THE GLOBAL IMPACT OF VETIVER GRASS TECHNOLOGY ON THE ENVIRONMENT

Paul N.V. Truong
Resource Sciences Centre
Queensland Department of Natural Resources
Brisbane, Australia

Abstract

Vetiver grass technology (VGT), which is based on the application of vetiver grass, was first developed by the World Bank for soil and water conservation in India in the 1980s. While this application still has a vital role in agricultural lands, scientific research conducted in the last ten years has clearly demonstrated that VGT is also one of the most effective, low cost and natural methods of environmental protection. As a result VGT is now increasingly being used worldwide for this purpose.

Pollution of the environment due to soil erosion and agro-chemical contamination from agricultural lands, urban wastes and by-products of industrial and mining operations is a major global problem, as most of the pollutants are often toxic to flora, fauna and human beings living in the vicinity or downstream of the contaminated sites.

The main factors that have contributed to the global application and acceptance of VGT are the availability of scientific data to back up anecdotal field observation and also to provide explanations to vetiver's phenomenal and unique characteristics. More specifically, the breakthrough was achieved following the establishment of high tolerance levels of vetiver grass to adverse soil conditions, heavy metal toxicities and agro-chemicals in the last six years.

This has subsequently led to: (i) establish VGT as an effective, low-tech and low-cost method of mine rehabilitation, (ii) establish VGT as an effective offsite pollution control method by trapping pesticides, herbicides and nutrients in runoff water from agricultural lands, and (iii) demonstrate that vetiver is highly suitable as a wetland species, as it is extremely tolerant to high levels of agro-chemicals under wetland conditions. This paper presents the state of knowledge of the proven and potential applications of VGT in the above fields, and also other applications in protecting the terrestrial, aquatic, aerial and social environments.

Introduction

VGT, which is based on the application of vetiver grass (*Vetiveria zizanioides*), was first developed by the World Bank for soil and water conservation in India in the 1980s. In addition to its very important application in agricultural lands, scientific research conducted in the last 10 years has clearly demonstrated that VGT is also one of the most effective and low-cost natural methods of environmental protection. As a result VGT is now increasingly being used worldwide for this purpose. For this reason, vetiver grass is known as a wonder grass, a miracle grass and a magic grass in various parts of the world.

The two main factors that contributed to the global application and acceptance of VGT are, first, the availability of scientific data to back up anecdotal field observation and also to provide explanations to vetiver's phenomenal and unique characteristics, and second, its promotion through The Vetiver Network by Dick Grimshaw.

In terms of scientific research, the two most significant breakthroughs are, first, research leading to the establishment of benchmark tolerance levels of vetiver grass to adverse soil conditions and heavy metal toxicity in the last six years and more recently on bio-remedial measures with direct applications in environmental protection. The second breakthrough is research that established the structural and shear strength of vetiver roots. Although this is not directly related to environmental protection per se, it gave engineers more confidence in specifying vetiver for steep slope stabilization, which protects infrastructure from erosion.

This paper presents the state of knowledge of the proven and potential applications of VGT in the field of environmental protection, including the protection of terrestrial, aquatic, aerial and social environments.

Environmental Degradation

Land disturbance by construction activities has resulted in soil erosion increases from two to 40 000 times the pre-construction rates (Goldman et al.1986), with sediment being the principal transport mechanism for a range of pollutants entering watercourses (Anon. 1995). The global concern regarding the contamination of the environment by soil erosion in agricultural lands, urban wastes and by-products of rural, industrial and mining industries is increasing. Most of these contaminants are high levels of chemicals from products and heavy metals, which can affect flora, fauna and humans living in the vicinity or downstream of the contaminated sites. Table 1 shows the maximum levels of heavy metals tolerated by environmental and health authorities in Australia and New Zealand (Anon. 1992).

Concern about the spreading of these pollutants has resulted in strict guidelines being established globally for the decontamination and rehabilitation of these sites. Methods used in these situations have often been to treat the contaminants chemically, to bury them or to remove them from the site. These methods are expensive and at times impossible to carry out, as the volume of contaminated material in most cases is very large, notably gold and coal mine tailings.

If these wastes cannot be economically treated or removed, offsite contamination must be prevented. Wind and water erosion and leachate often cause offsite pollution. An effective erosion and sediment control program can be used to rehabilitate such sites. Vegetative methods are the most practical and economical. However, re-vegetation of these sites is often difficult and slow due to the hostile growing conditions present, which include toxic levels of heavy metals.

