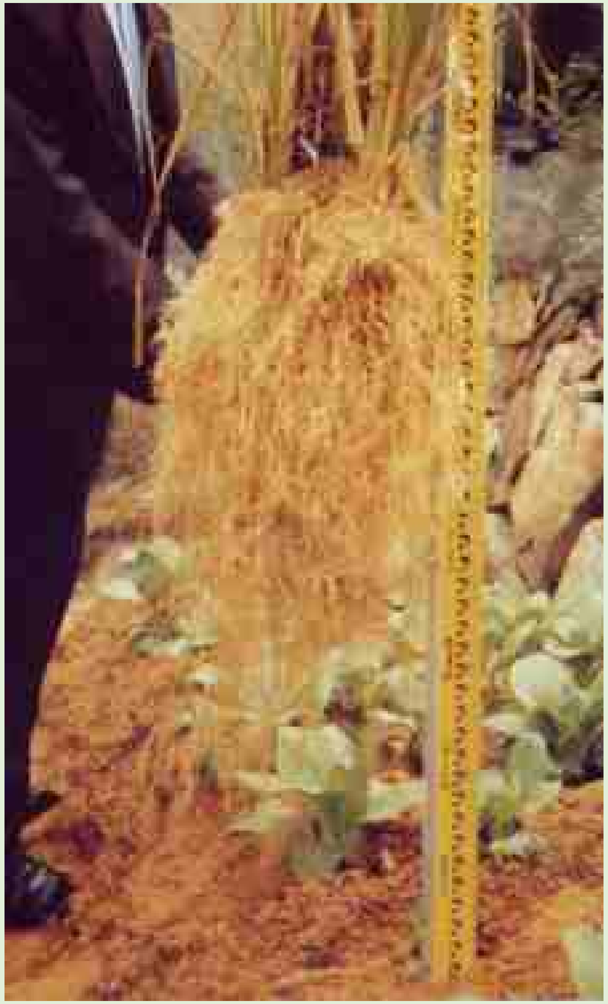
1. 香根草的基本特性 Basic characteristics of vetiver



1-1 香根草根系一般可以深达 1 m 左右 One meter roots are usual

1-2 香根草发达的根系可以有效地固土 Strong roots can stabilize soil effectively（by Feng Ziyuan 冯 子元）

1-3 栽种 2 个月后可高达 1 m　One meter high after planting for 2 months

1-4 某些树木根系有时可挤裂建筑物 Some roots may split construction

1-5 香根草耐旱，可生长在干旱瘠薄的上边坡上 Draught-tolerant and can grow on barren slopes

1-6 在水中浸泡数月不会死 Alive under water for months

1-7 耐火烧 Burning tolerant

1-8 耐盐碱 Saline and alkaline tolerant

1-9 耐家畜啃食　Can withstand grazing by livestock

1-10 在适度耐荫情况也能生长 Grows under shade (up to 60%shade

2. 香根草系统在农业上的应用 Vetiver systems for agriculture production

2-1 土壤侵蚀常导致农田毁坏 Farmland destroyed by soil erosion

2-2 用枯死秸秆保护梯田但不能持久 Protect terrace by dead plants but cannot remain long

2-3 石砌梯田有时也被毁坏 Stone terrace can also be destroyed

2-4 因土壤侵蚀茶园很难长成 Tea garden could hardly grow up because of soil erosion

2-5 用小石块护坡再栽上香根草 Protect slope by small stones and then plant vetiver

2-6 在坡面上新栽的香根草 Newly planted vetiver for slope erosion control

2-7 新栽香根草保护梯田小麦 Vetiver protect terrace planted with wheat

2-8 新栽香根草篱保护经济林 Vetiver fence protects economy forest

2-9 香根草可促进茶树生长，提高茶叶品质 Vetiver can advance tea grow, improve tea quality

2-10 用香根草保护的茶园 Tea garden protected by vetiver

2-11 用香根草保护的板栗 Chestnut protected by vetiver

2-12 在旱季把香根草割下铺在地表 Vetiver mulch on ground surface in dry season

2-13 农民在管理用香根草保护的茶园 Farmer manage vetiver protected tea garden

2-14 香根草可以喂羊 Feeding goats with pruning

2-15 香根草可以喂牛 (格雷姆肖) Feeding buffalo with pruning （by Grimshaw） 2-16 用香根草培养的食用菌 (张菁摄) Mushroom cultivation with pruning (by Zhang Jing)

