Vetiver System for Slope Stabilization

Reviewer

Diti Hengchaovanich
APT Consult Co., Ltd, Bangkok, Thailand

Abstract: Vetiver, a plant promoted to help conserve soil and water for farmland by the World Bank in the 1980's, has evolved strongly in the late 1990's to become an important soil bioengineering tool ever since the late 1990's. The benchmark experiments on vetiver root strength in 1996 have played a role toward its wider acceptance. New grounds or harder grounds recently broken into by vetiver include cost-effective stabilization of karst stony slopes in high altitude region and the revegetation of barren quarried face by an innovative patented method by vetiver combined with other ancillary works were conceived and implemented in China. River bank stabilization has been successfully carried out on a major scale in fresh and brackish water environment in the Mekong Delta in Vietnam subjected to waves caused by motorised boat traffic, as well as on the Hanjiang River (a Yangzi River tributary) in China. Trials on the use of vetiver for beach protection were successfully achieved in Senegal and slope stabilization of 100 km length of 18 coastal polders by vetiver was attempted in Bangladesh with varying success. Flume tests were conducted in Australia to throw light on hydraulic characteristics of vetiver in deep flow that will aid in the design of channel stabilization and flood erosion control.

Key words: slope stabilization, roots, tensile strength, karst region, quarried face revegetation, river bank stabilization, polder, hydraulic characteristics.

Email contact: Diti Hengchaovanich <diti@samart.co.th>

1 INTRODUCTION

From time immemorial in India, vetiver, locally known as *khus*, has been used for various purposes: for scents, medicine and as a useful soil binder. However, it was mostly planted around rice paddies, along rivers, and beside canals and ponds to strengthen the banks and keep the land from collapsing into the water (NRC, 1993). This indigenous knowledge was taken along when Indians migrated overseas and usage resumed in new localities around the globe. Thus one reads of vetiver usage for slope protection and reinforcement of embankments and cuttings outside of farmlands since the early 1900's in the West Indies, South Africa (NRC, 1993), Brazil (Grimshaw, 1994) and Fiji (Truong and Gawander, 1996), etc. In 1931, it was on record that vetiver was grown at Serdang (near Kuala Lumpur), Malaysia, where " it is used for holding up steep banks. It is well known to be good for this purpose" (World Bank, 1995). These applications of vetiver, however, were based on past experiences that showed them to be effective but without any quantitative engineering data to back them up.

Over the last two decades or so, due to heightened awareness of environmental issues, engineers have begun to look for solutions to erosion and stability problems that would incorporate vegetative components, wholly or partially, to make end products less 'hard' or harsh and environmentally more friendly; in other words, 'greener'. To lend technical credence to its introduction, researches have been conducted on the roles of vegetation in relation to slope stability, in particular on tree roots which are the main factor contributing to slope stabilization (Greenway, 1978; Coppin and Richards, 1990; Gray, 1994; Wu, 1995). Over the same period, the World Bank had been actively promoting vetiver as a grass that would help conserve soil (erosion control) and water (runoff retention/more infiltration) in the farmlands (Greenfield, 1996). Taking cue from the agricultural sector and exploring the possibility of introducing vetiver as a new vegetative candidate for bioengineering slope stabilization work (based on empirical precedent successes of the Indian people), this author and his colleague embarked on a study of the tensile root strength properties of vetiver in its resistance to shallow mass stability and surficial erosion (Hengchaovanich and Nilaweera, 1996). It emerged that the tensile strength of vetiver roots is as strong as, or even stronger, that of many hardwoods. In fact, because of its long (2-3.5 m) and massive root networks which are also very fast-growing (functionable in only 4-6 months), it is better than many types of trees which normally take 2-3 years to be effective.

Amplifying this in Technical Bulletin No. 1998/2 (Hengchaovanich, 1998) and followed up by a number of presentations in several countires, that expounded the efficacy of vetiver for slope stabilization, the enginering sector has begun to take notice of vetiver (Grimshaw, 2003). This resulted in its applications having taken off significantly on highways and railways in many countries, in particular Thailand, China, South America, Australia, the Philippines and Madagascar (Hengchaovanich and Freudenberger, 2003), to name just a few, in the last few years.