These contaminations are particularly acute in the rapidly growing economies of developing countries, where resources are not adequate to provide a satisfactory solution to the problem. As VGT has been shown to be a natural, effective, low-tech and low-cost alternative means of solving the problem, it is therefore ideally suited not only to the developing countries but also globally to the protection of the environment.

Some Special Attributes of Vetiver Grass

The following characteristics make vetiver an ideal species for environmental protection:

- Vetiver grass has neither stolons nor rhizomes but a massive, finely structured root system, reaching 3-4 m in the first year. This massively thick root system reinforces the soil and makes it very difficult to be dislodged under high velocity flows (Hengchaovanich 1999; Hengchaovanich and Nilaweera 1998).
- Stiff and erect stems, which form dense hedges when planted close together. These hedges can stand up to relatively deep water flows, reduce flow velocity and trap sediment (Truong et al. 1995).
- High resistance to pests, diseases and fire (West et al. 1996).
- Tolerance to extreme climatic variations such as extreme temperatures from -15^o to 55^o C.
- High tolerance to acidity, alkalinity, salinity, sodicity and magnesium (Truong and Baker 1997, 1998).
- High tolerance to Al, Mn, As, Cd, Cr, Ni, Pb, Hg, Se and Zn in the soil (Truong 1999a; Truong and Baker 1998).
- High tolerance to herbicides and pesticides (Cull et. 2000, Pinthong et al. 1998).
- High efficiency in absorbing dissolved N, P, Hg, Cd and Pb in polluted water (Pinthong et al. 1998; Sripen et al. 1996).
- Ability to grow again very quickly after being affected by the above adverse conditions once growing conditions have improved or soil ameliorants have been added (Truong et al. 1995).

Table 1. Investigation of threshold levels for potential soil contaminants set by ANZECC/ NHMRC (1992) and the Chemical Hazards and Emergency Management Unit (CHEM) (1991) in Australia and New Zealand

Substance	ANZECC/NHMRC thresholds (mg/kg)		CHEM Unit (1991)
	Environment*	Health*	
Inorganic			
Antimony	20		
Arsenic	20	100	30
Barium			400
Cadmium	3	20	3
Cobalt			50
Chromium^{6+}			25
Total Cr	50		250
Copper	60		100
Lead	300	300	200
Molybdenum			10
Manganese	500		
Mercury	1		2
Nickel	60		100
Selenium			20
Sulphate	2000		
Tin	50		50
Zinc	200		500
Organics, etc			
CN (free, total)			25
CN (complex, total)			250
Mono aromatic hydrocarbons			7
Poly aromatic hydrocarbons		20	20
Phenols			5
PCBs	1		1
Gasoline (C_5-C_{10})			100
Kerosene (C_{10}-C_{16})			100
Oil ($C_{17} \rightarrow$)			1000
Dieldrin	0.2		
Benzo(a)pyrine		1	1

Protection of the Terrestrial Environment

Agriculture

Soil erosion and sediment control on sloping farmlands: Both research and field results in Australia, Asia, Africa and South America show that in comparison with conventional cultivation practices, surface runoff and soil loss from fields treated with vetiver were significantly lower and crop yield was much improved. The yield increase was attributed mainly to uniform in situ soil and moisture conservation over the entire topo-sequence under the vetiver hedge system (Truong 1993).

Erosion and sediment control on floodplain: VGT has been used as an alternative to strip cropping practice on the flood plain of Queensland. This practice relies on the stubble of previous crops for erosion control of fallow land and young crops. On this experimental site, vetiver hedges that were established at 90 m interval provided a permanent protection against flood water. Results over the last five years (including several major flood events) have shown that VGT is very successful in reducing flood velocity and limiting soil movement, with very little erosion in fallow strips (Dalton et al. 1996, 1998; Truong et al. 1998).

The incorporation of vetiver hedges as an alternative to strip cropping on floodplains has resulted in more flexibility, more easily managed land and more effective spreading of flood flows in drought years and with low stubble-producing crops. An added benefit is that the area cropped at any one time could be increased by up to 30% (Chen 1999).

Rehabilitation of saline and acid sulphate soils: The spread of salinity in both dry and irrigated lands is of major concern in low rainfall and semiarid regions of the world. Vetiver has been used very successfully in erosion control and rehabilitation of these salt-affected lands (Truong and Baker 1997).

