Revegetation of Quarry Using a Complex Vetiver Eco-engineering Technique

Ping Zhang [1] and Hanping Xia [2]

[1]Guangzhou Eco Environment Science and Technology Co. Ltd., Guangzhou 510400, China

[2] South China Institute of Botany, Chinese Academy of Sciences, Guangzhou 510650, China

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Abstract: Stone quarrying activities always result in a severe damage to the environment, vegetation and landscape. Revegetation for quarries, especially for quarried faces, however, is always a very thorny thing, and even a world-class difficult problem, which is still resolved unsuccessfully so far. The main reasons resulting in extreme difficulty for revegetation of quarried faces are because: 1) the surface is very glossy, and there is almost no any soil or loose substrate on it; 2) they are all quite steep, usually up to 70–80°, and even perpendicular to the ground; and 3) most of them are quite high, often up to dozens of meters and even up to over 100 m and therefore, are extremely difficult to carry out construction. Since 1999, the vetiver technique has been used to restore quarries in China. Through years of research and exploration, a complex yet innovative vetiver technique eventually emerged. Combining the traditional vetiver technique with special cement concrete troughs and construction methods, the new technique successfully solves the problem of quarried face revegetation. Like the traditional vetiver technique, the new one aims to establish a permanent, stable ecological system on the quarried face taking vetiver’s excellent slope stabilizing property and collaborating with the excellent ecological characteristics of other strongly adaptive species. Its core mechanisms are: 1) special troughs made from armored concrete and particular construction technique; 2) hedgerows formed mainly by vetiver and established on the troughs; 3) a rationally spatial configuration composed of trees, shrubs, grasses and lianas, and an effective nutrient-recycling system coming from the configuration; and 4) special moisture- and nutrient- preserving measures. The new technique has been testified to be effective, rapid, persistent and relatively cheap. It costs only 20–50% of the present engineering techniques. As such, it is worth disseminating and applying in South China and even around the tropical and subtropical regions of the globe. Currently, the technique has been accepted and heard as a patent by the China National Intellectual Property Bureau.

Key words: quarry, headwall, complex vetiver eco-engineering technique, revegetation

Contact: Hanping Xia < xiahanp@scib.ac.cn> or Ping Zhang <zhpzhyl@mail.china.com>

1 A BRIEF INTRODUCTION TO VETIVER AND THE VETIVER

TECHNIQUE

Vetiver grass (*Vetiveria zizanioides* (L.) Nash) is a perennial of grass family. Its specific name "zizanioides" was given first by the great Swedish taxonomist Carolus Linnaeus in 1771. It means "by the riverside", reflecting that the species is commonly found along waterways (National Research Council, 1993). Vetiver grows up to 1.5–2.5 m high, its crown stays in clumps and its stems are erect, strong and hard; therefore the plant can easily form hedgerows when it is planted densely along the contour. Vetiver has deep, massive and rapid-growing roots, which can grows down to 2–3 m in one year and at most, down to 5 m or so 2–3 years later. Moreover, the roots have great tensile strength, about 75 Mpa at 0.7–0.8 mm root diameter. This is approximately equivalent to 1/6 of the ultimate tensile strength of mild steel (Hengchaovanich, 1998), which makes it "anchor" soil and keep soil stable even under the condition of heavy downpours or floods.

Vetiver can adapt itself to various soil conditions, irrespective of fertility, acidity, compactness, and toxicity of heavy metals or organic pollutants. It has been testified to thrive in landfills, quarries, and industrial polluted areas in China (Xia *et al.*, 1998; Xia, 2001). It can resist long-term dry or water-logged or flooding adverse conditions and can grow permanently under the condition of partial submergence and resist at least 100-day complete submergence.

The core of the Vetiver Eco-engineering Technique is just utilizing its prominent physio-ecological features and combining it with some local plant species, including trees, shrubs, grasses and vines with characteristics of strong resistance and widespread adaptation, supported by simple engineering structures where necessary and then is applied to erosion control, polluted environment mitigation, and degraded ecosystem restoration (Xia *et al.*, 1998; 1999). It has been well documented that the Vetiver Eco-engineering Technique is quite successful in these aspects mentioned above. It not only rapidly covers barren lands and produces good afforestation efficiency, but also beautifies the environment. So far, there are over 100 countries and regions around the globe that apply the Vetiver Eco-engineering successfully for the purpose of ecological restoration and environmental amelioration.