The papers submitted for ICV-3 will take slope stabilization work by vetiver to greater heights. As will be reviewed in the sections hereunder, they provide further research on vetiver tensile root strengths, examples of drawings and documentation for a proper implementation of vetiver grassing on highway projects, incorporation of other vegetation species to enhance its attributes on slopes, its application on rocky karst slopes in a high altitude region and a patented, innovative method of greening barren quarried faces. Moreover, bringing back vetiver to its original riverine home, papers are presented on its role in preventing erosion, scouring and thereby stabilizing banks of waterways in China and Vietnam. Vetiver was tried for protecting coastal regions in Bangladesh and Senegal under harsh saline water environment and wave actions. To obtain hydraulic characteristics of vetiver hedges in deep flows which are important for riverbank and flood erosion control designs, experiments and analysis was carried out to derive the relevant parameters.

2 SLOPE STABILITY AND ROOT STRENGTH

Before we delve into the strength of vetiver roots and their contribution to slope stability, it is essential to define the 2 types of slips or mass movements that characterize stability problems. Slips or slides on slopes fall into 2 categories: deep seated and shallow seated (Fig. 1). Deep-seated problem is geotechnical or geological in nature. It can only be addressed taking into account slope geometry, soil strength, climatic condition, groundwater characteristics, etc. and can be ascertained by slope stability analysis. For shallow-seated slip or shallow mass movement (Gray and Leiser, 1982), the problem is somewhat difficult to quantify. Shallow slips of 1-1.5 m, on the other hand, comprise the majority of problems faced by most people after slope formation, especially in regions with prolonged and high rainfall. This problem still arises despite the fact that slope analysis might have shown a slope to have adequate overall factor of safety. To tackle this problem, engineers conventionally rely on the use of 'hard' or 'inert' material such as mortared riprap, shotcrete or the like to seal off the slope to prevent water infiltration that is deemed to be the cause of the slippage in the first place. However, not in all cases they succeed, as shown in Fig. 2 below.

Fig. 1 Slippage pattern

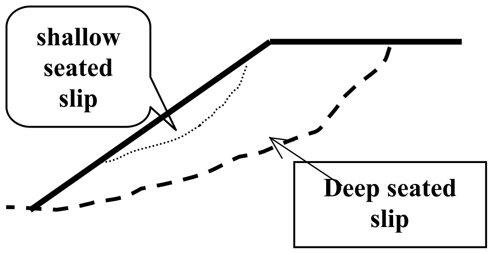
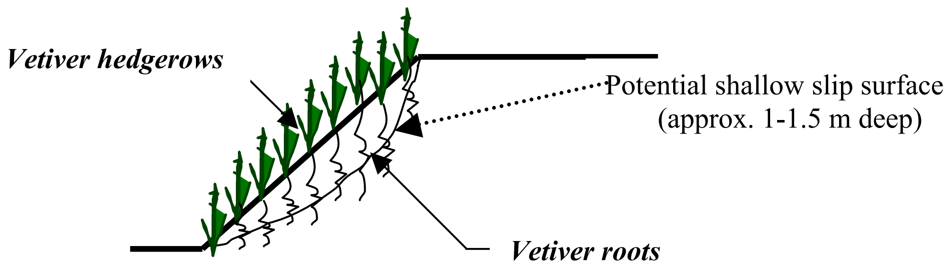


Fig. 2 Hard surface breaks up too!

