Study on Application of Vetiver Eco-engineering Technique for Stabilization and Revegetation of Karst Stony Slopes

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Abstract: A study on application of the vetiver eco-engineering technique for stabilization and revegetation of Karst stony slopes was conducted in the Karst region, Jiuxiang Town, Kunming, Yunnan province. The experimental site is 1984m above sea level (asl); the slope height is over 50 m with a gradient of about 75. The substrate on the slope, account for 90%, is mainly decomposed, weathered shale, On the whole, the environmental conditions here were quite harsh. The experimental results showed that the survival rate of vetiver planted the slope was up to 92% even under an extreme weather condition of 186 days of successive drought and 72.7 mm of maximum rainfall in one single day.

After vetiver was planted for 4 months along the contour on the slope, the mean tiller number per slip were 4.6, the mean height 76.6 cm, and the mean root depth 70.8 cm. The hedgerows began to take shape at this time. One year later after planting, each slip had an average of 8.6 tillers, and the largest one was up to 15 tillers; the plant height averaged out to 100.6 cm, and the highest one was up to 136 cm; the root depth averaged out to 98.6 cm, and the longest one was up to 101.3 cm. The dense hedgerows began to take shape at this time. As a result the Vetiver Eco-engineering played an important role in erosion control, slope stabilization and environmental amelioration to the Karst stony slope.

On the contrary, on slopes without vetiver planting several mountain slopes collapsed and landslide took place. Therefore, the new Vetiver Eco-engineering replaced the conventional stone-based measures that are expensive, and scarce of ecological and landscape benefits, and is therefore worth disseminating in Karst regions.

Key words: Vetiver Eco-engineering, Karst, slope protection, ecological protection, slope slope

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1 INTRODUCTION

Infrastructure construction of highway and hydropower has developed rapidly in recent years. However, the phenomenon of soil and stone erosion and landslip frequently occurs on the slopes formed by mountains excavation and ravines filling. The general engineering measurement is to stabilize the slopes with concrete, which needs high investment and, therefore, is difficult to be implemented (Xia *et al.*, 1999). Ecological engineering measurement developed in last twenty years, using the powerful root system of plants, to stabilize soil and stone on slope and to prevent slope from eroding and collapsing. Moreover, hedgerows and ground cover formed by the aboveground part of plants can prevent sloping soil from spattering by rain drops, slow down the speed of runoff. The ecological engineering measurements are easy to carry out with low investment and costs, and produce obvious ecological, economic, and social benefit. Among them the “Vetiver Eco-engineering” using vetiver (*Vetiveria zizanioides*) as the main grass is a new technique developed in the last ten years (Xia, *et al.*, 1998, 1999; Cheng *et al.*, 2000; Bao *et al.*, 2001a).

Jiuxiang Town, Kunming, Yunnan Province, 1900 to 2000 m above sea lever, is in the Karst region of

China. With the construction of the new Maitian River hydropower station, weathered shale was exposed and defined as seriously weathered unstable slope. The average slope was up to 75°. Without careful protection, this slope would be eroded by rainfall and surface runoff, and even collapse. Therefore, It is important to study the ecological protection techniques aiming at slope in Karst region, with 2000 m asl, very steep slope and weathered rock stratum.

In the original design of Maitian River hydropower station, the concrete slice system was adopted to fix the slope. The "Vetiver Eco-engineering" had great risk because there had not any samples and data of the ecological adaptability and protection effect of vetiver grass in such extreme conditions. If the effect were not satisfied, the process of construction and operation of the power station would be affected. Under the support of the Biological Resource Development and Innovation Office of Yunnan Provincial Government, the experiment of "Vetiver Eco-engineering" was carried out on the slope of Maitian River hydropower station in spring of 2002. After finishing the fourteen-month' experiment, its process and results were summarized in here in order to offer some references and exampless for future similar projects.