2 OUTLINE OF QUARRIES IN GUANGDONG, CHINA

2.1 Characteristics of Quarries

Stone quarrying exists in many countries or regions in the world including, of course, China. The ecological effects of stone extraction are far-reaching and extreme, resulting frequently in the complete removal of the overlying ecosystem. According to the status of various quarries, particularly their geological structure and exterior features, a quarry is generally composed of the following four parts. 1) The scree piled by stripped topsoil and discarded stones coming from stone quarrying and processing. The scree dump or pile is usually loose stony structure and especially its slopes are so loose that they become muddy or are washed away by rainwater when it rains. In general, however, the scree slopes are gentle and therefore are easily controlled or stabilized. Furthermore, plants take roots easily on the slopes; thereby they are covered quite easily by vegetation. 2) The hard slope left after quarrying. Generally speaking, it is steeper than scree dump and usually has hard block structure, but it is not so steep as a quarried face. Its top layer is almost always covered by surface soil; some hard slopes still have small access roads used during the period of quarrying. Thereby they are also rehabilitated easily as long as some measures are taken to ensure plants can gain an early foothold. 3) The platform left after rocks are excavated away. The platform is usually the hardest stones, and has almost no loose substrate, but it is not very difficult to be revegetated. The simplest method is filling a layer of soil on it and then raising plants in the soil. 4) The rock quarried face. The most prominent properties of quarried faces are their surfaces: shiny with no substrate; furthermore most of them are at over 80^0 or even up to 90^0 angle to the ground; therefore making them wall-like or cliff-like. In other words, a man-made escarpment.

2.2 Common Methods for Revegetation of Quarried Faces

In the past, quarries were often abandoned once they ceased to be excavated. Subsequently, natural colonization of plants gradually took place. However, since the process of natural colonization is extremely slow and moreover at some places, such as quarried faces and large rock outcrops are not covered naturally by plants, some artificial restoration methods therefore stand out. At present, the familiar vegetation covering methods for quarries mainly contain (Cullen *et al.*, 1998; Luo and Zheng, 2001; Chen, 2002): 1) step building method; 2) method of bird's nest formed from blast; 3) method of platform formed from blast; and 4) substrate- and seeds- spraying (hydromulching) method, etc. The step building method needs lots of construction materials and a wider and larger surface on the bottom of the quarried face. Steps are built on the surface from the bottom to the top of the quarried face. Then afforestation is carried out on the steps after they are filled with soil (Luo and Zheng, 2001). Obviously, this method is confined by the quarry condition and thereby, is difficult to be implemented in many quarries. The core issue of both bird's nest and platform methods is the blast impact . Apart from difficulty and danger, the blast itself, in fact, is a continuation of the quarrying *per se* and therefore large masses of fragmental stones need to be carted away. Furthermore, revegetation is conducted on the platforms or in the holes of bird's nests and therefore large quantity of soils need to be backfilled. On the whole, the principal engineering parts of the above three methods are mainly earth and stone engineering and the costs therefore are all very high, 4–8 times higher than the common bio-engineering. As to the hydromulching method, the first step is installing metal grids and then spraying substrate (e.g. slurry with mulch) and seeds to cover the whole quarried face. The cost for the spraying method is only 1.5–3 times as high as the common bio-engineering and furthermore it can produce quite good revegetation results in the first 1–3 years after spraying. Therefore, this method is very welcome for revegetation of quarries in China today. However, 2–3 years later, the substrate begins to fall off and the formed vegetation begins to degrade. The main reasons are due to the following two aspects. First, the sprayed substrate thickness is very limited and therefore, cannot continue to sustain plants to grow after nutrients in the substrate are used up by plants. Second, the tackification of substrate itself to quarried face will become poorer and poorer as time passes; it falls off from the quarried face under the scour of rainwater in time. Therefore, the four existing methods for quarried faces afforestation are all quite constrained. In addition to the routine methods above-mentioned, some quarries are restored for a certain purpose, such as industrial heritage tourism (Edwards and Llurdes, 1996), landfill sites (Lyle *et al.*, 1996) and habitats for wildlife (Cullen *et al.*, 1998).