Acid sulphate soils constitute a major component of arable lands in many tropical countries in Africa and Asia such as Thailand and Viet Nam, where rice is the main food crop. These soils are highly erodible and difficult to stabilize and rehabilitate. Eroded sediment and leachate from acid sulphate soils are extremely acidic. The leachate from acid sulphate soils has led to disease and death of fish in several coastal zones of eastern Australia. Vetiver has been successfully used to stabilize and rehabilitate a highly erodible acid sulphate soil on the coastal plain in tropical Australia, where actual soil pH is about 3.5 and oxidized pH is as low as 2.8 (Truong and Baker 1996, 1998).

Bioremedial: Vetiver has played an important role in the retention and decontamination of agro-chemicals, especially pesticides, preventing them from contaminating and accumulating in the soils and crops. Research conducted in cabbage crops grown on steep slope (60%) in Thailand indicated that vetiver hedges had an important role in the process of captivity and decontamination of agrochemicals, especially pesticides such as carbofuran, monocrotophos and anachlor, preventing them from contaminating and accumulating in the soils and crops (Pinthong et al. 1998; Sripen et al. 1996).

Biological pest control: Research conducted at Guangxi University, China (Chen 1999), showed that of the 79 species of insect found on the vetiver rows, only four attacked young vetiver leaves. However, due to their small population the damage was minimal. On the contrary, 30 other species found in the vetiver rows are considered beneficial insects, as they are the all-important enemies of garden, agriculture and forest pests. This indicates that an integrated pest management scheme will be put into operation when vetiver is introduced to a new environment.

In Thailand, methanol extracts of ground stem and root were found to be very effective in preventing the germination of a number of both monocotyledon and dicotyledonous weed species. These results indicate the potential of vetiver extract as a natural pre-emergent weed killer (Techapinyawat et al. 1996).

Natural Disasters

Typhoon (cyclone or hurricane): Trees take several years to develop extensive and deep root systems necessary to anchor the soil on steep slopes to prevent landslides and reduce erosion, whereas vetiver grass, when properly established, can provide the same effect within 12 months.

Due to the El Niño effects, a series of hurricanes, particularly Mitch and Georges, devastated several countries of Central America in 1998, causing floods and landslides, cutting off highways and other severe infrastructure damages and killing several people. Damage assessment carried out after the typhoons revealed that VGT provided a very effective protection against high rainfall, high wind and floods. Both civil construction structures such as roads, dams, etc, and farmlands remained stable if they were protected by VGT. As a result of that observation, the World Bank sponsored a workshop on the bioengineering application of VGT in San Salvador in May 1999. Participants from several countries in Central and South America and speakers from El Salvador, Mexico, Venezuela and Costa Rica evaluated the effectiveness and exchanged experience on the application of VGT for the protection and stabilization of infrastructure in the region (Miller 1999).

Landslide: Landslides are often caused by the lack of structural strength of the ground on steep slopes and the event is triggered by saturation during heavy rainfall periods. The problem can be exacerbated by the presence of tall trees, which top over under strong wind. Under natural conditions such as forests, deep-rooted trees provide structural reinforcement, but when deforestation is carried out for agriculture and forestry production or infrastructure construction, this structural protection is lost. When this occurs, landslide often results. A good example of this is found in Madagascar (Truong 1998).

A common type of landslide is known in Madagascar as *lavaka*, where the whole hillside collapses. The size of *lavaka* varies but it can be up to 300-500m high and 200-300m wide. The main factors contributing to the initiation of *lavaka* are:

- Deforestation
- Highly erodible soils which have very deep and unstructured profiles
- Overgrazing and burning before the rainy season
- Concentrated runoff intensified by pasture burning and high intensity rainfall from early season storms

Of all these causes, the only rehabilitation method that is feasible, practical and socially acceptable is to reduce concentrated runoff, which can be effectively spread out by vetiver hedges. This involves planting overlapping short hedges to spread and divert runoff water away from the actively eroded *lavaka* heads. When the hedges are fully established, the concentrated flow will either spread out or be diverted to a more stable area. Rehabilitation works on the eroded land below the head can be started by using vetiver grass first and either native or eucalyptus trees later.