An alternative solution, as mentioned in the Introduction, is to resort to vegetation, in this case vetiver, to help strengthen the surficial 1-1.5 m layer that is prone to slippage. How vetiver roots help in the strengthening the outer zone is explained diagrammatically below (Fig. 3):

Fig. 3 Slope stabilization mechanism by vetiver



When vetiver roots interact with the soil in which it is grown, a new composite material comprising roots with high tensile strength and adhesion embedded in a matrix of lower tensile strength is formed. Vetiver roots reinforce a soil by transfer of shear stress in the soil matrix to tensile inclusions. In other words, the shear strength of the soil is enhanced by the root matrix (Styczen and Morgan, 1995). As mentioned in the introduction, vetiver roots are very strong with high mean tensile strength of 75 MPa or approximately 1/6th of strength of mild steel. When the dense and massive root networks act in unison, they resemble the behavior of soil nails normally used in civil engineering works. With its innate power to penetrate through hardpans or rocky layers, the action of vetiver roots is analogically likened to 'living soil nails' by the author (Hengchaovanich, 1998).

Cheng *et al*. (2003) supplemented the author's root strength research by conducting further tests on other herbs (grasses) as tabulated below (Table 1)

As is obvious, vetiver has the highest strength of all grasses. However, some disparity between his findings and the author's for vetiver can be explained by way of root diameters. In the author's strength vs diameter curve, the strength derived from 0.66 mm diameter is about 80 MPa, being fairly close to his results. It is unfortunate that Cheng *et al*. did not provide the root lengths of the grasses, as did Ke *et al*. (2003) in his paper under review.

Table 1 Diameter and tensile strength of root of various herbs

Grass	Avg diam. of roots (mm)	Avg tensile strength (MPa)
Late Juncellus	0.38±0.43	24.50±4.2
Dallis grass	0.92±0.28	19.74±3.00
White Clover	0.91±0.11	24.64±3.36
Vetiver grass	0.66±0.32	85.10±31.2
Common Centipede grass	0.66±0.05	27.30±1.74
Bahia grass	0.73±0.07	19.23±3.59
Manila grass	0.77±0.67	17.55±2.85
Bermuda grass	0.99±0.17	13.45±2.18

3 SLOPE STABILIZATION WORK BY VETIVER-SOME NOTCHES UP

As mentioned in the introduction, as vetiver becomes more widely adopted globally, the implementation will need to be improved in accordance with practice on the ground. Sanguankaew *et al.* (2003) describe the experience of the Thai Department of Highways in implementing the vetiver slope protection works on mountainous highways in the North, Northeast and South Thailand. Standard drawings detailing the quality of slips, planting procedures and maintenance techniques, planting patterns for various types of situation: on slopes, end of drainage lines, at bridge approaches, etc have been prepared to aid field practice. Training to highway officials involved in vetiver implementation was provided to ensure satisfactory performance. Some cautionary note was hinted in the conflict between timing in planting and construction period, which needs to be ironed out.

The use of vetiver for highway slope stabilization has progressed by leaps and bounds in recent years, especially inn China, taking the view that the cost of embankment stabilization compared with conventional engineering methods can be reduced by 90% when vetiver is chosen as an alternative. Fine although vetiver may be, it should be complemented by other species, to offer better aesthetics for example during winter period. Work by Kong *et al.* (2003) illustrates the successful growing of eight native species in association with vetiver on exposed sites and poor soil conditions in Guangzhou, China.

On farmlands where topography is mostly gentle or rolling with about 10-15% gradient; however, there are occasional instances where steep slopes may be encountered such as banks of fish farm ponds in Northeast Thailand. With their soils being sandy and saline, erosion is a major problem, with sediments tending to make ponds shallower and water quality poorer. By introducing 3 rows of Songkhla-3 ecotype vetiver on a 45-degree inner pond bank, at 30 cm spacing between rows, it was found (Panchaban *et al.*, 2003) that soil sediments have significantly reduced and thereby bring about better water quality.

4 BREAKTHROUGH THROUGH BREAKING THROUGH

That vetiver had the 'innate power' to penetrate through soils mixed with stone or pebbles, through asphalt layer and through hard pan (Chomchalow, 1997), have been well documented. Until the publication of the two papers described below, no attempt has yet been made to try to plant vetiver in mostly rocky strata.