2 APPLICATION ENVIRONMENT

2.1 Geologic and Geomorphic Conditions of Slope of Maitian River Power Station

The experiment is located at Jiuxiang Town, Yiliang County, Kunming, in Karst region. The slope, composed of loose Paleozoic shale and mudstone, was excavated for constructing the power station in December 2001. It was defined as seriously weathered and weaken slope after investigation and survey. The surface was mainly made of strongly weathered mudstone, shale and moderately mudstone, accounting for 90% of the total substrate. The main rock body is composed of soft rock, such as shale, mudstone, and sandstone in some parts. The entire slope was weathered and became fragmental structure with poor shear strength. Therefore, under the influence of acute physical changes, such as heat difference, moisture variance, etc., especially heavy rainfall, the slope would collapse without protection, which threatened safety of the power station. Before the experiment was conducted, many ravines were formed by rainwater on the left side of the slope, and stones were often washed down from the right side of the slope.

The entire slope was completely barren. Formed by excavating the mountain slope, the slope was nearly a steep triangle with the gradient of 60-70°, even 80° in some parts. The length of sideline near the spillway was 60 m, the bottom line was 65 m, and the highest point of slope was 26 m. The total area was some 1600 m^2.

2.2 Climate Condition of Experiment Spot

The annual average temperature is 19.6℃. The minimum temperature is -4℃, and the maximum is 30 ℃. The annual rainfall is about 1200 mm. And the dry season is in winter and spring (nearly six months of drought appeared from November 2002 to May 2003), while rainstorms concentrate in autumn and the highest daily precipitation is up to 72.4 mm in July 2002 and 96 mm in June 2003. Such high intensity of rainfall often caused soil erosion, even landslide.

2.3 Soil Characteristics of the Slope

The soil of the slope is typical red soil developed from weathered mudstone, shale in Karst region. The surface soil did not exist because of excavating mountain; only mudstone and weathered detritus of mother rock were on the slope. Shale and mudstone had a very high proportion, accounting for 2/3 of total soil weight. The soil fertility was very poor, very low in lacking nutrients (Table 1).

Table 1. Basic Characteristics of Soils in Slopes

Locality	PH (1:5)		Organic matter	Total N	Hydrolysable N	Available P	Exchangeable K	Gravel to soil
	H_2O	KCl	(g/kg)	(g/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(%)
Left side slopes	4.21	4.01	0.56	0.06	20.6	0.03	1.03	58
Right side slopes	3.62	3.27	0.28	0.05	18.3	0.02	0.85	90

3 MATERIALS AND METHODS

In spring 2002, 16,000 tillers of vetiver and 500 kg of bahia grass seed (*Paspalum notatum*) were introduced from South China Institute of Botany in three batches. The engineering measurement was conducted first and then the biological method. The engineering measure was to dig up a 90-cm-wide channel on the top of slope to disperse upper runoff. The biological method was conducted from February 26 to March 18, 2002. The main aim was to plant vetiver along contour line. Contour platforms with a width of 30-40 cm, and planting ditches with a depth of 15 cm were first built on a row spacing of 80 cm, and then vetiver was planted according at 10-15 cm spacing, 2-3 tillers for each slip. Before planting, organic manure and a small amount of Ca, Mg and P fertilizer into were put into the channels. CK without fertilization was also set up. Bahia grass was planted between vetiver hedgerows, and Creeper (*Parthenocissus* sp.) was planted on the top and bottom of the slope. No species were planted on the middle part of right slope and the area near to the bottom where gradient was up to 90°. The slope opposite to the experimental slope in the same section was acted as the control one, which was completely under natural state so that change of biodiversity and the effect of slope protection between the control and the experimental slope could be investigated and compared. The experimental plot was applied with compound fertilizer twice on July 29 and August 28, and no further fertilizer was applied. After planting, eight inspections were carried out at 4 sampling sites, A, B, C, and D, on 6 May, 28 July, 28 August, and 10 October 2002, 20 March, 18 May, and 28 June 2003. The survey items included plant survival rate, growth state, species invasion and erosion resistance effect of the Vetiver Eco-engineering. Twelve slips Vetiver grass were selected at each site to measure plant height, root length and tiller number. Bahia grass was recorded for its coverage and its compatibility and complimentarily with vetiver grass.

