Design Principles and Engineering Samples of Applying Vetiver Eco-engineering Technology for Steep Slope and River Bank Stabilisation

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Abstract: Application of the Vetiver Eco-engineering Technology (VET) for anti-slide and anti-scour is planting vetiver plus supplementary plants on rocky or soil slopes of natural, cut or filled to control sheet and gully erosion, and surface layer landslide resulted from heavy rainfall, excessively steep slope, flood scouring and so on. Through a complete or partial replacement to traditional hard engineering measures, such as concrete or masonry protective coverings, VET can realize two goals: 1) to reinforce the stability of slopes more economically and practically, and 2) to beautify environment and increase ecological effects. The most conspicuous biological characteristics of vetiver used to resist landslide and prevent flood scouring was introduced in the present paper. In addition, the mechanical characteristics of vetiver roots and their growing curves measured at different regions of southern China were also depicted in here. Supplementary plants can revegetate slope rapidly. Their roots and vetiver roots are composed of a three-dimensional root net consists, which can consolidate the ability of VET to control erosion and to stabilize slope. Three kinds of design working conditions for VET used in slope stabilization and river dyke protection were put forth in the paper. Their design principles and application examples in two large rivers were also narrated, which were river dyke protection for the Golden Congkou Section of Hanjiang River dike in Wuhan City, Hubei, and landslide prevention for the Youjing River bank in Baise City, Guangxi. In the end, a wonderful prospect of VET applying to civil engineering was described.

Key words: Vetiver Eco-engineering Technology, anti-slide, anti-scouring, design principle, engineering application

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1 INTRODUCTION

Since the end of 1980s, a great achievement has been obtained in China on introduction from abroad, research and application of the Vetiver Eco-engineering Technique; furthermore it is becoming increasingly mature from both theory and practice. Today, the technique is revealing a wonderful prospect in China due to huge scales of infrastructure construction.

2 OUTSTANDING CHARACTERISTIC OF VETIVER

2.1 Biological Characteristics of Vetiver

Vetiver has many outstanding characteristics. Its main biological characteristics used for anti-slide and anti-scour engineering are as follows.

- If reasonable design and correct planting in regions of the middle and lower reaches of Yangtze

River, its stiff and upright stems and leaves can grow up to 1.5 m high after 2-3 months, forming a dense hedgerow to effectively slow down surface runoff, filter and to trap eroded sediments. It can reduce 60-73% runoff and trap90-98% sediments (Kon and Lim, 1991; Xia *et al.*, 1996).

• It has a vigorous and massive root system that can penetrate 5 cm thick layer of asphalt concrete (Hengchaovanich,1998). In regions of the middle and lower reaches of Yangtze River, its roots can reach 1.3 m deep 3 months after planting, and reach 2-4 m one year after planting. The strong root system like rows of biological piles penetrating into the soil layer and thus it can largely enforce shear strength of soil body.

• The stiff shoots and strong roots can keep the plant stand steadily in water with 0.6-0.8 m deep and 3.5 m/s velocity of water flow. Thus it can reduce scouring energy of strong flow, and protect safety of dike or riverbank.

• It grows rapidly and has strong vitality, long life, and strong resistance to drought and submergence.

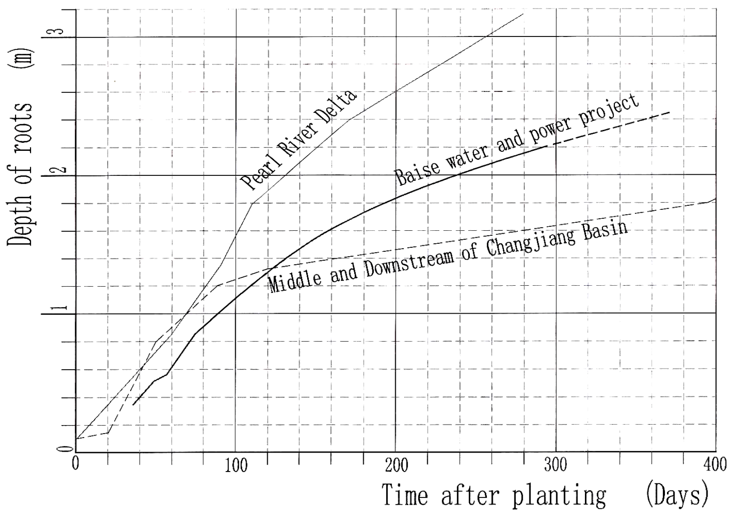
2.2 Growth and Development Regular Pattern of Vetiver Roots

The growth and development regular pattern of vetiver roots is related to air temperature, soil quality, nutrition, planting method, and so on. Among them, temperature is the most important one.