Huang *et al.* (2003) narrated in details their experiences in the planting of vetiver on the weathered shale and mudstone slope of the Maitian Hydropower station in Jiuxiang, (near Kunming), Yunnan Province, China. It was a bold attempt to stabilize a slope by the Vetiver Eco-engineering Technique - VET, (which in the original design scheme envisaged the use of concrete or 'hard' engineering) against the odds of hard substrate, relatively cold and drought climatic conditions and high altitude (approx 2000 m above mean sea level). Compared with control slope in the vicinity, which collapsed after a severe rainstorm, veti- ver-protected slope was able to withstand the onslaught precipitation very well without any damage. Vetiver hedgerows have been found to able to resist scouring of water flow of 0.028 m^3/s.

Some observations were also made whereby it was noted that the because of the rather hard ground, vetiver was able to achieve a rooting depth of about 1m, compared to 2-3 m in normal soils.

Analysis is made of the cost of the VET in relation to conventional stone-based engineering. It is highly interesting to note that the former approximately cost only 1/8 of the latter, while producing the same slope protection capability coupled with incomparable aesthetic or landscape value.

An innovative VET will make its debut at ICV-3 on the successful revegetation of quarried face (Zhang and Xia, 2003). In a nutshell, it consists of cement troughs filled with special nutrition liquid and water-preserving agent, installed on the quarried face, in which high-quality vetiver seedlings are grown along with other companion creepers and plants.

It is believed to be a first-ever successful effort to sustainably green the unaesthetic quarried faces that have severely marred many scenic spots in Guangdong province. The rapid economic development that entails winning quarry products for infrastructure construction is largely to blame for the eyesores encountered. Previous trials using hydromulching method yielded mostly temporary results that failed in only 3-4 years. Because of its many innovative features requiring human input endeavors, the authors have applied and received a patent for the technique by the China National Intellectual Property Bureau.

5 BACK TO ITS NATIVE HOME—RIVER BANK

The Latin name of vetiver is *Vetiveria zizanioides. Zizanioides* means by the riverside. Anatomically vetiver can be classified as a hydrophyte (an aquatic plant) because its roots possess aerenchyma- tissues with air passages that enable roots of certain plants - rice, for example - to grow under water. In aquatic plants, the corky tissue aids gas exchange and buoyancy.

Instead of a root packed with an organized array of cells, roots with aerenchyma are spongy, with large holes formed by cells either pulling apart or disintegrating. The holes run longitudinally through the roots. They enable flooded roots to snorkel air from above-water plant parts (Behling, 1998). This explains why vetiver can survive several months of submergence or waterlogged conditions.

As mentioned in the introduction, Indians were the first who used vetiver to strengthen riverbanks, probably through observation and expediency. Presently, use of vetiver for waterway protection is still in its infancy when compared to roadworks slope stabilization, although there has been sporadic instances in Australia, China, Malaysia, Tanzania, Thailand, etc. The two papers under review appear to be systematic and fairly large-scale applications to date.

In his paper, Ke *et al.* (2003) explained the rationale for using vetiver for erosion control, slope stabilization and scour prevention at two rivers in China. He endorsed its utilization vis-à-vis the conventional 'hard/stone-based' techniques prevalent elsewhere in his country for equivalent efficacy yet with better ecological impacts and much lower costs. He is to be commended for contributing to the database of vetiver growth characteristics, root lengths from various locations in China. The paper made some important observations: at Hanjiang River dike at Wuhan, Hubei, apart from stabilizing the bank slope, vetiver managed to stay luxuriant although partly-submerged in river water. It was reported by the second author (Feng, 2002) that when severe flooding occurred on the Yangzi (Changjiang) River last year (of which the Hanjiang River is a tributary), vetiver planted there remained intact. Another good observation pointed out by the paper is that vetiver planted on the Youjiang River Bank in the Baise Water and Power Project in Guangxi province, was already working effectively after merely 1.5-2 months' of growth and was protecting against scouring from flood with velocity of 2.0 m/s.

