Vetiver System for Land Reclamation

Reviewer

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Application of the Vetiver System in the Reclamation of Degraded Land

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Abstract: Land degradation is becoming one of the severest environmental issues in the world, especially in developing nations. Land degradation, usually accompanied by soil erosion, always results in a decrease or complete loss of land productivity, and produces on-site and off-site pollution to soil and water. The methods for land reclamation are various, including physical, chemical and biological. The cost for reclamation of degraded land using old methods is huge, but far cheaper, using new biological methods. Vegetation or revegetation is a chief biological measure, but the key is choosing the right species. Trees, shrubs, creepers, and herbs can be used to reclaim degraded land, but the best species are grasses due to their strong resistance to adverse conditions, and fast-growing feature. Among them, vetiver (*Vetiveria zizanioides*) is the most typical representative. As a species of land reclamation, vetiver has various kinds of miraculous characteristics and functions, such as rapid growth, huge biomass, massive and long roots, strong abilities to control erosion and stabilize slopes, and huge capacities of phytoremediation. Applications around the globe as well as in China indicate that vetiver is really a miracle species for land reclamation, including reclamation to barren mountains or hills, contaminated water and soil, mined lands, quarries, etc. It exhibits a very wonderful future in South China for land reclamation.

Key words: Vetiver System, land reclamation, phytoremediation, erosion control, sustainable development

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1 INTRODUCTION

Land degradation is referred to a reduction or loss in the capacity of land to supply benefits to humanity. It results from an intricate nexus of social, economic, cultural, political, and natural forces operating across a broad spectrum of time and spatial scales (Barrow, 1991; Daily, 1995). A great part of land degradation is derived directly from soil erosion. The two ecological processes, generally concurrent, usually cause a serial of other ecological and social problems. Among them, the most prominent one is on-site and off-site pollution, thus causing a decrease of land productivity or land degradation in the lower reaches. The main factors evoking land degradation consist of natural or artificial factors, and the artificial factors contain excessive deforesting, pasturing, mining, quarrying, contamination and pollution coming from industrial or agricultural development, etc. With the development of human society, land degradation evoked by artificial factors is becoming more and more conspicuous, accounting for a far greater part of degraded lands.

2 SEVERE SITUATION OF LAND DEGRADATION AROUND THE GLOBE

It is estimated there has been nearly 2_10^{9} hm^{2} soil degraded due to excessive artificial activities since 1945, accounting for 15% of the total terrestrial areas. Of this, about 750 _10^{6} hm^{2} (38%) are classified as lightly degraded (defined as exhibiting a small decline in agricultural productivity and retaining full potential for recovery); about 910_10^{6} hm^{2} (46%) are moderately degraded (exhibiting a great reduction in agricultural productivity; amenable to restoration only through considerable financial and technical investment); about 300_10^{6} hm^{2} (15%) are severely degraded (offering no agricultural utility under local management systems; reclaimable only with major international assistance); and about 9_10^{6} hm^{2} (0.5%) are extremely degraded (incapable of supporting agriculture and unreclaimable) (Daily, 1995). Up to 2000, 50% of wetlands in the world have been destroyed, and 50% of rivers polluted; desertification has influenced over 100 nations, nearly 1 billion people. At present, the forest resource vanishes at the speed of 16_10^{6} hm^{2} annually (Qing *et al*., 2002). Therefore, it is very urgent to control land degradation and to reclaim the degraded lands.

3 COMMON METHODS FOR LAND RECLAMATION AND THEIR COSTS

In order to rehabilitate or reclaim degraded lands, especially mined lands, various methods have been utilized globally. Of them, the physical and chemical methods, such as irrigation, burying, filtration, or removal of pollutants, or similar treatments (Table 1), are extensively used (Bradshaw, 1997; Xia and Cai, 2002). However, these methods are generally expensive, and sometimes are impossible to carry out, for the volume of contaminated materials in many cases is very large, especially those produced by mining and industrial production.

