Vetiver System: A Green Investment For Sustainable Development

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Abstract

The basic Vetiver Grass Technology comprises a dense vetiver grass (*Vetiveria zizanioides L*) hedgerow that is planted across the slope of the land or embankment. The hedgerow traps sediments, spreads out rain-water runoff, and provides though its roots significant reinforcement to the soil. Vetiver grass technology (VGT) is the basis of every application that are known collectively as the Vetiver System (VS). VS covers many applications and includes: soil and water conservation, land rehabilitation and gully control, slope stabilization, disaster mitigation, improvement of the interface of water and structures, water quality, remediation of polluted sites, agricultural uses, and other applications that are unrelated to the forgoing. VS applications are used to remedy past problems and prevent new problems re-occurring. This paper sets out the most important characteristics necessary for a plant to be useful for agricultural and biological engineering, and describes ten basic and key facts relating to VS that makes it an acceptable and safe technology for the mitigation of problems relating to soil and water. To avoid repetition, detailed information relating to the many different applications of VS has been left to other presentations at this conference.

Key words: vetiver grass, soil and water conservation, soil stabilization, degradation, Vetiver grass technology, Vetiver Systems, slope stabilization, disaster mitigation, water quality improvement, pollution control, land rehabilitation.

Introduction

As a result of an initiative, in 1986, by the World Bank [1], VGT was introduced to development projects in India as a low cost vegetative system for soil and water conservation. Since that time VGT has been used in over 100 countries, primarily in the tropics and semi tropics, and has become of principal interest of civil and environmental engineers as a biological method for stabilization of constructed earthworks such as railroads and highways, mine land rehabilitation, wastewater management and water quality improvement. VGT is a "green" and very "sustainable" technology. VGT is labor intensive and is therefore a good employment generating technology in countries where there are large populations of poor people. VGT is also a low cost, simple and effective technology that can be used by individuals and communities to solve some of their problems.

The world faces many ecological and environmental problems that relate to soil and water, including: soil loss that results in physical, chemical and biological degradation and loss of ability to produce food; overuse and misuse of large areas of land and contamination by toxic runoff from mine dumps, feedlots, and salinization; water polluted by mineral and organic sediments, and pollutants that are detrimental to drinking water and often are unfit for irrigation; decreased groundwater recharge resulting in water shortages and salinization; and inattention to construction site maintenance leading to infrastructure failure and losses. Solutions to dealing with the foregoing problems are often complex and comprise high cost engineering designs that are impractical, demand high quality input and supervision, and have a record of poor sustainability and maintenance. An alternative to this approach is to seek remedial solutions using low cost biological methods.

For a plant to be useful for agricultural and biological engineering, and be accepted as "safe" it should have as many as the following characteristics:

- Its seeds should be sterile, and the plant should not produce stolons or rhizomes that could become invasive or weedy.
- Its crown should be below the soil surface so that it can resist fire, traffic and overgrazing.
- It should be capable of forming a dense, ground level permanent hedge, performing as an effective filter, preventing soil loss from runoff. Apparently only clonal material seems to be able to grow 'into' each other to form such a hedge.
- It should be perennial and long lasting, capable of surviving as a dense hedge for decades, but only growing where we plant it.
- It should have stiff erect stems that can withstand a water flows of at least 1 cusec (.028 cumecs) 12 inches (0.3m) deep.
- It should exhibit xerophytic and hydrophytic characteristics if it is to survive the forces of nature.
- It should have a deep penetrating root system, capable of withstanding tunneling and cracking characteristics of soils. The roots should penetrate vertically below the plant to at least three meters.
- It should be capable of growing in extreme soil types, regardless of nutrient status, pH, sodicity, acid sulphate or salinity, and toxic minerals. This includes sands, shales, gravels, even more toxic soils and mine tailings.
- It should be capable of developing new roots from nodes when buried by trapped sediment, and continue to grow with the new ground level, to eventually forming natural terraces.
- It should not compete with the crop plants it is protecting.
- It should be free of pests and diseases
- It should be capable of growing in a wide range of climates -- from less than 300 mm of rainfall to over 6,000 mm -- from temperatures of -15º C to more than 55º C. It should be able to withstand long and sustained droughts (>6 months).
- It should be inexpensive and easy to establish as a hedge and easily maintained by the user at little cost.
- It should be easily removed when no longer required.

Vetiver grass has all these characteristics.

Vetiver Grass Technology

The Vetiver Grass Technology (VGT), in its most common form, is simply the establishment of a narrow (less than 1 meter wide) live stiff vetiver grass barrier, in the form of a hedge, across the slope of the land. When applied correctly the technology is effective on slopes from less than 1 to over 100%. A well-established vetiver grass hedge will slow down rainfall runoff, spreading it out evenly, and will trap runoff sediments to create natural terraces. In addition its massive root system will increase the shear strength of soil (thus providing improved stability of soils on steep slopes).