With its location at the mouth of another mighty river in Asia, the Mekong, southern Vietnam basically sits on alluvial/marine clay formations. This renders the deltaic foundation very soft and unsuitable for civil structures such as roads or building construction unless expensive improvements to the subsoils are first carried out and later costly maintained. Thus the Mekong and its tributaries remains a vital transport network as important as roads for the citizen's livelihood. The burgeoning population growth and government measures to increase rice production result in new dykes being constructed. Natural riverbanks, man-made dikes all consist of slope vulnerable to erosion by rainwater, waves by wind or motorised boats, and tidal fluctuations, which also stress the batters. Vetiver planting demonstration project as reported by Le Viet Dung *et al.* (2003) has shown its merits in terms of an appropriate technology as well as cost effectiveness especially for manpower-abundant Vietnam. The project will be a precursor of numerous projects to come that will go toward protecting the natural river banks and man-made dikes that are so vital to that nation's economy.

Although vetiver had been tried with relative success in China and Vietnam as mentioned above, when one is to propose its use for riverbank stabilization or flood erosion control to a prospective client whose knowledge on vetiver is scant, oftentimes the hydraulic characteristics of vetiver hedges are queried, in particular the Manning coefficient ***n***. Experiments carried out by Metcalfe *et al.* (2003) throws some light into the behavior of vetiver hedges in deep flow. Hedges planted in rows were found to be in hydraulic resistance Class A (the highest) with resistance decreasing with increased hedge spacing and suitable for steep slopes/highly erosive flows, while those planted in diamond-shaped pattern were in Class B retardance category and suitable for slower flow rate/shallow slopes where sedimentation was high.

6 SEA COAST PROTECTION— INTO 'UNCHARTED WATERS'

Instances in the use of coastal and shoreline protection are relatively rare, although there were isolated cases in Australia, Thailand and China being mentioned. The reason for shying away from using vetiver in this brackish or saline environment could partly be attributed to the concerns on its salt tolerance limit and its ability to cope with wave or tidal surges.

In a series of glasshouse and field experiments, it was determined by Truong and Baker (1995) that soil salinity level higher than EC_{se}= 8 dS/m would adversely affect vetiver growth, while soil EC_{se} values of 10 and 20 dS/m would reduce yield by 10% and 50% respectively. These indicate that vetiver compares favorably with some of the most salt tolerant crop and pasture species. In another research by Nanakorn *et al.* (1996), it was reported that vetiver could tolerate NaCl at a level 15 times higher than that of normal plant.

In a previous paper by Le Viet Dung *et al.* (2003), it was reported that in Long My District, Vietnam, vetiver can be grown on acid sulfate soil and brackish water when irrigated after planting. And in the following 2 papers, vetiver has been shown to work on coastal protection in Senegal and Bangladesh respectively.

In his paper, Sy (2003) described how he won the respect of hotel owners in the Southern part of Senegal who, prior to his introduction of the vetiver-based bioengineering system, had spent large sums of money on mechanical method for beach area and infrastructure (stairway, walkway and bungalows) protection system but without satisfactory results. Vetiver, along with a companion species, namely *Casuarina equisetifolia*, was successfully planted to protect a beach erosion that might have encroached a tourist complex. Based on his planting experience, he suggested that vetiver be soaked first in 'cow tea ' (a mixture of water and cow dung for 3-5 days and pig or cow manure be supplemented to the fertilizer application, during propagation phase, to obtain better slip establishment and later seedlings survival. He cautioned that because of the harsh environment on dune, beaches and anti-salt dikes, planting bare-root slips should be avoided as the survival rate is slow and the plants are slower to take hold.