2-17 人们参观用香根草培养的食用菌展览 Mushroom cultivation exhibition

2-18 用香根草编织的工艺品 （张菁摄）Handcrafting (by Zhang Jing)

2-19 用香根草编织工艺品 （张菁摄）Handcraft (by Zhang Jing)

2-20 大量香根草用于农业开发项目地 Planting materials for agriculture project

2-21 大量香根草用于农业开发项目地 Planting materials for agriculture project

2-22 农民把生产的香根草苗运往外地 Farmers produce and sell vetiver seedlings

2-23 用营养杯生产的草苗外销用于工程保护 Container seedlings produced by farmers and sold for engineering protection 2-24 香根草培训班(湖北)Training course (Hubei Province)

2-25 香根草培训班（安徽）Training course (Anhui Province) 2-26 国际援助机构观察香根草篱的作用 International donors investigate vetiver project

2-27 征求农民对香根草的意见 Discuss with farmers

2-28 及时对香根草项目作总结 Evaluate project periodically

3 香根草系统应用于公路边坡防护 Vetiver systems for highway embankment protection

3-1 新修公路很易遭受土壤侵蚀 New highway subject to erosion

3-2 混凝土常用于保护道路边坡 Concrete usually for road embankment protection

3-3 钢筋混凝土护坡 Steel and cement for slope stabilization

3-4 "硬性措施"有时也遭破坏 Hard measure was destroyed sometimes

3-5 混凝土挡墙有时也会崩塌 Concrete wall destroyed if slope was not fixed

3-6 石砌挡墙因侵蚀而破坏 The rock wall destroyed by erosion

3-7 寸草不生的某路边坡有时可以延续好多年 Slope may last years without any plants

3-8 用香根草保护公路边坡 Vetiver protected highway

3-9 用香根草保护公路边坡（张菁摄）Vetiver protected highway (by Zhang Jing)

3-10 用香根草保护公路边坡（张菁摄）Vetiver protected highway（by Zhang Jing）

3-11 用香根草保护公路边坡（张菁摄）Vetiver protected highway (by Zhang Jing) 3-12 栽后 3 个月可起到护路作用（张菁摄） Protect highway 3 months since planting (by Zhang Jing)

3-13 用香根草保护的下边坡（张菁摄）Vetiver protected highway fills (by Zhang Jing) 3-14 泰国客人参观用香根草保护的公路边坡 Thai gusts visit vetiver protected highway

3-15 用香根草保护的公路下边坡 Vetiver protected highway fills

3-16 用香根草篱保护公路排水渠 Protect highway ditches

3-17 用香根草保护高速公路上边坡 Vetiver protected express way (huge cuts)