2.2.1 Relations between root depth and days after planting in spring and summer in different regions of southern China

According to the practical observations conducted in regions of the middle and lower of Yangtze River Valley and of Pearl River Valley, a relationship between root depth and days of growth can be drawn into a curve, which may offer reference for the design of anti-scouring engineering (Fig. 1).

Fig. 1 Relationship between root depth and days after planting in spring and summer in South China



The data of the Middle and Lower reaches of Yangtze River were provided by the Traffic Department of Zhejiang Province, and all other data by the Guangzhou City Vetiver Grass Industry Science and Technology Co. Ltd.

The information above indicates that vetiver roots grow more than 1 m deep and shoots grow over 1 m high after planting for 2-3 months in spring or summer, which begin to prevent soil erosion, and stabilize slopes. If vetiver seedlings meet heavy rainfall or flood soon after planting, they will probably be washed away. So there is some risk in this spell of time. This kind of risk should be avoided or reduced in practical projects according to the local hydrometric and meteorological data to chose correct planting seasons.

2.2.2 Relations between root depth and its cross section

The relationship between root depth and its cross section (Hengchaovanich, 1998) is shown as Table 1, which indicates that the deeper roots grow, the bigger its cross section is.

Table 1 The relationship between root depth and its cross section

Depth	m	0.25	0.50	0.75	1.00	1.25	1.50
Cross section	mm^2	326	175	140	105	65	45

2.3 Engineering and Mechanic Characteristics of Vetiver

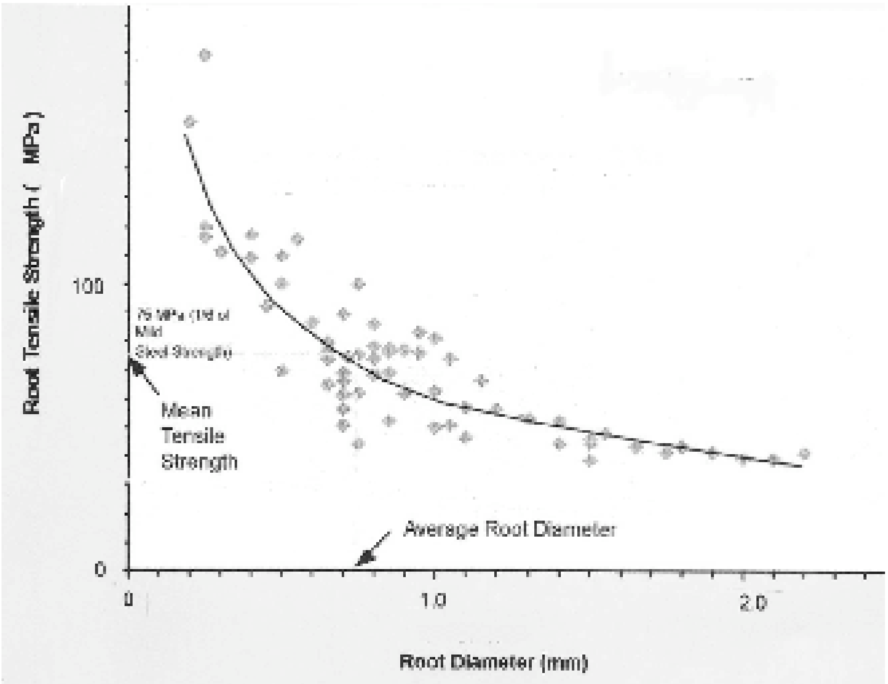
2.3.1 Tensile strength of vetiver root

Tensile strength of vetiver root is the largest among all kinds of plants. The relationship between diameter of vetiver roots and its tensile strength is shown in Table 2 and Fig. 2 (Hengchaovanich,1998).