2.3 An Outline of Quarries in Guangdong Province, China

Driven by economic necessities, especially the construction of real estates and infrastructures, stone quarrying from rocky mountains is now an indispensable and very common production activity in China, particularly in Guangdong. As a result, Guangdong has become one of the most intensive quarry-exploiting provinces in China and has created a conflict between economic development and environmental protection. At present, it is estimated that there are approximately 13,000 quarries in Guangdong and over 600 in Shenzhen City alone (Chen, 2002). Some quarries are very near downtown sites, thus causing an adverse impact on the city's landscape. For instance, Shenou Quarry is located in the near suburb of Shenzhen City, only 1 km from the city. Even pedestrians on the street can see the cracked mountain and therefore it needs to be vegetated urgently. Due to these reasons, Guangdong Provincial Government and her junior governments are very determined to repair and revegetate quarries. However, there are no ideal methods, so far, to effectively restore quarries, especially quarried faces; consequently quarry revegetation work has not processed very smoothly until recently.

3 THE GENERAL SITUATION OF THE VETIVER ECO-ENGINEERING TECHNIQUE AS APPLIED TO QUARRIES IN THE PAST

Since 1991, the research and dissemination on vetiver has been conducted in South China as well as in Guangdong. Through well over 10 years of endeavor, some research works have delivered creative results and the demonstration projects can be found in various areas of Guangdong for the purposes of erosion control, pollution mitigation and environmental protection. The majority of projects were successful and vetiver is therefore testified to be one of the best species for water and soil conservation and environmental protection in the southern region of China. Since 1999, we have tried the Vetiver Eco-engineering Technique in quarries, applying it successively in provinces of Guizhou, Hunan, Guangdong (including Dongguan, Shenzhen, and Zhuhai). Now taking the Shenou Quarry of Shenzhen as an example, let's see how the Vetiver Technique was applied to that quarry, what have been achieved and what problems still exist.

Shenzhen, nearby Hong Kong, is a modern and beautiful neighbor City. During the past 20 years, because of mammoth infrastructure construction acitivities which needed a multitude of construction materials, more than 600 quarries were set up in the circumference of the city making it virtually 'quarry-ringed', a striking contrast to its beautiful "Garden City" moniker (Liu and Qi, 2001; Cai *et al.*, 2000; Chen, 2002). Owing to the above reasons, the Shenzhen Municipal Government was conscious of the problem's severity and made a decision to artificially cover these quarries. The Shenou Quarry fortunately became one of the earliest batches that were artificially revegetated. The soil in the quarry red laterite developed from the weathering of granite; it is loose, infertile and prone to slippage; furthermore the steepest parts are nearly 80^0. Therefore it is quite difficult to revegetate. It started to be covered with plants in April 2000. The main measures are planting vetiver grass along the contour with a spacing of 2 m on the slope and then planting bahia grass (*Paspalum notatum*), wall creeper (*Parthenocissus* sp.), *Acacia* spp., etc. Along the side slopes piled by screes, sand bags were first put along the contour to stabilize the slope surface and then vetiver hedgerows were planted above the sand bags. Regarding the stony, steeper slopes formed from stone quarrying, the first step was to dig holes with the diameter of 20 cm and depth of 20 cm with pneumatic drills; the second step was to fill soil into the holes and then to plant vetiver and other plants. The restoration efficiency on the scree-piled slopes was quite successful due to reasonable design and correct construction; the survival rate of plants was high. In less than one year, the original scree-piled slope became a "green hill" with luxuriant trees and dense grasses. However the revegetation effects of the stony steep slopes were not so ideal due to too the big distance between holes and small volume of each hole. Obviously, the cost would greatly increase accordingly if, the volume of each hole or density of holes were increased. Furthermore, this measure would be equivalent to quarring the stony mountain again and would produce piles of fragmental stones garbage. Therefore, it is not an ideal approach to hole the headwall for quarried face revegetation.

4 THE INNOVATIVE VETIVER ECO-ENGINEERING TECHNIQUE

4.1 The New Technique's Characteristics

Through several years of research and practice, an innovative complex eco-engineering technique was eventually born recently. Its guiding ideology is to establish permanent, firm, and multi-layer (trees, shrubs, grasses, and vines) ecological restoration system utilizing the Vetiver Eco-engineering assisted with engineering structures. The features of the creative technique are as follows.