Flood: The combination of the deep-root system and thick growth of the vetiver hedges will protect the banks of rivers and streams under flood conditions. Its deep roots prevent it from being washed away while its thick top growth reduces flow velocity and its erosive power. In addition, properly laid out hedges can be designed to direct water flows to the appropriate area (Truong 1999d).

Very successful stream bank and riverbank stabilization has been carried out in Australia, Malaysia and the Philippines. Viet Nam is now very interested in using VGT to stabilize the extensive Red River dyke system, which was built over centuries to protect the Red River delta in the north of Viet Nam from annual flooding. This delta is currently protected by 5 000 km of dykes, 20% of which is damaged every year during the rainy season. This translates into 1 000 km of dykes which need repair every year. According to one study (Truong and Hengchaovanich 1999), the engineer in charge admitted that rock baskets (mattress/gabions), which he called Chinese technology, did not work as they were always washed away when the earthen bank collapsed under them. He added that the Red River was now full of rocks from previous attempts over the years.

Infrastructure

The most rapid impact of VGT in the last four years has been in the area of steep slope stabilization for infrastructure protection. This follows Diti Hengchaovanich's presentation of the results of his works in Malaysia at the First International Conference on Vetiver in Chiang Rai in 1996. Besides Malaysia (Hengchaovanich 1998; Hengchaaovanich and Nilaweera 1998), two other countries have adopted VGT for infrastructure stabilization on a very large scale, namely China and Madagascar.

Following the International Vetiver Workshop in October 1997 in Fuzhou, China, the Fujian Highway Bureau officially accepted vetiver for standard highway embankment stabilization. Subsequently the bureau formally issued a memorandum asking all highway institutions throughout the province to study vetiver technology and to use the grass to protect embankments (Xia 1997; Xia et al. 1999; and Xu and Zhang 1999). In October 1999, due to great interest shown by other provinces recently, the China Vetiver Network again organized an International Conference on Vetiver Bioengineering Technology for Erosion and Sediment Control in Civil Construction in Nanchang.

In Madagascar, following the visits by Richard Grimshaw in 1997 and Paul Truong in 1998 and under the leadership of Criss Juliard, VGT has become the leading technology in road and highway stabilization, is now being applied to all roadwork investments and is fully endorsed by the

Madagascar Society of Engineers. Several rural road systems and railways are now protected by VGT. With this momentum, VGT will be the main technology protecting the Madagascar road and highway networks in the near future (Juliard, pers. com.).

The other countries which have adopted VGT for infrastructure protection are Australia, the Philippines, El Salvador and several Central American countries (Truong 1999c).

Mining

Onsite and offsite pollution control from mining wastes is another major breakthrough in the application of VGT for environmental protection. Research conducted by this author over the last six years has clearly established the extremely high levels of tolerance of vetiver grass to Al, Mn, As, Cd, Cr, Ni, Cu, Pb, Hg, Se and Zn in the soil (Table 2) (Truong and Baker 1998).

Table 2. Threshold levels of heavy metals to vetiver growth (Truong 1999a)

Heavy metal	Threshold to plant growth (mg/kg)		Threshold to vetiver growth (mg/kg)	
	Hydroponic level	Soil level	Soil level	Shoot level
Arsenic	0.02-7.5	2.0	100-250	21-72
Cadmium	0.2-9.0	1.5	20-60	45-48
Copper	0.5-8.0	NA	50-100	13-15
Chromium	0.5-10.0	NA	200-600	5-18
Lead	NA	NA	>1 500	>78
Mercury	NA	NA	>6	>0.12
Nickel	0.5-2.0	7-10	100	347
Selenium	NA	2-14	>74	>11
Zinc	NA	NA	>750	880

NA = not available

Table 3. Average distribution of heavy metals in vetiver shoots and roots

Metal	Soil (mg/kg)	Shoot (mg/kg)	Root (mg/kg)	Shoot/Root %	Shoot/Total %
Arsenic	688.4	8.4	180.2	4.8	4.6
Cadmium	1.0	0.3	11.0	3.1	2.9
Copper	50	13	68	19	16
Chromium	283.3	9.0	1108	<1	<1
Lead	469	35	46	57	33
Mercury	1.98	0.05	2.27	6	5
Nickel	300	448	1040	43	30
Selenium	19.9	4.4	8.4	53	33
Zinc	390	461	643	69	40

Table 3 shows that the distribution of heavy metals in vetiver plant can be divided into three groups:

- very little of the arsenic, cadmium, chromium and mercury absorbed was translocated to the shoots (1 to 5%);
- a moderate proportion of copper, lead, nickel and selenium was translocated (16 to 33%); and
- zinc was almost evenly distributed between shoot and root (40%).