4 RESULTS AND DISCUSSION

4.1 Survival Rate and Early Growth of Vetiver Grass

The results at the four sites, A, B, C and D showed that vetiver still did not grow 40 days after planting; the seedlings in non-fertilized area first became green after planting for 60 days, and their growing performance was better than those grown in fertilized area (Table 2). Moreover, tiller number per slip of the non-fertilized treatment was more than that of fertilized treatment at the first observation (May 6), but on the contrary from the second observation (July 28). The main reason why vetiver became green so slow was obviously because of a long drought, and strong sunlight and evaporation from February 26 to the beginning of May, 2002, which made shoots of vetiver, including almost all new buds turn brown and withered. Another reason might be that this species needed an ecological adaptation process when it was introduced from Guangdong with low sea level and high rainfall and temperature to Kunming with high sea lever and Karst physiognomy. However, observation found that vetiver grew 3 to 4 cm long new roots in this period, indicating that it had a strong resistance to the harsh surroundings and a good adaptability to high sea level climate. The soil in the slope was very infertile as shown in Table 1, but why did vetiver plants with basal fertilization grow not as good as those without basal fertilization? This was probably because: 1) fertilization made soil become dryer in the condition of non-rainfall, thus the fertilized plants was stressed by drought more severely than those without fertilization; and 2) fertilizer itself caused damage to newly transferred plants, especially to those physically damaged via a long distance of transportation. The similar phenomenon has already been reported (Ke *et al.*, 2000). The result of the first observation, carried out on May 6 (60 days after planting), showed that the average survival rate was 90%, and new tillers began to appear, increased by 1 to 3 for each slip and even 6 in some plants. It indicated that vetiver grass has already adapted itself to the extreme environment of Karst region of Yunnan after a spell of acclimation. After entering the rapid growing stage, the growing speed of fertilized treatment were much faster than those of unfertilized ones, and the tiller number of the former was much higher than that of the latter (Table 3), showing that fertilization still had positive effect to vetiver after turning green.

Table 2. Effects of fertilization on survival rate and initial growth of vetiver (Recorded on May 6)

Site	Fertilization			Non-fertilization		
	Survival rate (%)	Height (m)	Tillers per slip	Height (m)	Tillers per slip	Tiller number of the largest slip
A	89	0.03	1	0.05	2	3
B	92	0.03	2	0.05	3-4	5
C	91	0.05	2-3	0.06	3-4	5
D	96	0.06	2-3	0.08	3-4	6

Table 3. Effects of fertilization on early growth of vetiver (Recorded on July 28)

Site	Fertilization		Non-fertilization		Fertilization
	Height (cm)	Tillers per slip	Height (cm)	Tillers per slip	Tillers number of the largest slip
A	64	4-8	55	3-4	8
B	58	4-6	51	3-4	6
C	60	4	49	3	5
D	69	5	61	4-5	6