Table 2 Relations between diameter (D) of root and its tensile strength (R)

D (mm)	0.2	0.3	0.4	0.5	0.6	0.73	0.9	1.0	1.2	1.4	1.6	1.8	2.0	2.2
R (Mpa)	155	120	102	90	82	75	65	60	56	52	45	43	40	38

Fig. 2 Relationship between root diameter and its tensile strength



Hengchaovanich of Thailand and Chen Hong of China all measured the tensile strength of vetiver roots with spring balance. The tensile strength obtained by Hengchaovanich is about 75 Mpa, approximately equivalent to 1/6 of ultimate tensile strength of mild steel; it is defined as ultimate root tensile force divided by the cross-section area of naked root (without bark). But the tensile strength got by Chen Hong was defined as ultimate root tensile force divided by the cross-section area of stressed root, which is about 85 Mpa, 13.3% larger than the former.

The authors think that the reason producing the difference between results got by Hengchaovanich and Chen is using different cress-section area of root. Of course, the tested root samples coming from different region, different weather and soil condition also have some differences. On the whole, the mean tensile strengths of 75 and 85 Mpa all lie in a reasonable scope. However, the mean tensile strength of 75 Mpa, defined as ultimate root tensile force divided by the cross-section area of unstressed root, is more reasonable and safe when using them for engineering strengthen. Therefore, it is suggested to use the 75 Mpa mean tensile strength for engineering design.

2.3.2 Shear strength of vetiver roots

Large–scale direct shear tests indicated that the penetration of vetiver roots increases shear strength of the soil (Hengchaovanich,1998). Mean shear strength of vetiver root can be calculated (Table 3), which is 25 Mpa approximately equivalent to 1/3 of ultimate tensile strength of vetiver root (Ke and Feng, 2000).

Table 3 Calculation table for mean strength of vetiver roots

Depth from surface _m_	Cross-section of roots (mm^2)	Increased shear strength of soil (kN/m^2)	Calculated shear strength of vitiver root (Mpa)
0.5	175	4.2	24.5
1.0	105	2.6	25.3
1.5	45	1.2	27.2

Mean shear strength of vetiver root is 25 Mpa

2.3.3 Hydraulic properties of vetiver hedges

Deep root system of vetiver cannot be dislodged by the strong flow. Its thick hedges can stand up in flow of at least 0.6 m depth, which reduces flow velocity and its erosion power. Hydraulic characteristics of vetiver hedges under deeper flow were determined by flume tests at the University of Southern Queensland, Australia. A water cascade was built in tropical Queensland, vetiver was used to stabilize the steep side slope, and it successfully protected bank from several flood flows during the last 6 years, with flow velocity estimated up to 3.5 m/sec.

Vetiver was planted at one section of the left bank of Youjiang River lied in the upper reaches, 20 km away from the Baise City, Guangxi Province, China on 25 May to 11 June 2002. The bank covered by vetiver was 243 m long and 1:1.5 gradient, and its rain-collecting area is 19,600 km^2. Two months later, vetiver in here went through a scouring of 2.0 m/s, successfully protecting slope stability and security.

3 DESIGN WORKING CONDITIONS AND DESIGN PRINCIPLES

3.1 Design Working Conditions

- First kind of working condition. This is the most basic and common working condition. Slopes have been constructed according to pertinent design and construction specification and, therefore, are stable in general. But this kind of rainfall-induced surface still cannot be avoided to produce surface slide and erosion. The vetiver system can prevent this kind of surface landslide and erosion.
- Second kind of working condition. Potentially unstable, natural or man-made cut or filled slopes, especially those unstable slopes affected by heavy rainfall or seeping pressure of underground water.
- Third kind of working condition. For generally stable natural or man-made cut or fill slopes, will be unstable under the influence of scouring of higher water flow velocity. This condition usually includes the first kind of working condition.

3.2 Design Principles

3.2.1 First working condition

According to gradient angle and its meteorological and geologic condition such as soil and strata behavior, and Employer's request for the time of greening slope and forming fixing slope preliminary to decide planting raw distance and clump distance. Direction of raw is generally along contour; chose proper supplementary plants and relative cultivating technology, in order to make vetiver system greening slope on time, its stiff stem control runoff and reduce flow velocity; Its root system network fix soil and prevent soil lose and anti-slide fixing slope. All of these can get double purposes: economically practically enforce engineering structures, and beautify environment, increasing ecological results.

3.2.2 Second working condition

1. According to topographical and geological conditions, to estimate the area that may be sliding. At the border of that area should arrange drain and so on. Face of sliding should be at region in depth of vetiver roots (if it is beyond that depth of roots, traditional engineering measures should be added). Deciding stable slope by calculating with usual mechanical method or by experience. If the slope is unstable or the stable factor is less than that stipulated by national standard, it is needed to strengthen the slope by vetiver and so on.