The important implication of these findings is that when vetiver is used for the rehabilitation of sites contaminated with high levels of arsenic, cadmium, chromium and mercury, its shoots can be safely grazed by animals or harvested for mulch, as very little of these heavy metals is translocated to the shoots. As for copper, lead, nickel, selenium and zinc, their uses for the above purposes are limited to the thresholds set by the environmental agencies and the tolerance of the animal concerned.

In addition, although vetiver is not a hyper-accumulator, it can be used to remove some heavy metals from the contaminated sites to be disposed off safely elsewhere, thus gradually reducing the contaminant levels. For example, vetiver roots and shoots can accumulate more than five times the chromium and zinc levels in the soil.

These results have led the two main mining countries, Australia (poster) and South Africa, to increasingly adopt VGT as a major component of their rehabilitation strategy.

In Australia, VGT is highly successful in the rehabilitation of old quarries and mines, where very few species can be established due to the hostile environment. Vetiver is able to stabilize the erodible surface first so that other species can colonize the area between hedges later. After two years, the site was completely re-vegetated with vetiver and local species (Truong et al. 1995). In Queensland, vetiver has been successfully used to stabilize mining overburden and highly saline, sodic and alkaline tailings of coal mines (Radloff et al. 1995) and highly acidic (pH 3.5) tailings of a gold mine. Recently VGT has been used to rehabilitate bentonite mine waste, and tailing dam walls of major bauxite and copper mines and an alumina refinery in northern Australia (Truong 1999a).

In South Africa, rehabilitation trials conducted by De Beers on both tailing dumps and slime dams at several sites have found that vetiver possessed the necessary attributes for self-sustainable growth on kimberlite spoils (Knoll 1997). Vetiver grew vigorously on kimberlite, containing runoff, arresting erosion and creating an ideal micro-habitat for the establishment of indigenous grass species. At Premier (800 mm annual rainfall) and Koffiefonteine (300mm rainfall) diamond mines where surface temperature of the black kimberlite often exceeds 55°C, most seeds are unable to germinate. Vetiver planted at 2 m VI provided shades that cooled the surface, allowing the germination of other grass seeds (Grimshaw, pers. com.). More recently, very successful rehabilitation of slime dams has also been carried out at Foskor mines.

Vetiver is being used to rehabilitate a large copper mine in China and coal mines in Indonesia.

Landfill and Contaminated Lands

Old landfills, and industrial waste dumps such as tanneries, galvanized and electrolytic factories are usually contaminated with heavy metals such as As, Cd, Cr, Hg, Pb and Zn. As these heavy metals are highly toxic to humans, the movement of these metals offsite must be controlled.

The erosion at an old landfill site at Cleveland in Australia is of great concern to the local community, as contaminated materials and leachate polluted adjacent ground and watercourses. The landfill was capped with 1 m of topsoil and successfully rehabilitated with local vegetation, except for the side slopes (70%), which remained bare of vegetation for over 20 years due to high levels of heavy metals and other toxic chemicals. These slopes were highly erodible (Truong et al. 1996).

Rehabilitation work was carried out by planting vetiver rows on the side slopes for erosion control. For leachate control, vetiver was planted en masse at the toe of the slope where leachate appeared. Although the landfill was contaminated (Table 4), vetiver established easily and grew well with N and P application at planting. The slopes were completely stabilized within 12 months and local vegetation established naturally between the hedgerows. During the same period, leachate export was reduced substantially during the wet season and was eliminated during the dry season. When the slope was stabilized, native tree and shrubs were planted to complete the rehabilitation works. In this application vetiver acted as a pioneer plant.

On the same principles thick stands of vetiver have been used in Australia to soak up sub-surface effluent drained from septic tanks and intensive animal farms such as piggeries, cattle feedlots and dairy farms.

In China, similar results were obtained in Guangzhou, where rehabilitation was quickly achieved with vetiver planting. The effectiveness of vetiver in purifying urban garbage leachate was compared with that of *Alternanthera philoxeroides*, *Paspaulum notatum* and *Eichhornia crassipes*. On the whole, the results showed that the growth of vetiver in highly concentrated leachate (HCL) and its purification of HCL were much better than those of other species. Of the seven parameters measured in the study, ammoniac nitrogen was the best cleansed, and its purification rate was between 83 and 92%. In addition, vetiver showed a quite high purification rate for phosphorus (more than 74%) (Xia et al. 1997).