- Cement troughs installed on the quarried face and formed at an angle with the quarried face;
- Soil with special nutrition liquid and water-preserving reagent filled in the troughs;
- High quality vetiver seedlings that can produce massive roots and form strong soil-stabilizing ability;
- Local ecological plants with strong vitality and rapid growth;
- Maintenance measures assuring plants survival

In summary, the core mechanisms of the new technique are: 1) special cement-board making and level-trough installing techniques; 2) organic disposition of plant community including trees, shrubs, grasses, lianas as well as vetiver for the purpose of establishing a solid ecological system with effective nutrients cycle; and 3) special moisture-preserving techniques and measures. The following is one detailed example of the new technique applying to quarry restoration, from which it can be seen the effectiveness of the new vetiver technique.

4.2 A Representative Example of Using the New Technique to Vegetate Quarry

Zhuhai, near Macao, is a "Garden City" of Guangdong This city has been paying great attention to ecological and environmental construction since it became the Special Economic Zone of China in 1980; therefore the number of “Earth Scars” like quarries are few in Zhuhai. Though this is the case, the Zhuhai Municipal Government still attaches importance to quarry revegetation. For instance, Baitengshan Quarry is 20 km away from downtown Zhuhai, but the Municipal Government decided to revegetate it. The pertinent departments in Zhuhai City screened out the New Vetiver Eco-engineering Technique from nearly 10 candidate schemes after making lots of reviews and discussions to them. As a leader coming from Zhuhai Municipal Land Bureau said, the Vetiver Complex Ecological Technique not only is creative and novel, but also tallies with the major premise that Zhuhai plans to build itself into an “Ecological Homeland”.

Baitengshan Quarry is a large-scale quarry; the quarried face alone is nearly 60000 m^2, made up of 3 small-sized, nearby quarries and 8 large-sized quarried face. The slopes of these quarried faces almost all exceed 80^0 and some are perpendicular to the ground; moreover the average height of the headwalls are well over 50 m and the highest point approaches 90 m. It is obvious, therefore, that it is extremely difficult to ecologically vegetate. The project began to be constructed in May 2002. After only several months of construction and maintenance, the restoration benefits start to show up. The concrete design, construction and benefits are introduced as follows.

4.2.1 Physical engineering measures

In order to prevent erosion and collapse and to guarantee the restoration to ensure permanent ecological benefits, the first step was to dredge the logged water on confluences of the quarry and to tidy up an operation platform and then to cart away the cleaned fragmental stones. After that, scaffolds were put up along the quarried face to facilitate construction.

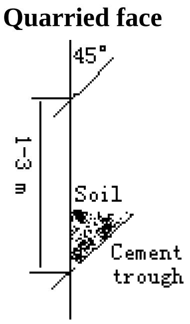

Fig.1: Sketch of cement trough established on the quarried face

Prior to construction at the quarry, precast slabs with reinforcing steel bars were made first on the spot. Each precast slab, approximately 40–50 cm of side length and 5 cm of thickness, was put into 2 screw-threaded steel bars with the diameter of 12 mm and 2 round steel bars with the diameter of 6.5 mm. One end of each screw-threaded steel bar protruded 15 cm or so. Then holes are punched with a pneumatic drill along the contour of the quarried face. The orientation of all holes extending into the quarried face assumes an angle of around 45°. The spacing between 2 rows of holes is generally about 1–3 m, which is determined mainly in terms of the requisite spacing for plants’ normal growth and development and of the requirement of effective erosion control. The distance between 2 neighboring holes is identical with that between 2 neighboring screw-threaded steel bars in the precast slabs. Thus, the precast slabs, one close tightly to another, could be installed on the face easily. The method used was putting the screw-thread steel bars into holes on the face, and then stick these slabs on it with concrete. Therefore it is very important to first make highly quality precast slabs with reinforcing steel bars. Thus the basic framework is put up, which is rows of V-typed troughs, arraying along the contour at an angle of about 45° with the headwall surface (Fig. 1). The planting troughs must be firmly installed to ensure the cement slabs do not fall off in 10 years. The perpendicular section area of troughs is 0.06 m^2 or so and their top width is about 0.35 m, therefore grasses and lianas would have no problem getting planted in them. Apart from being installed along the contour on the perpendicular face surface, precast slabs were also fixed in the sunken places or special topographies to form larger spaces in which trees and shrubs could be planted. After finishing installment of concrete troughs, soil was then put into the troughs. Tackifying reagents, water-preserving reagents and special nutrition liquids were put into the filled soil to ensure soil would adhere to the face and to ensure the established plants get sufficient water and nutrients simultaneously.