4.2 Late Growth and Tiller of Vetiver Grass and Its Protection Effects

Five inspections in 2002 showed that vetiver planted along contour could form hedgerows, but the growing speed was different in different stages. The fastest growing season was from July to October (Table 4 and 5). At the fifth inspection (December 2002), vetiver grass had formed dense hedgerows; the average tiller number was up to 8.6 each slip, average height to 100.6 cm and average root depth to 98.6 cm. The gradient of site A and B was about 60°averagely, and their soil was mainly composed of 40% mudstone, while the gradient of site C and D was up to 75-80°and their soil was chiefly (90%) composed of shale. Obviously the habitat condition at site A and B was better than at site C and D. As a result, bahia grass planted in site A and B formed a thick covering layer after six months and the reached 96% cover, which took auxiliary effects on stabilizing slope and preventing soil from washing away. On the contrary, bahia was difficult to form a grass layer at site C and D because of steep slope and shaley soil; as a result the coverage was nearly 50% lower than that at site A and B. However, vetiver still formed hedgerows at site C and D. In summer of 2002 (June and July), there was lots of rainfall. In June the rainfall was 30% more than the same period of previous years, and furthermore storms ware frequent; in July there were 3-4 days whose rainfall came to 72.4 mm. As a result, the control under completely natural situation had serious landslip and the channel of the power station was also badly eroded, close to collapse, while there were no damages on the slope protected by vetiver hedgerows. More importantly, the highly erodible slope was effectively protected and stabilized in rainy season, and its soil erosion was also completely controlled.

Table 4 Tiller formation and plant growth of vetiver grass in the late 2002

Site	July 28		August 28		October 10		December 3		Root largest depth (cm)
	Height (cm)	Tillers per slip	Height (cm)	Tillers per slip	Height (m)	Tillers per slip	Height (cm)	Tillers per slip	
A	64	4-8	89	8-16	131	8-18	137	8-18	103
B	58	4-8	86	8-12	130	8-19	130	8-19	95
C	60	4	76	6-10	110	6-12	110	6-15	80
D	69	5	84	7-13	129	8-16	129	8-16	91

Three inspections were conducted in 2003 (Table 5) when vetiver grass had grown for 14 months. The coverage was up to 85% and dense hedgerows were formed; as a result, the whole protected slope was firmly stabilized, and soil erosion and landslip did not occur on the slope any longer. The growth of vetiver and bahia was vigorous and they successfully resisted the extreme drought of 186 days and rainstorm of 96 mm in a day. Vetiver grew up to 8-20 tillers averagely for each slip, to 110-136 cm for plant height, and to 110-121 cm for root depth. In contrast to several landslips in Yiliang County in June 2003, the Vetiver Eco-engineering played an important role in preventing soil erosion and stabilizing slope; moreover it greatly improved the eco-environment and landscape of the steep slopes in Karst region. It can be seen how prominent the effect of Vetiver Eco-engineering for slope protection. In addition, an interesting phenomenon was that *Galinsoga parviflora* covered all the slope but not a single plant invaded into the vetiver part. The reasons need to be studied further.

As stated above, the dry season lasted 186 days, from November 2002 to May 2003, but vetiver did not wilt or perish during this period, fully indicating that it had powerful drought resistance. The new leaves grown out after the dry season assumed purple under irradiation of plateau sunlight, and recovered to green when the rain season was coming.

Table 5 Tiller formation and plant growth of vetiver grass in 2003

Site	March 20		May 18		June 28		Mean height (cm)	Mean tillers per slip	Root largest depth (cm)
	Height* (cm)	Tillers per slip	Height (cm)	Tillers per slip	Height (cm)	Tillers per slip			
A	46	8-18	63	8-19	96	16	120	19	121
B	48	8-19	61	8-20	93	16	127	20	118
C	48	6-16	54	8-12	88	11	106	12	100
D	46	8-16	61	8-18	94	15	115	18	119

*Vetiver plants were cut to 40 cm height in winter.

4.3 Comparison of Growth Pattern of Vetiver Between in the High Altitude Area, Juxiang, Yuannan Province and in the Low Altitude Area, Dangyang, Hubei Province

In term of tiller formation speed and height of vetiver, there was a difference in the Karst stony slope of Juxiang, Kunming, Yunnan Province from in the low altitude highway slope of Dangyang, Hubei Province (Bao *et al.*, 2001a, b). It can be seen from data in July and August that the survival rate, plant height, and tiller number per slip of vetiver were all lower in Juxiang than in Dangyang, but the roots were longer (Table 6). This was probably because at high altitude, high shale and mud stone contents, infertile soil, low rainfall, high wind, strong sunshine, and high evaporation in Juxiang slow down vetiver growth. As to the reason why roots grew longer in Juxiang, it was obvious due to lower rainfall and soil moisture, which forced vetiver roots to penetrate deeper for taking up sufficient water (Liu, 2001).