3-18 公路部门培育的香根草苗 Seedling cultivation by highway institutions

4. 香根草系统在铁路边坡防护上的试验 Vetiver systems for railway embankment protection

4-1 新修的铁路路基 Newly constructed railway embankment

4-2 新栽的香根草篱 Newly planted vetiver

4-3 栽后 2 个月草篱基本成形 The hedges formed 2 months after planting

4-4 栽后 3 个月即可有效起到护坡作用 Protect the embankment effectively 3 months after planting

4-5 欧洲客人参观香根草护坡 European gusts visiting demonstration

4-6 铁路边坡防护成果鉴定会 The technology was fully approved by railway experts

4-7 铁路边坡防护成果鉴定会 The evaluation and identification conference by railway experts

4-8 铁路部门专家参观现场 Railway experts visiting demonstration

5. 香根草系统在矿山尾矿植被恢复上的试验与应用 Vetiver for re-vegetation on mine tailings

5-1 侵蚀严重的尾矿 Seriously eroded mine tails

5-2 用废旧轮胎护坡填土植树 Used tyres were fixed, filled with soil, and planted trees

5-3 土壤侵蚀仍然很难控制 Soil erosion was still difficult to control

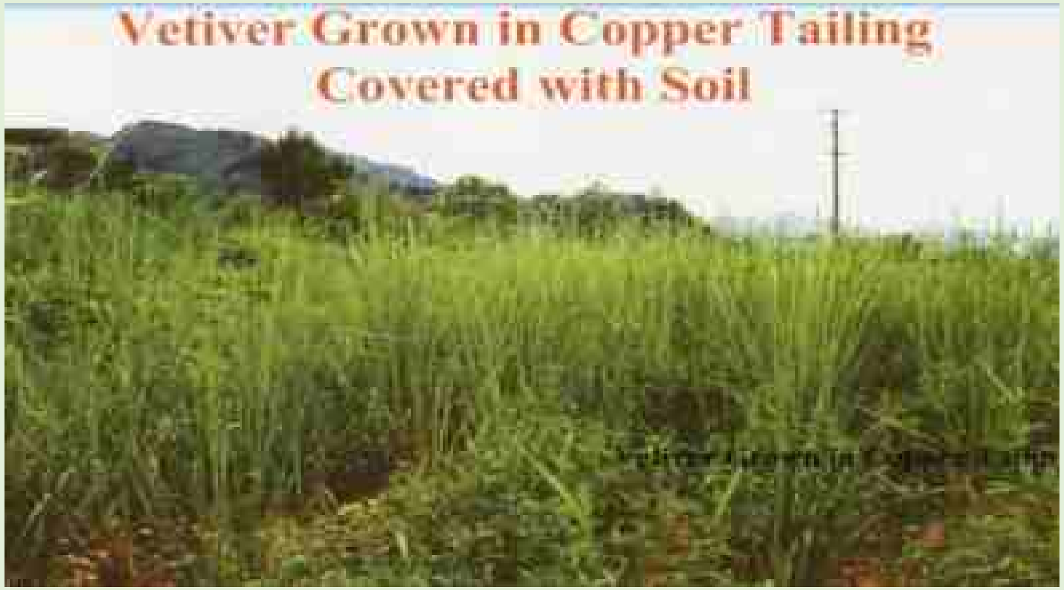
5-4 香根草护坡可有效恢复尾矿植被 Vetiver for mine tail erosion control

5-5 香根草护坡可有效恢复尾矿植被 The slope was fixed and re-vegetated by vetiver 5-6 高温酷暑石楠已经枯黄，香根草长势很好 In hot season vetiver grew well while photinia serrulata looked burnt

5-7 在岩石上打洞种植香根草 Drill holes and planted vetiver on the rock

5-8 在采石场废渣上种植的香根草 Vetiver for quarrying re-vegetation

5-9 铜矿废渣上加5%污泥可促进香根草生长（郑春荣摄） 5% sewage sludge promoted growth on copper mine (by Zheng Chunrong) 5-10 在铜矿尾矿上种植香根草（郑春荣摄）Vetiver planted on copper mine tail with soil (by Zheng Chunrong)



6. 香根草系统在固岸上的作用 Vetiver systems for bank protection

6-1 用香根草保护海边鱼池 Protect coastal fish pond

6-2 用香根草保护海岛淡水河 Protect fresh water river in Pingtan Island

6-3 香根草保护的海岸 Protect coastal bank

6-4 江边上种植的香根草（冯子元摄）Vetiver planted on river bank (by Feng Ziyuan)

6-5 香根草保护的江岸 Vetiver for river bank protection

6-6 香根草保护的水库 Protected reservoir

7. 香根草系统在环境保护上的应用 Vetiver systems for environment protection

7-1 垃圾场（自左而右：香根草坡，土坝，垃圾填埋场）Vetiver slope, dam, landfill ground (from left to right)