The scenario in Bangladesh is much more adverse. Polders, which are coastal embankments that provide protection from cyclone storm and salt-water intrusion to establish conditions conducive to agriculture, need protection under Coastal Embankment Rehabilitation Project (CERP). Islam (2003) is to be commended for initiating vetiver program on 18 coastal polders over about one hundred km of earthen embankment with other economic plants. This is a pioneer trial which can have significant future impact on the rest of the nearly 4000 km of coastal embankments in the country (Islam, 2000). The intention of trying vetiver is to see how it can help replace the conventional engineering measures that entail high costs which the country can ill afford. Partial replacement instances incorporating vetiver include toe-protection trials with soil-cement mixture bags, precast concrete frames, zigzag bars, octagonal blocks, etc. Preliminary results indicate that there are successful cases if proper planting care (in particular watering) is in place. But vertical growth of roots tends to be somewhat short (< 1 m) probably due to adverse saline environment. Despite some setbacks such as washing away by cyclone or tidal surges changing seawater levels etc, the program is still worth pursuing and expanding in a more rigorous manner in the future.

7 CONCLUSION

From a farmland plant promoted for soil and water conservation in the early 80's, vetiver has evolved into an important soil bioengineering tool in the late 90s and onto this new millenium. Encouraged by data from the author's benchmark tests on root tensile strength, engineers have widened vetiver researches and introduced novel usages as reported in several papers under review. New grounds or rather harder grounds have been broken into in the case of stabilization of karst region stony slopes and revegetation of basically rocky-quarried faces. Riverine home of vetiver sees more bank stabilization being carried out while new research data have been added to lend scientific credence. Trials of vetiver in very harsh saline environment with wave problems have been carried out with some successes although some further work remain to be done to refine its effectiveness. With progress achieved to date and probably more to come, one cannot but tend to agree to an Australian engineer's remark that it is as if vetiver has been designed as a tool for engineering purposes.

References

Behling A. 1998. These soybeans survive wet feet. In: The Corn and Soybean Digest, February 1, 1998 issue, Kansas, USA

Cheng H, Yang X, Liu A, *et al.* 2003. An experimental study on mechanic performance and mechanism of soil-reinforcement by herb root system. Proceedings of the Third International Conference on Vetiver and Exhibition, Guangzhou, China

Chowchalow N. 1997. Veteveria 2: 1, Pacific Rim Vetiver Network, ORDPB, Bangkok

Coppin NJ, and Richards IG. 1990. Use of vegetation in civil engineering construction industry and research information association (CIRIA), Butterworths, London

Feng ZY. 2002. Personal communications

Gray DH. 1994. Influence of vegetation on stability of slopes. In: Vegetation and Slopes. Institution of Civil Engineers, London. 2-25

Gray DH, and Leiser AT. 1982. Biotechnical slope protection and erosion control, Van Nostrand Reinhold, New York, NY

Greenfield JC. 1996. Vegetative vs mechanical soil conservation systemas they affect moisture conservation and sustained production. Proceedings of the First International Conference on Vetiver. Office of the Royal Development Projects Board, Bangkok. 1-7

Greenway DR. 1978. Vegetation and slope stability. In: Anderson and Richards (eds.), Slope Stability, John Wiley and Sons, New York, NY

Grimshaw RG. 1994. Vetiver grass—its use for slope and structure stabilizatioon under tropical and semi-tropical conditions. In: Vegetation and Slopes. Institution of Civil Engineers, London. 26-35

Grimshaw RG. 2003. Vetiver grass-a world technology and its impact on water. Proceedings of the Third International Conference on Vetiver and Exhibition, Guangzhou, China

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

Hengchaovanich D, and Nilaweera N. 1996. An assessment of strength properties of vetiver grass roots in relation to slope stabilization. Proceedings of the First International Conference on Vetiver. Office of the Royal Development Projects Board, Bangkok. 153-158

Hengchaovanich D, and Freudenberger KS. 2003. Vetiver Victorious: The Systematic Use of Vetiver to Save Madagascar's FCE Railway. Tech. Bull. No. 2003/2, PRVN / ORDPB, Bangkok, Thailand

Huang B, Xia HP, and Duan G. 2003. Study on Application of veetiver eco-engineering technique for stabilization and revegetation of Karst stoney slopes. Proceedings of the Third International Conference on Vetiver and Exhibition, Guangzhou, China