Table 6 Comparison of growth situations of vetiver between in Juxiang, Yunnan and in Dangyang, Hubei Province

Site	Survival rate (%)	July		August		Root depth (cm)
		Height (cm)	Tillers per slip	Height (cm)	Tillers per slip	
Highway slope, Dangyang, Hubei	96%	100	20	110	28	43
Forebay slope, Jiuxiang, Yunnan	92%	65	4-8	71	8-12	51

4.4 Economic Benefits Analysis of Vetiver Eco-engineering

In the past time, nearly all projects of slope protection and stabilization conducted for power station construction were stone-based engineering. They are short of ecological benefits, very expensive, and are easily to be destroyed by flood. The price for stoned-based structures is generally 200 Yuan/m^2, and even approximately 500 Yuan/m^2 for some difficult sites. The design of the original project was to carry out concrete works, costing 260,000 Yuan, but this Vetiver Eco-engineering technique costed only 30,000 Yuan. That means the cost for the project was actually 19 Yuan/m^2, only 1/8 of the original stone-based project.

Table 7 Comparison of benefits of the Vetiver Eco-engineering and stone-based engineering

Stone-based engineering technology	Vetiver Eco-engineering technology
1. Design and construction are complex, and various kinds of raw materials were needed, such as concrete, stone, sand, steel, plants, etc.	1. Design and construction are simple, and only a few kinds of raw materials are needed. In one growth season, vetiver roots can grow up to nearly 1-3 m, and even to 5 m. The tensile strength of roots is 75 MPa, approximately equivalent to 1/6 of ultimate tensile strength of mild steel
2. Cost is high (160-500 Yuan/m^2)	2. Cost is low, only some 1/8 of stone-based engineering
3. Construction and management are complex and expensive	3. Construction and management are simple, and cheap
4. Erosion and landslide are easily to happen under scouring of lots of rainwater	4. Erosion and landslides are difficult to happen. Under 30 m deep water, vetiver hedgerows can resistance scouring of water flow of with 0.028m^3/s
5. Used only in slope stabilization and erosion control	5. Used in slope stabilization, erosion control, and landscape

The cost for the stone-based engineering is 160-500 Yuan/m^2 in Yunnan Province in 2000 according to the current market price, but the cost for the Vetiver Eco-engineering is only 19-29 Yuan/m^2 (Table 8). The cost of the latter is only 11-18% of the former, consistent with the previous report (Xia *et al.*, 1999). Although some complementary stone-based projects are still needed when the Vetiver Eco-engineering is applied to protect slopes, which will probably enhance the cost, the total cost is still cheaper than that of pure stone-based structure (Xia, *et al.*, 1998, 2002).

Table 8 Comparison of costs of the Vetiver Eco-engineering and the stone based engineering*

Engineering type	Raw material	Labor rate	Management rate	Other	Total*
Stone based Engineering	160-500	5-7	2-3	3-5	209-515
Vetiver Eco-engineering	13-19	4-6	1-2	1-2	19-29

* All values are Yuan/m^2

5 CONCLUSION REMARKS

These results show that vetiver could grow normally under the extreme environmental conditions of the stony ill slope lied in the Karst region of Jiuxiang, Kunming with high altitude, escarpment, low soil N, P, K and organic contents, 186 days' successive drought and 96 mm of maximum rainfall in one single day. Furthermore, strongly netted roots and dense hedgerows were formed only within 4 months. The root system of vetiver improved the slope stabiliy, restored the loose deposit cohesion and, therefore, solved the erosion problem completlyly. It indicates that the Vetiver Eco-engineering technique is quite efficient for slope stabilization and protection in Karst stony region of Yunnan Province, and moreover it is quite cheap; Thereby, the soft biological measure will certainly reveal a great application prospect in the least developed western regions of China. Today, the green eco-environment is becoming increasingly important and indispensable; thereby stone based engineering is getting less and less attention, while cheap vegetation eco-engineering is given more and more recognition (Chen *et al*., 1997; Xu *et al.*, 2000; Bao *et al*., 2001b; Xia *et al.*, 2002).