So far, information on rehabilitation cost is still lack. In general, however, the rehabilitation for degraded lands by common methods is quite expensive. For example, it is estimated that cleanup of hazardous wastes by conventional technologies is projected to cost at least $400 billion in the U.S. alone; and cleanup of the U.S. sites contaminated with heavy metals alone can cost $7.1 billion while mixtures of heavy metals and organics bear an additional $35.4 billion price tag (Salt *et al*., 1995). UNEP's estimates of the direct annual cost of all preventive and rehabilitative measures range between $10.0 billion and $22.4 billion, and the direct, on-site cost of failure to prevent desertification during the period 1978–1991 at between US $300 billion and $600 billion.

4 VEGETATIVE MEASURES FOR LAND RECLAMATION

If wastes cannot be effectively treated or removed, off-site pollution, usually coming from wind or water erosion or leachate, must be prevented first. An effective approach is the vegetation measure, one of the most practical and economical methods for pollution control and land reclamation. Table 1 shows that the long-term treatment measures for mined land restoration are almost all vegetation or tolerant species selection. However, revegetation to polluted sites is often difficult and slow due to the hostile growing conditions, which include the toxicity of heavy metals, organic compounds, strong acidity, etc.

Table 1 The major problems of mined land and their Immediate and long-term treatment measures for rehabilitation or reclamation*

Limiting factor	Problem	Immediate treatment method	Long-term treatment method
Heavy metal	Too high	Organic matter or tolerant	Tolerant or hyperaccumulator
Acidity	Too low	Lime	Tolerant species leaching
	Too high	Pyritic waste or organic	Weathering or tolerant species
Organic matter	Deficiency	Manure, sludge, garbage	Vegetation or tolerant species
Nutrient	N deficiency	N fertilizer	Legume or other N-fixer
	Deficiency of other elements	Appropriate fertilizer	Mineral weathering or tolerant species
Moisture	Too wet	Drainage	Tolerant species
	Too dry	Irrigation or cover	Tolerant species
Structure	Too compact	Rip or scarify	Vegetation
	Too loose	Press or cover with fine material	Vegetation or leaching
Organic pollutant	Too high	Covering or irrigation	Biodegradation
Salinity	Too high	Irrigation	Tolerant species
Stability	Erosion	Cover	Vegetation
	Slippage	Engineered measure (e.g. soil–keeping stone wall)	Vegetation or engineered measure
Texture	Too coarse	Organic matter or clayed soil	Natural weathering
	Too fine	Organic matter	Vegetation

*Cited from Bradshaw (1997), and Xia and Cai (2002); slightly modified

In fact, vegetation or revegetation for erosion control, pollution mitigation and land reclamation has been used since ancient times, usually based on past experience, observation, or empirical methods. For example, there was precise recordation in a Chinese ancient agricultural monograph named “Huai Nan Zi” and finished some 2000 years ago that it should adopt different tillage and culture measures to fertile soil, infertile land, high mountain, and low hill; the places that are not suitable to plant crops should be vegetated with trees or bamboos.

The resurgence of the practice in a more scientific and methodical manner began in the 1930s in Europe. Over the last two decades, the practice has become more popular due to heightened awareness of environmental issues as well as its availability, persistence, and cheapness (Bradshaw and Chadwick, 1980; Peng, 2003). The planting of grasses, legumes, shrubs and trees have been used for quite a few decades for land reclamation with varying degree of results. However, it is very important to select appropriate plant species according to the different soil and topography situations. *Eucalyptus* and *Acacia* are two types of usually used pioneer trees for land reclamation in tropical and subtropical regions like China, due to their some excellent characteristics, such as rapid growth and relatively strong resistance to harsh environments. But eucalyptus has lots of negative ecological effects. 1) It has a huge water absorbing capacity, which makes ground water level decrease distinctly. 2) Some kinds of eucalyptus, such as *E. exserta* and *E. urophylla*, have strong allelopathic effects, or have significant inhibitions on seedlings growth of many plants, thus making the undergrowth sparse or scarce (Zeng and Li, 1997). 3) Eucalyptus hardens the soil surface (Zhou, 1997a). *Acacia* like *A. mangium* or *A. aurifuliformis*, has also been utilized extensively in the tropics and subtropics for the identical goal. As a pioneer, it takes good effect for land reclamation and ecological restoration in the early stage, but its ecological effects decrease gradually about twelve years later. Another drawback often encountered with *A. mangium* is that its branches are rather brittle and prone to snap in the event of strong winds or typhoons (Hengchaovanich, 1999). In addition, *Acacia* cannot solve the erosion problem effectively because it initiates substantial stem-flow, possibly up to hundreds of litres a day during rain, resulting in local scouring (Hengchaovanich, 1999). Apart from this above, the dribbling water drops from leaves of broad-leaved trees generally have larger diameter than those from coniferous trees or from atmospheric precipitation; as a result, they increase the dash of waterdrops to the forest land, especially in the situation of low intensity of rainfall. Therefore, the canopy of broad-leaved forest without understory generally hampers the topsoil conservation on forestland (Zhou, 1997a,b). It is well-known that *Eucalyptus* and *Acacia* almost all formed pure artificial forests with little or even without understory, therefore they both are not very suitable for erosion control and land reclamation.