Besides the above engineering aspects, some ancillary measures such as discharge systems, were also built according to work requirements. Analogically speaking, these projects constructed horizontal and longitudinal canals corresponding to the hill's slope and then to plant vetiver hedgerows along two sides of the canals to spread runoff and to protect the canal banks. There is at least one discharge system for each quarried face.

4.2.2 Bio-engineering measures

The core aspect of bio-engineering measures is selecting excellent plant species. The plants must have strong resistance to drought, infertility and their roots must adhere to quarried faces or penetrate into stone crevices. The chief principles are: 1) Plant vetiver, which has strong resistance to adverse conditions and good moisture conservation efficiency as a pioneer to solve the soil erosion and landslide problem, to provide other plants with parts of nutrients at the same time through its strong holdup function to intercept deadwood and rotten leaves above vetiver hedgerows. No any other plant can replace vetiver with these excellent features. 2) Select trees and shrubs with the characteristics of ornamental value and strong resistance, some defoliate and some evergreen, to be used as the main species. 3) Screen some lianas and leguminous herbs to cover soil and quarried face. It aims to form a stable soil nutrition system through the mutual effects of vetiver, legumes and defoliating species. The detailed biological measures are as follows.

1) Establishment of vetiver hedgerows. Vetiver was planted in the troughs of precast slabs to form level green hedgerows with the spacing of 2 m or so. This is utilizing the unique bio- and eco- features of vetiver to form a permanent "bio-dam" that can effectively holdup runoff, sand, litter, and prevent landslide. Thus the layer upon layer holdup from underground to earth's surface firmly fix soil and water, ameliorate the environmental conditions and eventually offer a relatively good habitat to the growth of other species.

2) Establishment of surface covering vegetation. After finishing the planting of vetiver, other covering plants and creepers with strong vitality, such as *Paspalum notatum*, *Wedelia trilobata*, *Parthenocissus* spp., *Ipomaea pes-capre*, were planted. *P. notatum* and little leguminous creepers were covered the surface of troughs; *Wedelia trilobata* and *I. pes-capre* drooped to cover headwalls; and *Parthenocissus* spp. crept up to cover headwalls. Since the row spacing between troughs is controlled at 2 m or so, the covering method can cover the whole headwall and land surface rapidly and at the same time produce the permanent green landscape all year round.

3) Establishment of tridimensional virescent system. As above mentioned, relatively larger spaces can be formed in sunken places or special landforms after precast slabs are put up; thus such rapidly-growing strongly-resistant trees and shrubs such as *Acacia* spp., *Eucalyptus* spp., *Hibiscus rosa-sinensis*, *Murraya paniculata*, *Bauhinia* spp. can be planted. Apart from these, small shrubs were also planted in troughs at a distance of about 2 m and trees were planted at the foot of the quarried face at the spacing of 1–3 m.

After the above bio-engineering measure was finished, an eco-system that has solid afforestation efficiency, plant populations mutual support and nutrients self-sustaining functions was soon formed.

4.2.3 Other aspects worthy of attention

Generally speaking, soil slopes and stone blocks at a quarry are loose and easily produce landslide, collapse and mud and rock flow, especially construction on the quarried face which is high above the ground. Thereby it is necessary to equip safety facilities and intensify the safety consciousness to guarantee construction safety.

It is also important to establish a quality-checking system to check each work procedure and assign persons specifically in charge of supervising each sub-project to ensure construction quality.

In general, the total time limit for a project of 50 000 m^2 or so is 150–180 days, among them 60–90 days is for construction and the left 90 days is for maintenance. In order to put the design into effect, a detailed plan, including the monthly, and weekly plan and daily working content must be drawn up.

Generally, the price for quarry revegetation is quoted on the basis of the cost per square meter. Due to the difference of various quarry types, construction environments and measures, the prices for each quarry is different. According to the new technique, the quoted price for a quarry varies between Renminbi 30–80 Yuan/m^2 (equivalent to US$4–10/$m^2$), 50–80% less than those of “hard” engineering projects. The exact price is determined according to the scheme and construction task relevant to a certain quarry.