2. For the project Employer's detail request, vetiver can be planted along the contour. Stable calculating and experiences should decide Row distance and clumps distance. Planting suitable supplementary plants between rows, in order to prevent soil erosion early and develop anti-slide capability of network roots of vetiver system_make the project is reasonable and economical_green engineering position and beauty environment.

3.2.3 Third working condition

According to its topographical and geological condition such as gradient angle, soil and strata behavior and meteorological condition, esp. distributing situation of flow velocity in river channel, to decide the slope, which is needed or not to plant vetiver increasing its anti-scour capability. If it is needed, one is decided row distance planting along the contour; two is decided other rows, which are vertical or oblique-crossed to the contour.

4 PROJECT SAMPLES

Since the end of eighth decade last century applying vetiver eco-engineering strengthen measures for anti-slide of civil engineering such as water and hydropower, communication, to replace or partly replace tradition "hard" engineering measures, have many successful samples. Only in last three years, the authors have managed or designed 12 items of anti-slide and anti-scour projects, 62,940 m^2, which are in 5 provinces in southern of China (Table 4) (Ke and Feng, 2000).

In order to welcome the Third International Conference on Vetiver and Exhibition (ICV-3) with its theme "Vetiver and Water", which will be held in Guangzhou, China from October 6-9, 2003, 2 successful samples for anti-slide and anti-scour on large river in China are introduced as follows.

4.1 Anti-scour Protecting Dike Project at Golden Congkou Section of Hanjiang River Dike, Wuhan, Hubei

Hanjiang River is an important branch of Yangtze River. Hanjiang River dike and Wuhan section of Yangtze River dike, both of them are protecting safety of important city of Center China—Wuhan City, and vast rich Jianghan Plain. Golden Congkou section of Hanjiang River dike is located at near exit of Hanjiang River where water surface is wide with large wind and waves. The wave by boats is also large since that is a navigable river. The soil at the place planted vetiver is sandy loam, is terrace and bank formed by Quaternary alluvial deposit. Average yearly rainfall at that place is 1170 mm; Mean annual temperature 16.3_, highest recorded temperature 40_, lowest recorded temperature -12.6__

Table 4 Samples for anti-slide and anti-scour projects

No.	Name of project	Areas (m^2)	Completed time	Working Condition	Results
1	Anti-slide in Sitang Hydro Power Station, Xinxing, Guangdong	7500	April 2000	1	Good
2	Anti-slide in Yutang Hydro Power Station, Zhangjiajie, Hunan	3700	July 2000	2	Good
3	Anti-slide in Helong Transformer Substation, Songzhi, Hunan	3200	August 2000	1	Good
4	Treatment for Collapsing hilloke, Dongchen, Xinxing, Guangding	9000	March 2001	2	Good
5	Treatment for slope of Oil Warehouse, Guiyang Airport	6200	May 2001	1	Good
6	Anti-scour and Protecting Slope at Golden Congkou Section of Hanjiang Dike, Wuhan, Hubei	2300	May 2001	3	Good
7	Anti-slide at high slope in Qinglongsan Park, Jiangxia, Wuhan	3200	Augsut 2001	1	Good
8	Anti-slide at Quanzhou Section of Jiang-Zhu Express Highway	12,400	September 2001	1	Good
9	Anti-slide at Hanyan Section of Han-Zhao Express Highway	4300	September 2001	1	Good
10	Anti-slide at 2 # Highway, Longtan Water Power Station, Guangxi	9000	June, 2002	1	Good
11	Anti-slide and anti-scour Works at Left Bank of Youjiang River, Employer's Front Campus of Baise Multi-purpose Project, Guangxi	3240	June, 2002	3	Good
12	Anti-slide and anti-scour at Spillway of Yansan reservoir, Guangxi	2000	November 2002	3	Good

Areas of vetiver planted were 2300 m^2. Design and construction were done by Guangzhou City Vetiver Grass Industry Science Co. LTD. Among them: 2000 m^2 on foreland, 300 m^2 on bank slope. Considering the direct and velocity of river flow, along contour planting rows of vetiver, another rows distance is 300 cm, their directions are 45^0 oblique-crossed contours. Two direction rows are form diamond structure. Supplementary grasses such as Bahia and St. August grass covered their spare places. Using matched 1 # and 2 # vetiver special fertilizer studied and made by Guangzhou City Vetiver Grass Industry Science Co. LTD. The construction time was 21 April 2001-1 May 2001; the maintain time was 1 May 2001 - 30 June 2001.