Obviously, plants used for land reclamation should be species with strong resistance, rapid growth, and good rehabilitation effect. Grasses and herbaceous legumes are generally the first choice because the majority of the two kinds of plants have strong vitality and infertility-enduring ability; furthermore the latter can fix nitrogen. However, compared with grasses, the resistance of legumes to adverse conditions is still limited, on the whole; they cannot survive in some very harsh habitats. As to grasses and other creepers, many of them have strong resistance and huge biomass and therefore some of them can be used effectively to reclaim degraded land. However, there are still many species of grasses that are not very suitable to be as land stabilization. For example, *Miscanthus* (e.g. *M. floridulus* and *M. sinensis*), and *Arundinell nepalensis* generally grow on rocky mountains, but their roots are neither so massive nor strongly penetrative. Another example, *Wedelia trilobata* can produce a very quick and good covering effect on a barren land surface, but it has an allelopathy to other plants, and furthermore it is easily to prone to become a weed. Therefore, it is natural and also imperative to look for a new plant species for the purpose of land reclamation that is cheap, effective, persistent, and easy to be cultivated and managed.

5 VETIVER TECHNIQUE FOR LAND RECLAMATION

Vetiver (*Vetiveria zizanioides*), a perennial grass, has been widely accepted as a better alternative for land reclamation in the past a twelve years due to it's following excellent features: 1) strong resistance to adverse conditions, which adapts it to various harsh weather and environmental conditions; 2) strong ability to remove pollutants, which makes it rehabilitate the polluted land rapidly; and 3) huge biomass, including shoots and roots, which makes it effectively ameliorate the degraded soil and cover barren land rapidly. Today, the application of vetiver technique is increasingly extensive.

5.1 The Earliest Application in China

In the spring of 1991, the first project was carried out in Xingning County, East Guangdong for the purpose of recovering a barren red soil slope called 'Red Skin Hill' (RSH) (Ao *et al*., 1993). This is the earliest application for land reclamation in China (Xia *et al*, 1996; Xia, 2001). Prior to conducting the Vetiver Eco-engineering, the slope had been tried to cover artificially four times, but none had success due to the harsh environmental conditions of RSH. One year after applying the vetiver technique, dense vetiver hedgerows were formed and erosion was controlled and furthermore tree saplings began to grow. 29 months after applying the technique, the content of most soil nutrients increased except for available P (Table 2). Moreover, soil moisture in the fruit-grass complex garden was increased by 4–42%, relative humidity increased by approximately 4–5%, and air temperature in summer decreased by 1–3 degrees centigrade, compared with the pure fruit grarden garden (Table 3). Nine years later, the little tree saplings planted in those days became forest, and the original 'Red Desert' finally became an 'oasis' (Xia, 2001). As a result the soil quality was enhanced and the farmland microclimate was ameliorated distinctly.