Similarly, in Thailand, vetiver was successfully used to rehabilitate a landfill site near Bangkok.

Table 4: A typical heavy metal profile of the old landfill at Cleveland

Element	Unit	Sample depth (cm)		
		0-10	20-30	40-50
pH	-	3.7	3.5	4.0
EC	$dmSm^{-1}$	2.75	2.38	1.9
Al	%	6.42	7.96	7.55
Na	%	0.34	0.33	0.35
Ti	%	0.82	1.16	1.09
As	$mgkg^{-1}$	9.9	9.4	11.0
Ba	$mgkg^{-1}$	180	170	190
Cd	$mgkg^{-1}$	5*	7*	6*
Co	$mgkg^{-1}$	16	23	23
Cl	$mgkg^{-1}$	20.45	20.30	18.60
Cr	$mgkg^{-1}$	190*	260*	210*
Cu	$mgkg^{-1}$	27	32	31
Fe	$mgkg^{-1}$	6.30	8.40	8.01
Mn	$mgkg^{-1}$	150	230	180
Ni	$mgkg^{-1}$	25	37	31
Pb	$mgkg^{-1}$	15	25	25
Sr	$mgkg^{-1}$	24	11	40
V	$mgkg^{-1}$	100	210	200
Zn	$mgkg^{-1}$	56	66	62

** Values exceed permitted levels*

Protection of the Aquatic Environment

Purification of Polluted Water

In China, research showed that vetiver can reduce soluble P up to 99% after three weeks and 74% of soluble N after five weeks. With proper planning, VGT has the potential of removing up to 102 t of N and 54 t of P/yr/ha of vetiver planting (Zheng et al. 1997).

Control of Algal Growth in Rivers and Dams

As soluble N and particularly P are usually considered to be key elements for water eutrophication which normally leads to blue green algal growth in inland waterways and lakes, the removal of these elements by vegetation is a most cost-effective and environmentally friendly method of controlling algal growth.

Chinese works indicated that vetiver could remove dissolved nutrients and reduce algal growth within two days under experimental conditions (Xia et al. 1997, Zheng et al. 1997). Therefore, VGT can be used very effectively to control algal growth in water infested with blue-green algae. This can be achieved by planting vetiver on the edges of the streams or in the shallow parts of the lakes where usually high concentrations of soluble N and P occur. Alternatively vetiver can be grown hydroponically on floating platforms which can be moved to the worst affected parts of the lake or pond. The advantages of the platform method is that vetiver tops can be harvested easily for stock feed or mulch and vetiver roots can also be removed for essential oil production.

Removal of Heavy Metals

Works in Thailand showed that VGS could absorb substantial amounts of Cd, Hg and Pb in waste water (Sripen et al. 1996). Therefore it can be effectively used for the following applications:

Effluent disposal: With the potential of removing very high quantities of N and P, vetiver planting can be used to remove P, N and other nutrients in effluent from sewage, abattoirs, feedlots, piggeries and other intensive livestock industries. In Australia, VGT was used very successfully as an integral part of a wastewater purification program in removing nutrient from effluent from septic tanks.

Trapping agrochemicals and nutrients: When established across drainage lines and watercourses, vetiver hedges filter and trap both coarse and fine sediments, resulting in cleaner runoff water.

In Australia, the combination of vetiver and African star grass has filtered out both bed and suspended load of runoff water on a pineapple farm in Queensland. Sediment load was reduced from 3.94 g/L to 2.33 g/L after passing through the hedge. Similarly, electrical conductivity was reduced to half (263 uSm/cm to 128 uSm/cm). The high dose of weed killers used did not affect vetiver growth (Dalton et al. 1996a). In other trials on sugarcane and cotton farms, vetiver hedges planted across drainage lines were particularly efficient in trapping particulate sediment containing high concentrations of nutrients and agrochemicals. In sugarcane farms 69% of P in runoff sediments were trapped and on a cotton farm from 67 to 90% of pesticides, 48% of herbicides, 52% of P, 73% of N and 55% of S (Truong et al. 2002).