First observation after planting: May 20, turning green rate of vetiver was 85%, bare beach was almost covered by grasses; Second observation after planting: June 22 (52 days after planting), survival rate of vetiver was 98%, mean depth of their root system was 70 cm, maximum depth was 90 cm; mean depth of root system of Bahia was 45 cm, maximum depth was 60 cm; Third observation after planting: vetiver about ground was 150 cm high, average depth of their roots was 120 cm. All function of vetiver system was got fully reflected. Esp. partly vetiver were submerged by river water, but they were still very strong and luxuriant.

4.2 Anti-slide Anti-scour Works at Youjiang River Bank of Employer's Front Camps of Baise Water and Power Project, Guangxi

Baise Water and Power Project is located at Youjiang River (a tributary of Pearl River) of upstream 20 km from Baise City, West part of Guangxi, collecting area 19,600 km^2, average yearly discharge at that dam site is 263 m^3/s; Storage capacity 5.6 billion m^3, installed capacity 580 mW. It is located at tropical monsoon climate area, its mean annual temperature 22.2_, highest daily mean temperature 42.5_, lowest daily mean temperature –2_, average yearly rainfall at that area is 1107.8 mm. Author[1] as a basic member of Dam Safety Review Panel of the World Bank for Baise Project, suggested Employer and Designer several times to adopt vetiver for soil and water conservancy, anti-slide anti-scour and quarry rehabilitation. Guangxi Hydro Power Design Institute made a planning and outline design for the bank protecting under Employer's front camps of Youjiang river left bank at downstream 1 km of the dam site, 243.2 m long, slope high 19 m, ratio of slope after regulation is 1:1.5. Soil property of that slope are: spoil at slopes of upstream and downstream sides, their main component are yellow silty shale, siltstone, including part of yellow loam; toe of slope is mud or mud mix sand and gravel; middle section of that bank is a small rock hill, strong or weak weathered siliceous limestone. Soil property on all of these slopes is infertile, acid, low ability for water conservancy. In order to prevent scouring to toe of slope by river flow, using cement-masonry revetment above the piles had been used from 120 to 123 m elevation; from 123 to 132 m elevation planted vetiver system, 3240 m^2; from 132 to 139 m elevation planted Manila grass, 4000 m^2. Guangzhou City Vetiver Grass Industry Science Co. LTD practiced detail design and construction. Vetiver was planted with exposed roots; between vetiver hedges planted three kinds of grasses such as Bahia and used matched 1 # and 2 # vetiver special fertilizer, which studied and made by Guangzhou City Vetiver Grass Industry Science Co. LTD. Construction time was 25 May 2000–11 June 2000; professional maintaining time was 12 June 2002–12 August 2002.

In order to know growing situation of vetiver, established 7 boxes near by that works side for observation at same steps, which made by angle steel and glass, 1.5-2.5 m high. Filled soil in these boxes as same as that of the works site, planted same vetiver with same method of planting, maintaining and observation.

Observation explain that: from June 14 to 18, river flood-peak stage went up 124.31 m elevation, flow velocity reached 2.5 m/s, so the surface soil and most vetiver seedlings planted less than 10 days under the water level had been washed away. But in next 2 flood peak period, duration 18 days: from July 20-26 and August 11-22, even though the highest flood-peak stage went up to 129.55 m, average flow velocity in river reached 2.57 m/s, these vetiver under the water level had not affected due to they had been planted more than 40 and 60 days, their root system reached more than 40 and 70 cm. It showed that: the time for planting vetiver should be chosen more than 20-30 days before heavy rainfall and flood arrived, in order to avoid loss; after 1.5-2 months, vetiver system have had initially capability for anti-scour and protecting slope.

After professional maintaining 2 months, the mean growing high, tillering quantity and rate of covering of vetiver system reached standard or exceeded request of design. During this period, go through tests of several heavy rainfalls and flood-peak, most of impact energy of rainfall had been delayed or absorbed by vetiver and other plants, the phenomenon of landslide and soil loss cannot be seen. Vetiver system after planting 1.5-2 months can bear scouring of 2.0 m/s flow velocity and protect successfully slope stability and security. April 5, 2003, 7 # observation box was opened and tested after growing for 296 days, root system was 210cm depth, average diameter of main roots was _1.5 mm, crown of root system was 40 cm. (Appendix photo 2).