4.2.4 Restoration benefits

After establishment of vegetation, the survival rates of vetiver grass, other herbaceous plants and xylophyta are generally up to over 95%, 90–95% and 80–85%, respectively, through elaborate maintenance at the beginning. Four months later, vetiver begins to form green hedgrows; six months later, herbaceous plants begin to cover the land surface; one year later, trees and shrubs grow up to 0.8–1.5 m and become quite luxuriant. At this time, barren, perpendicular headwalls are also covered at 60–80% of their surface area by vegetation and the erosion and landslide incidence of whole quarry is almost controlled. Furthermore, vetiver hedgerows no longer need any maintenance with the exception of occasional pruning. They guarantee the foothold and growth conditions of other plants. In the aftemath, plants near the quarry gradually intrude and colonize here and therefore the “earth scar” is cured and the barren mountain becomes an “oasis”. Finally, a self-persistent ecosystem is gradually formed.

4.3 A New Project that just proceeded

The new project lied in the Litchi Hill, Guangzhou Science Town. This is the only quarry in the town, severely influencing the natural landscape of the whole town. Therefore, there is an urgent need for revegetation. It is, however, extremely difficult to cover the quarry with artificial measures; this is because: 1) the quarried face is up to 90 m at the highest points and furthermore the whole face is very steep, almost perpendicular to the ground; and 2) there is no platform at the foot of the headwall; only a pond of water over 30 m deep! Strictly speaking, it is a deep pit formed by excavation of stone. At present, it is full of water and therefore makes the construction extremely difficult, almost the limit for revegetation of a quarry. The authors, especially Mr. Zhang, however, always like to challenges it presents; they took on the project and are constructing it using the innovative vetiver technique. According to the agreement, the project must be finished before the middle of October; thereby a completely new appearance will be expected to emerge at the time of ICV-3. Let’s wait and visit it in the course of ICV-3.

5 CONCLUSION

During the past two decades, the demand for stone materials has increased rapidly with the vigorous development of China’s economic reconstruction, as a result the number of quarrying and mining fields proliferate (Wu *et al.*, 1997). Due to excessive exploitation and relatively laggard restoration, the ecological landscape has been severely destroyed by quarrying and mining activities, especially the former (Liu and Qi, 2001). “City scars” or “Earth scars” are eyesores to be seen everywhere.

Revegetation of quarries was implemented in the past, but it concentrated mainly on platforms and slopes of scree and soil; no effective way was found to drape quarried face with greenery. Sometimes, the bird’s nest and other traditional methods were used to revegetate quarried face, but they are awful because they are extremely expensive or temporary in nature. In recent years, the hydromulching method has been carried out more and more, but the practical application benefits are not so ideal either. The chief reasons are that the sprayed substrate cannot sustain the nutrients supply to plants for long and furthermore, the substrate and grasses grown on it will fall off 2–3 years later.

Through several years of exploration, we eventually invented the Vetiver Complex Eco-engineering Technique, which takes the precast troughs as the key, takes vetiver hedgerow as tie, takes nutrition additives as the core and takes the organic arrangement of trees, shrubs, grasses and vines to establish a natural firm solid complex ecosystem as the goal. The practice has verified that the newly typed vetiver technique can realize permanent greenery for revegetation of quarries. The technique thoroughly resolves the long-term thorny social problem that seedlings are planted year by year but very few survive, as a result manpower and money are wasted and quarries cannot be vegetated. In addition, the new technique costs less 55–85% than the traditional engineering techniques. Due to the creativity and novelty, the new technique deserves to be conferred a patent and to be disseminated throughout the tropical and subtropical regions as well as South China. In the end of 2002, we put forward to a patent application for the new technique; as a result, it was accepted and heard as a patent by China National Intellectual Property Bureau (the application number is 03113672.9) in January 2003. This is the first patent application on vetiver in China.

At present, there are at least 13,000 quarries in Guangdong alone waiting for revegetation; therefore the new technique will have a broad application prospect in the province. In fact, it is being or will be applied soon in Guangzhou, Dongguan, Shenzhen, Huizhou of Guangdong and in Hong Kong.

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A Brief Introduction to the First Author

Mr. Zhang Ping, The president of Guangzhou Eco Environment Science and Technology Co. Ltd., has begun to embark on running the vetiver industry since 1999. In 2001, he founded the company. Since then, he has conducted vetiver projects. So far, every project he conducted has won success. Especially in the aspect of quarry revegetation, he has taken over charge of several large-sized projects, producing a big social influence. Through years of endeavor, he and Dr. Xia Hanping jointly invented a new vetiver technique for headwall revegetation. At present, the technique has accepted and heard as a patent by China National Intellectual Property Bureau.