Table 2 Changes of soil properties 29 months after applying the Vetiver System on the Red Skin Hill (RSH)

No.	Sampling locality	Depth (cm)	Organic matter (%) Before*	After	Total N (%) Before	After	Hydrolytic N (mg/kg) Before	After	Available P (mg/kg) Before	After	Available K (mg/kg) Before	After
1	Top of RSH	0-20	1.10	1.07	0.039	0.063	37.5	57.4	0.8	0.6	13.3	19.1
2	Top of RSH	20-40	0.66	0.95	0.032	0.061	33.4	56.7	1.6	0.7	11.6	15.4
3	Top of RSH	40-60	0.81	0.74	0.038	0.059	36.3	48.2	1.1	0.6	8.34	15.4
4	Middle of RSH	0-20	0.41	0.49	0.018	0.028	37.9	49.5	1.0	0.3	17.8	26.5
5	Middle of RSH	20-40	0.36	0.38	0.016	0.027	36.2	45.8	0.9	0.3	23.2	22.0
6	Middle of RSH	40-60	0.37	0.57	0.020	0.025	38.1	46.1	0.9	0.2	17.8	24.9

* "Before" means before planting vetiver, and "After" means after planting vetiver for 29 months

Table 3 Comparison of microclimatic characteristics between two ecosystems of pure fruit garden (*Citrus grandis*) and fruit-grass complex garden(*C. grandis-V. zizanioides*)

Observing date (dd/mm/yy)	Ecosystem type	Soil surface temperature (_) Max.	Min.	Soil temperature in 20 cm deep (_) 8:00	14:00	17:00	Air temperature at 1.5 m high (_) 8:00	12:00	17:00	Relative humidity at 1.5 m high (%) 8:00	12:00	17:00
13/07/95	Pure fruit garden	44.5	25.0	27.8	32.0	30.6	26.7	34.5	26.6	87	62	93
	Fruit-grass complex garden	40.5	23.7	26.5	29.0	28.0	25.3	32.5	25.7	91	67	97
14/07/95	Pure fruit garden	43.3	23.3	27.8	29.1	27.5	25.8	31.4	24.3	94	69	99
	Fruit-grass complex garden	39.6	22.3	26.7	27.2	27.0	25.9	30.3	24.3	95	72	100

5.2 Recent Applications in China

5.2.1 Garbage landfill

Garbage landfill is the most disgusting place to urban people because it is extremely foul and poisonous; furthermore, it produces severe on-site pollution and results in extreme degradation of land. In 1997, the first reclamation project for landfill was conducted in the South China Institute of Botany, which was the first one in China and probably the first one in the world in this respect of VS application (Xia, 1998). Vetiver grew quite well in the landfill and even better than in other habitats. This is probably because it could absorb a lot of pollutants from landfill as nutrients. Two years later, the landfill, through vetiver's successful rehabilitation, became a very fertile nursery garden (Xia, 2001; Xia *et al.*, 2002).

Afterwards, a far bigger landfill, named Guangzhou Datianshan Garbage Landfill, was partially rehabilitated with vetiver in the year 2000–2001 by one company in Guangzhou. The aim of the project was stabilizing embankments of the landfill, preventing leachate from flowing out and abating the concentration of pollutants in leachate. At present, land reclamation for garbage landfill is conducted in some places of Guangdong, including Zhuhai, Zhongshan, Maoming, etc. The academic research and practice of Guangdong indicate that the VS is perhaps the most promising in application of garbage landfill.

5.2.2 Mined land

Apart from landfill, phytoremdiation and rehabilitation for mined land is another main battlefield of VS. It is well known that metalliferous mining activities produce a large quantity of waste materials, such as tailings and wastewater. They contain excessively high concentrations of heavy metals and therefore result in severe pollution problems and lots of land degradation.

The first mine conducting VS in Guangdong is the Lechang Pb/Zn mine located in the north of the province. In spring of 1999, the first experiment comparing growth and performance of vetiver and three other grasses, bahia (*Paspalum notatum*), bermuda (*Cynodon dactylon*), *Imperata cylindrica*, in the mine tailings was carried out. The result indicates that the height and biomass of vetiver are significantly greater than those of the other three grasses; moreover, the growth performance of vetiver is the best among the four species (Shu *et al.*, 2002). Thereafter, a pot experiment coming from Xia and Shu (2001) shows that vetiver has strong uptake ability to 2 heavy metals, Pb and Zn, stronger than bahia; but it is inferior to bahia with regard to uptake of Cu (Table 4). In addition, it can be seen from Table 5 that vetiver roots assume a bigger retention capacity to heavy metals than bahia roots, inferring that vetiver keeps relatively more amounts of heavy metals in its roots than bahia.