Islam MN. 2000. Embankment erosion control: towards cheap and simple practical solutions for Bangladesh. Proceedings of the Second International Conference on Vetiver. Office of the Royal Development Projects Board, Bangkok. 307-321

Islam MN. 2003. Role of vetiver in controlling water-borne erosion with particular reference to Bangladesh coastal region. Proceedings of the Third International Conference on Vetiver and Exhibition, Guangzhou, China

Ke CC, Feng ZY, Wu Xj, *et al*. 2003. Design principles and engineering samples of applying vetiver eco-engineering technology for land landslide control and slope stabilization of riverbank. Proceedings of the Third International Conference on Vetiver and Exhibition, Guangzhou, China

Kong XH, Lin WW, and Hao H. 2003. A preliminary experiment on slope rehabilitation with vetiver and native plant technique. Proceedings of the Third International Conference on Vetiver and Exhibition, Guangzhou, China

Le Viet Dung, Luu Thai Danh, Truong P, *et al*. 2003. Vetiver system for wave and erosion control in the Mekong delta, Vietnam. Proceedings of the Third International Conference on Vetiver and Exhibition, Guangzhou, China

Metcalfe O, Smith R, and Truong P. 2003. Hydraulic characteristics of vetiver hedges in deep flows. Proceedings of the Third International Conference on Vetiver and Exhibition, Guangzhou, China

National Research Council. 1993. Vetiver Grass: A Thin Green Line Against Erosion. National Academy Press, Washington DC, USA

Nanakorn M, Surawattananon, Namwongporm N, *et al*. 1996. In vitro selection of NaCl tolerance in vetiveria species. Paper presented at First Int. Conference on Vetiver, Chiang Rai, Thailand

Panchaban S, Phuaphan W, and Ta-oun M. 2003. Use of vetiver for better water quality of farm pond in salt affected sandy area of the northeast Thailand. Proceedings of the Third International Conference on Vetiver and Exhibition, Guangzhou, China

Sanguankaeo S, Chaisintarakul S, and Veerapunth E. 2003. The application of the vetiver system in erosion control and stabilization for highways construction and maintenance in Thailand. Proceedings of the Third International Conference on Vetiver and Exhibition, Guangzhou, China

Styczen ME, and Morgan RPC. 1995. Engineering properties of vegetation. In: RPC Morgan and RJ Rickson (eds.), Slope Stabilization and Erosion Control. E& FN Spon, London

Sy M. 2003. The vetiver: from nursery to the protection of infrastructures. Proceedings of the Third International Conference on Vetiver and Exhibition, Guangzhou, China

Truoung P, and Gawander JS. 1996. Back from the future: do's and don'ts after 50 years of vetiver utilisation in Fiji. Proceedings of the First International Conference on Vetiver. Office of the Royal Development Projects Board, Bangkok. 12-17

Truong P, and Baker D. 1998. Vetiver Grass System for Environmental Protection. ech. Bull. No. 1998/1, PRVN / ORDPB, Bangkok, Thailand

World Bank. 1995. Vetiver grass for soil and water conservation. Technical Paper No. 273, RG Grimshaw (ed). Washington DC, USA

Wu TH. 1995. Slope stabilization. In: Slope Stabilization and Erosion Control. RPC Morgan and RJ Rickson (eds). E& FN Spon, London

Zhang P, and Xia HP. 2003. Revegetation of quarry using the complex vetiver ecoengineering technique. Proceedings of the Third International Conference on Vetiver and Exhibition, Guangzhou, China

A Brief Introduction to the First Author

Diti Hengchaovanich is a geotechnical engineer who has been for many years involved in slope stability and erosion problems, especially in the high-rainfall regions of Southeast Asia. Following his studies and research on the properties of vetiver that reveal it to be an outstanding plant ideally suited for soil bioengineering purposes, he has written several technical papers and made presentations in a number of countries, expounding its attributes and efficacy. He has in no small measure lent credence to and helped promote wider engineering applications of vetiver, thereby making it a viable 'green' tool for infrastructure protection or rehabilitation.