5 CONCLUSION

1. Since the end of eighth decade last century, practice proved that dense green hedgerows of vetiver system can effectively slow down surface runoff, filter and to trap eroded sediments; Its deep and extensive root system can fix soil, anti-slide and anti-scour, protect slope, foreland, dike or river bank. Applying this biological measure to replace or partly replace traditional hard engineering measures such as concrete or masonry protective covering, anti-slide piles and etc. can be economically practically enforcing engineering structures, and beautifying environment, increasing ecological results, which can not be provided by traditional hard engineering measures. That mean is same as: When applying the Vetiver Eco-engineering, it is best to combine the biological measures (the Vetiver Eco-engineering) with the engineering measures, and to put the biological measures in the first place (Xia *et al.*, 1998).

2. Application of Vetiver Eco-engineering Technology in China has got achievements attracted people's attention. It is getting mature increasingly on theory and practice. According to statistics, the succeed rate of applying vetiver eco-engineering technology in water and power engineering is near 100%.

6 FORECAST

So far as now, application vetiver to anti-slide protect slope projects, either from water resources and communication departments of provincial of southern China or many private grasses companies, authors realize that: Now for most engineering application of vetiver system, which are still in the period of test. For comprehensive judging of its using life, environment results, unit price of 20-40 Yuan RMB/m^2 and so on, its economical advantage is obvious and unit price can be acceptable by most Employers. But for large-scale popularizing application of vetiver eco-engineering technology – edge technology of disciplinary and inter departments -- to civil engineering, forming huge vitality still have a lot of work to do. Besides strengthening basic research and engineering observation, esp. making Employers of relative civil projects to know this technology and promote application actively for projects design and construction. It is necessary to have design standard regarding vetiver eco-engineering technology if we hope to apply this technology to design. Author suggest that: firstly compiling enterprise standard, after getting responsive recognition, step by step to become professional standard, and finally it will become national standard. Guangzhou City Vetiver Grass Industry Science Corp. LTD is preparing to invite some experts to compile enterprise standard. Authors suggest that: supported by International Vetiver Network and China Vetiver Network, relative administrations, professional organizations organize relative units, corp. and so on to cooperate compiling design and construction standard for application vetiver eco-engineering for civil engineering as early as possible. Authors believe in getting perfect future that will be coming for widely application vetiver eco-engineering technology to civil engineering construction.

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References

Hengchaovanich D. 1998. Vetiver Grass for Slope Stabilization and Erosion Control. Tech. Bull. No. 1998/2, PRVN / ORDPB, Bangkok, Thailand

Ke CC, and Feng ZY, 2000. Introducing Key Species of bio-green hedge for strengthening engineering – Vetiver. Pearl River, (2): 42-43, 49

Kon KF, and Lim FW 1991. Vetiver research in Malaysia – some preliminary results on soil loss, runoff and yield. Vetiver Newsletter, Number 5: 4-5

Xia HP, Ao HX, and Liu SZ. 1998. The vetiver eco-engineering – a biological technique for realizing sustainable development. Chinese Journal of Ecology, 17(6): 44-50

A Brief Introduction to the First Author

Ke Chengchun, senior engineer (Prof. Level), graduated from Department of Hydro & Power Engineering, TSINGHUA UNIVERSITY in 1958; He have served as: Deputy Chief Engineer, Lishui Hydro & Power Corp., MWR & NUNAN, CHINA; Basic Member of Dam Safety Review Panel of the World Bank for Guangxi Baise Water and Power Project; Senior Visiting Scholar, Research Associate, LOUISIANA STATE UNIVERSITY, U.S.A. and so on. Forty-six academic papers and one collection of academic papers have all been published. His name was added to the roster of candidates for openings in the U.N. Technical Co-operation Programs in 1988, "The Expert of Enjoying Specific Technical Allowance" awarded by THE STATE OF CHINA in1992. At the beginning of this century, he stated to involve the field of application vetiver eco-engineering technology.

Fig. 1 Vetiver system 85 days after planting at Golden Congkou Section of Hanjiang Dike, Wuhan

Fig. 2 Vetiver roots 210cm long 296 days after planting