Table 4 Comparison of vetiver and bahia with regard to the ability to absorb heavy metals after they both grow in a Pb/Zn mine tailings for 130 days

Species	Pb		Zn		Cu	
	Shoot	Root	Shoot	Root	Shoot	Root
Vetiver	46.3a (7.1)*	309.5a (23.8)	105.1a (5.0)	380.4a (14.9)	6.9a (0.9)	25.2a (3.7)
Bahia	95.7b (7.6)	218.5b (26.3)	171.8b (23.4)	331.8b (21.2)	18.1b (1.8)	64.2b (9.0)

*Means (with (SD), n=4) followed by different letters in the same column indicate a significant difference at P=0.01 according to t-test.

Apart from the Lechang Pb/Zn mine, VS has been used to successfully rehabilitate Maoming oil shale mine tailings and Daboshan iron mine of Guangdong (Xia *et al.*, 2000, Lin *et al.*, 2003). Besides phytoremediation and revegetation, vetiver has also been utilized to treat leachate draining from mine lands (Xia *et al.*, 2003; Shu, 2003; Shu and Xia, 2003). The experiments and applications reconfirm that vetiver is a potential plant for wastewater and leachate purification, especially for removal of heavy metals or organic compounds from wastewater.

5.2.3 Quarry

Quarries and rocky hills are always "the hardest bone" to eco-restoration. In the last four years, VS has began to be applied in the field and won success one after another. The earliest vetiver eco-engineering for quarry revegetation began in 2000. At that time, 2 quarries, Shen'ou and Huada, in Shenzhen were concurrently restored by 2 private companies (Xia, 2001). In the last two years, a newly-typed vetiver technique that can make rock headwalls become green quickly was invented jointly by South China Institute of Botany and Guangzhou Eco Environmental Science and Technology Co. Ltd. The technique has been accepted and heard as a patent by China National Knowledge Property Bureau (the application number is 03113672.9). At present, the new technique has been applied in Zhuhai and Guangzhou for rapid revegetation of quarries, especially for headwalls; its effects are quite remarkable (Zhang and Xia, 2003). The main reasons why the new vetiver technique can revegetate headwalls quickly is due to the following aspects. 1) Deep, massive roots can penetrate weathered rocks or grow deeply down along stone wall; thus vetiver can provide other plants with an effective protection barrier. 2) The extremely strong tolerance of vetiver to drought makes it grow normally in such dry environment like quarries. 3) Some engineering measures offer a basic framework for vetiver and other plants to grow on the headwall.

5.3 Application of VS around the Globe

As early as the middle of 1990s, vetiver was used to successfully rehabilitate acid sulfate soils without any fertilizer, due to vetiver's extremely strong tolerance to soil Al (68% saturation) and acidity (pH3.8) (Truong and Baker, 1996). Thereafter, vetiver was also used to rehabilitate various kinds of contaminated mine lands, including coal, gold, and bentonite mines (Truong, 1998; Bevan and Truong, 2002). For instance, in an attempt to rehabilitate an old coal mine tailings dam with high sodicity and extremely low N and P contents, five tolerant species were tested: vetiver, marine couch (*Sporobolus virginicus*), reed (*Phragmites australis*), cumbungi (*Typha domingensis*), and *Sarcocornia* sp. As a result, complete mortality was recorded after 210 days for all species except vetiver and marine couch. Vetiver survival was significantly increased by mulching rather than fertilizer application; and furthermore mulching and fertilizers together increased growth of vetiver by 20 t hm^{-2}, which was almost 10 times higher than that of marine couch (Truong, 1998).