Wetland application: In the early 1970s Prof. Kikuth in Germany pioneered the use of wetland plants for wastewater treatment. Since then various forms of wetland have been used around the world to treat anything from sewage (primary, secondary and tertiary) to effluent from chemical and heavy industries. For example reed plants (*Phragmites* spp.) have been used successfully for remediation of groundwater contaminated with petrochemicals and also effluent from a large steelwork in the United Kingdom (Anon. 1999).

As vetiver thrives in wetlands, it is highly suitable for use in the wetland system to remove pollutant from industrial and agricultural wastes such as nutrients and agrochemicals from polluted water discharged from cropping lands and aquaculture ponds. Recent research in Australia also demonstrated that vetiver can tolerate extremely high levels of Atrazine and Diuron, under wetland conditions. At the concentration of 2 000 ug/L, while other wetland plants, including *Phragmites australis*, were either killed or had their growth severely reduced, vetiver growth was not affected by these two chemicals, which are the two most commonly used weed killers in sugarcane farms in Australia (Cull et al. 2002).

In the United States, researchers have recently reported that vertical flow wetland and horizontal flow wetland cells planted with vetiver, respectively removed 98 and 96% of total suspended solids, 91 and 72% of total chemical oxygen demand (COD) and 81 and 30% of dissolved COD from sludge derived from a trout farm. Both wetland types removed most (82-93%) of the dissolved phosphate, total Kjeldahl nitrogen and total phosphate.

Protection of the Aerial Environment

Dust Pollution Wind

When dry, the finely ground mine tailing material is easily blown away by windstorms if not protected by a surface cover. As gold tailings are often contaminated with heavy metals, wind erosion control is a very important factor in stopping the contamination of the surrounding environment. The usual method of wind erosion control in Australia is by establishing a vegetative cover, but due to the highly hostile nature of the tailings, re-vegetation is very difficult and often fails when native species are used. The short-term solution to the problem is to plant a cover crop such as millet or sorghum, but these species only last for a few years. Vetiver can offer a long-term solution, when planted in long rows at appropriate spacing to reduce wind velocity, and at the same time provide a less hostile environment (e.g. shading and moisture conservation) for local native species to establish voluntarily later.

In a trial comparing the effectiveness of vetiver hedges and wind barriers in controlling dust storms and promoting the establishment of ground cover on a 300 ha gold tailings dam, vetiver has proved to be far superior and much cheaper than the wind barrier and equally effective in promoting grass establishment. Vetiver growth after the first year was 1.5 m tall and the plant has survived several windstorms, which flattened sections of the wind barrier in the last 12 months.

Vetiver Grass and Greenhouse Gas

Vetiver grass offers a means to benefit the earth's atmosphere as well as its terrestrial environment. Vetiver can sequester large quantities of carbon dioxide from the atmosphere but nobody yet knows how much greenhouse gas vetiver can remove. A rough estimate can be gained from measurements made on a closely related grass, *Andropogon guyanus*. In 1995, the international agricultural research institute in Colombia, CIAT, reported that this species and another deep-rooted African grass grow so widely and prolifically in the savannas of South America that they "may remove as much as 2 billion tons of carbon dioxide from the atmosphere yearly". *Andropogon guyanus* roots penetrate 1 m into tropical soil and CIAT scientists found that the plant sequesters as much as 53 t of carbon dioxide as organic matter per hectare per year (Vietmyer 1997).

Vetiver roots, by contrast, are more extensive and penetrate tropical soils to depths of 5 m and beyond. The rate of absorbing the gas for vetiver is likely to be at least twice that of its botanical cousin. Approximate calculations suggest that a single vetiver plant may absorb 2 kg of $C0_2$ a year (Vietmyer 1997).

Protection of the Social Environment

VGT also exerted a beneficial effect on the socio-economic aspects of rural life in the Philippines. Due to the prolonged drought caused by El Niño in the last few years, there was no work for rural farming communities. This often led to the break-up of rural families as people moved to the cities to find work. Given the need to supply planting materials for various infrastructure projects in rural area, Vetiver Farms, Inc. in Manila was able to provide employment for local people propagating and planting vetiver near their villages. Therefore VGT provided opportunities for these people to remain in their villages instead of drifting to the big cities looking for work (Truong 1999b).

Conclusion

As most of the developments and applications mentioned above have taken place in the last four years, since the First International Conference on Vetiver, there is no doubt that with the present momentum the impact of VGT on the global scene will continue and will become the main technology for environmental protection.

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