Vetiver is an ideal pioneer species for slope stabilization and environmental protection due to its high efficiency, permanence, cheapness, multi-function, as well as its fast growth, and strong resistance attributes. However for effective and successful application, a good understanding of biological and engineering processes is required, particularly the biological processes, these two processes should be combined together to maximize the pioneer characteristics of vetiver grass. The physical support system can divert storm water runoff and provide a better foothold for vetiver and other plants in its early growing stage, which is more important on steep and loose slopes. Under the protection of the constructed measure, the eco-engineering measure can be established more rapidly and more effectively (Xia *et al.*, 1999).

6 References

Bao YH, Bai CR, Chen W, *et al*. 2001a. Protection and stabilization of slid and collapsed slopes using *Vetiveria zizanioides* and *Robinia Pseudoacacia* hedgerows. Highway, (4): 73-75

Bao YH, Bai CR, Chen W, *et al*. 2001b. Study on protection technique of highway slopes using *Vetiveria zizanioides* and *Robinia Pseudoacacia*. East China Highway, (4): 70-71

Cheng H, Chen FY, Chen SM. 2000. A way of the vetiver grass technology for stabilizing slope of highway. Research of Soil and Water Conservation, 7(3): 67-68

Chen HR, Xu P. 1997. The grass planting technology for highway slope lawn and its function in slope protection. Rural Eco-Environment, 13(1): 37-39

Fu HS, Lu SL, Xie WM, *et al*. 2000. Prospect of the vetiver eco-engineering technique for protection highway slope and its technical outlines. East China Highway, (3): 62-64

Ke HH, Li LL, Deng ZP, *et al.* 2000. Comparison on the growing situation of 4 grasses in oil shale spoil. Guangzhou Environmental Science, 15(4): 9-12

Liu ZH. 2001. How to plant vetiver grass on highway slope. East China Highway, (5): 68-69

National Research Council. 19993. Vetiver grass – A Thin Green Line against Erosion. National Academy Press, Washington, D.C.

Xia HP, Ao HX, Liu SZ. 2002. Studies on benefits of the Vetiver Eco-engineering for protection of highway slopes. Pratacultural Science, 19(2): 52-56

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

Xia HP, Ao HX, Liu SZ, *et al.* 1999. Application of the Vetiver Eco-engineering for the prevention of highway slippage in South China. In: Proceedings of the First Asia-Pacific Conference on Ground and Water Bioengineering Erosion Control and Slope Stabilization. Manila, The Philippines. 522-527

Xu JY, Wan M, Peng YS, *et al*. 2000. Application of vetiver contour hedgerow technique for protection of Shangfen Highway slope of Jiangxi Province, China. East China Highway, (3): 65-67

A Brief Introduce to the First Author

Bo Huang, the vice-Manager-General of Yunnan Green Land Enterprise Co. Ltd., is now responsible for research on biological resources protection and sustainable utilization, and biological technology application of ecological restoration and reclamation of degraded systems in Karst region of Yunnan Province. Graduated from fishery college of Shanghai Aquatic Production University, major in fresh water biology, he ever worked at Yunnan Research Institute of Environment during the period of 1987-1991, mainly engaged in research on lake ecology, environmental influence evaluation, and environmental science, Since 1991, he moved to Yunnan Introduction and Breed Center of Rare and Endangered Plant Species, leading the work of restoration and reconstruction.