An experiment conducted in Thailand indicates that vetiver can absorb pesticides (Pinthong *et al.*, 1998). Thereby, vetiver hedgerows against soil erosion not only save the fertility of cultivable land but can function as a living filter for capturing unwanted foreign chemicals or contaminants before they reach non-polluted soil and downstream areas. In fact, the capturing function includes two aspects, uptake of roots and holdup of hedgerows. For example, Truong *et al.*(2002) found that vetiver hedges trap 86% of total endosulfan and 67% of chlorpyrifos in the sediment of runoff water in the first year of growth alone, and trap 48% of diuron, 73% of N, 52% of P and 55% of S in the second year. The above findings indicate that vetiver has the potential to offer farmers an additional simple management practice which will reduce soil movement off-site while reducing the risk of off-site pollution by agrochemicals and nutrients.

Due to the miraculous effects in erosion control, land reclamation, pollution mitigation, and other aspects, the Vetiver System has become a key or an effective measure of sustainable development in some regions of the world (Xia *et al.*, 1998; Booth and Adinata, 2003).

6 THE FUTURE PERSPECTIVE OF VS FOR LAND RELCAMATION IN CHINA

As narrated above, the whole globe is now under unprecedented land degradation and environmental pollution. China, owing to rapid population increment and economic development, has become one of the severest nations with special reference to land degradation and environmental pollution.

In China, there has is a large quantity of degraded land. For example, the area of soil erosion is about3.56_10^6 km^2, accounting for 37% of the country's total land area. There is 80% of the Loess Plateau region suffers from soil erosion. The area of desert and desertification is up to 1.49_10^6 km^2, accounting for 11.5% of the total land area. The degraded areas of China's farmland, grassland, forestland, and freshwater surface are 28_10^6, 132_10^6, 31.2_10^6 , and 0.245_10^6 hm^2, respectively, accounting for 20–30% or so of the respective total areas (Ren and Peng, 2001). In South China only, there are approximately 5–6 million ha of lands losing their productivity per year.

As early as the 1980s, there were over 8000 national and 230 000 private mining companies in China. Although parts of illegal private companies were closed in recent years, environmental problems resulted from mining are still quite conspicuous, which produce 600 million tons of waste materials and destroy 25 000 hm^2 of land per year (Qin *et al.*, 2002). Therefore, it is urgent to control the pollution and reclaim the polluted land resulting from the mining industry.

In China, many cities, including Guangzhou, have formed a situation that garbage or landfill encloses city. Thereby, urban garbage and its effluent are also problem remains to be solved.

There are at least 13,000 quarries in Guangdong alone waiting for revegetation. At present, the Guangdong Provincial government has made the decision to close and revegetate large parts of the quarries.

The past and present experiences have clearly indicated that the Vetiver System is quite appropriate for solving the above problems occurring in South China. Therefore, the VS exhibits a huge application perspective in the southern regions of China.

7 CONCLUSION

Land degradation is becoming increasingly severe and extensive in the world. It and soil erosion usually cause: 1) land and water pollution; 2) poverty and disease; and 3) social instability and even chaos. The traditional reclamation techniques are expensive and lack of ecological benefits. The newly ecological reclamation technique for degraded land includes three aspects: phyto-stablization of degraded land to reduce wind and water erosion; phyto-amelioration of soil to increase soil organic matter and nutrients; and revegetation of degraded land to vegetatively cover barren land. If the reclaimed land was mined or contaminated land, two more aspects should be included: utilization of constructed wetlands to purify heavy metals or other contaminants in wastewater and phytoextraction of heavy metals or other contaminants from soils. Vetiver grass, due to its unique characteristics, such as higher biomass, fast growth, strong root system, higher metal tolerance and uptake ability, etc., has been documented to play an important role in reclamation of degraded land and even realization of sustainable development. What's more, this technique is showing a quite promising future around the globe, especially in South China.

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A Brief Introduction to the First Author

Dr. Hanping Xia (H.P. Xia), a restoration ecologist, is working at the South China Institute of Botany, Chinese Academy of Sciences. Since 1991, he has been engaged in a wide range of R&D on the Vetiver System for the purpose of soil erosion control and polluted environment mitigation, including highway slope stabilization, land reclamation and re-greening, quarry rehabilitation, mine and landfill phytoremediation, wastewater purification, etc. He creatively initiated “the Vetiver Eco-engineering” from his working experience of many years. So far he has one monograph and over 30 academic papers in this aspect published.