7-2 用香根草保护的土坝 Vetiver protected dam

7-3 用香根草保护的土坝 Vetiver protected dam (other side)

7-4 香根草强大的蒸发蒸腾可有效减少污水外溢 High evapor-transportation reduced polluted water flow

7-5 当地植物死于垃圾场流出的污水 Native plants died from polluted water

7-6 香根草在污水中仍能存活 Vetiver can survive polluted water

7-7 用香根草处理城市污水 Vetiver for city wasted water treatment

7-8 研究香根草在处理污水中的作用 Experiment on effect of vetiver for polluted water treatment

8. 中国香根草网络及其在香根草系统发展与传播上的作用 The China Vetiver Network—Its Role in Vetiver Systems Development and Dissemination

8-1 "福州会议"（1997）International Vetiver Workshop in Fuzhou 1997　8-2 "南昌会议"（1999）　International Conference on Vetiver　Bio-Engineering Technology in Nanchang 1999

8-3 与会者去平潭参观香根草示范区 Conference participants going to n Pengtan island　　8-4 与会者在现场参观 Participants visiting demonstrations

8-5 与会者观看香根草 VCD Participants watching vetiver film on VCD

8-6 中国代表赴菲律宾参加生物工程会议 Chinese people attend international conference in Manila

8-7 中国代表会后考察泰国北部 Chinese people investigate Thailand

8-8 泰国客人参观香根草 Thai gusts visit China

8-9 泰国客人来华访问政府部门 Thai gusts talk to Chinese government officials

8-10 县长向村民们介绍如何利用香根草地上部分 The County Chief introducing application of vetiver pruning

8-11 实地培训农民（张菁摄） Training farmers (by Zhang Jing)

8-12 外国客人参观香根草项目区 Foreigners visiting vetiver project site

8-13 泰国工艺品来华展出 Thai vetiver handcrafts on exhibition in Guangzhou

8-14 中外人士检查香根草项目进展情况 Donors and experts investigating vetiver project

8-15 大量不同的资料散发给不同的读者 Huge amount of multiple printed matter sent to different people

8-16 农民自己举办的图片展 Farmers made their own vetiver poster

8-17 在农村举办的培训班（安徽） Systematic vetiver training course (Anhui Province)

8-18 妇女们对香根草很感兴趣 Woman farmers had high interests in vetiver

8-19 地头举办的培训班（张菁摄）Training course in the field (Zhang Jing)

8-20 培训班内容包括香根草和经济林的栽培与管理 Training included economic tree cultivation with vetiver hedges

9. 香根草系统在护坡上的作用 Vetiver systems for slope stabilization

9-1 未被保护的边坡 Unprotected slope

9-2 用香根草保护的边坡 Vetiver protected slope

9-3 香根草保护住宅楼（坡上、坡对面均为住宅楼） Protect buildings on the top of the hill and opposite to the hill

9-4 用香根草保护的边坡 Vetiver protected slope

10. 2003 年以后的新照片 New photos since 2003

10-1 第三届国际香根草大会 The third International Conference on Vetiver （ICV-3） 10-2 第三届国际香根草大会(展览) Exhibition of ICV-3

10-3 利用香根草系统修复滇池流域学术交流会 National Conference on Vetiver for Dianci Watershed environment protection 10-4 Set of vetiver handicrafts

10-5 农民专业合作社养牛 （云南）Farmers cooperation raise cattle YunNan）

10-6 利用香根草扶贫 （Vetiver project for poverty reduction）（by Wang Xiaoquan）

10-7 各种各样的香根草制品 Multiple vetiver products

10-8 多种多样的香根草编织品 Multiple vetiver handicrafts

10-9 香根草编织品培训班 International vetiver handicraft training course

10-10 农民专业合作社 Farmers Specialized Cooperatives established

10-11 图片展览（昆明，2015） Photo exhibition （Kunming，2015）

10-12 香根草编制培训班(安徽) Vetiver handicraft training course (Anhui)