Vetiver grass is a clump grass, with erect and stiff stems that grow to as much as 2m high. The roots are very long (3-5 m) and in the main do not spread much beyond the footprint of the crown of the plant. The roots are extremely dense and have an average tensile strength of 75Mpa. The plant is propagated vegetatively by dividing the clump into slips with about 3 tillers each.

The vetiver grass hedge is established by planting slips 10-15 cm apart in a line on the contour. Time of planting is important, and is best done in the rainy season or with supplementary watering. Hedgerows vary in distance apart depending on the slope. As a rule of thumb the vertical interval between hedgerows should be about 1-2 m, depending on climate, slope gradient and soil types.

Vetiver grass (*Vetiveria zizanioides*) is an ancient grass with its center of origin in south India. Other related species such as *V. nigritana* and *V. nemoralis* have origins in Africa and South East Asia respectively. These species do not have all the characteristics of *V. zizanioides* and are not recommended as a base component of VGT.

The basic aspects of VGT, management, and application is set out in a small handbook for farmers, now in its fifth edition, "Vetiver Grass (*Vetiveria zizanioides)* A Method of Soil and Moisture Conservation" [2,3]. It has also been comprehensively discussed and reviewed in a more recent publication: "Vetiver Grass – An Essential Grass for Planet Earth" [4}. Both authored by John C. Greenfield. In addition "A Look See at Vetiver" by P.K. Yoon [5], available on CD ROM, is a remarkable collection of research data and photographs from Malaysia depicting the basic attributes and management of vetiver grass and related hedgerows

The following paragraphs set out some of the evidence to support the use of vetiver grass as the prime candidate for bio-engineering programs.

Vetiver grass hedgerow is an effective measure for soil and moisture retention and conservation.

Research at ICRISAT, India [6] compared VGT with stone barriers, lemon grass, and bare ground (control) under natural (total rainfall 689 mm.) and artificial rainfall conditions. In all cases VGT was the most effective technology for reducing soil and water losses. VGT reduced rainfall run off by 57%, and soil loss by over 80%. The results clearly showed from the experimental hydrographs the enhanced delay in release of run off from the vetiver plots, an interesting feature that could be applied as an upper catchment flood control measure. The same research team [7], confirmed that in the next year vetiver performed even better. Vetiver shows a distinct improvement in efficiency as the hedges become older and denser. At CIAT [8], Colombia, vetiver was compared to other vegetative systems grown in conjunction with cassava. At 11 months (rainfall 1240 mm.) vetiver hedges reduced soil loss from 142 tons/ha for bare fallow to 1.3 tons/ha. for cropped cassava between vetiver hedges Rainfall run off was reduced from 11.6% to 3.6%. Other researchers have reported similar results. Evidence [9] shows strong positive correlation between soil loss and water runoff reduction when VGT is applied on black vertisols in western India, and that VGT is significantly superior to other hedge type barriers. In Louisiana [10], demonstrations conclusively show the impact of vetiver hedges on sediment retention. In Malaysia [11], large-scale experiments have demonstrated substantial sediment deposits behind vetiver hedges, in one case of about 1 meter in 1 year.

Farmers have in nearly every case reported favorably on the use of VGT. A farmer [12] has used vetiver on the family sugar cane farm in Natal, South Africa, for over 70 years as a means of stabilizing roadsides. Since 1989 he has protected 186 ha. of farmland with vetiver hedges. Erosion losses have been reduced substantially and rainfall runoff was reduced to the extent that in a very serious drought in 1992 not one of his young lychee trees was lost. Vetiver grass users in Central America, amongst them those from Honduras [13], confirm that vetiver hedges are the most cost effective method of soil conservation, as do users, [14] in Ethiopia, and other African countries. The feedback from 17 farmers in Layete, Philippines [15], gives clear indication of the impact of VGT and its superiority over other systems. It should be noted that vetiver grass can regenerate from stem nodes. This means that as the sediment builds up behind and within the vetiver hedge to form a terrace, the grass will grow up with the rising terrace - in Fiji terraces with risers as high as 3 meters have been formed naturally [1] under such conditions.

There is no evidence to show that vetiver grass hedges are inferior to other types of hedge. To the contrary, evidence suggests that vetiver hedges are the most effective of all vegetative barriers.

Vetiver grass will grow over a wide range of site conditions.

Experiments [16] with vetiver under saline and sodic conditions in Australia demonstrated that vetiver will tolerate high levels of salinity up to EC_{se} of 38 $mScm^{-1}$. Vetiver shows a 50% dry matter yield reduction around EC_{se} of 20 $mScm^{-}$ Investigations [17] into the tolerance of vetiver to a range of soil pH have been carried out, and demonstrate the tolerance of vetiver to pH levels as low as 3.3 with soil Al toxicity levels of 68% - indications are that vetiver may be one of the most tolerant crop and pasture species to Al toxicity. It was also demonstrated that vetiver could be established on soils of pH 11.5 and that it survived well when adequate levels of P and N were supplied. Vetiver grass has been demonstrated to grow under a wide variety of soil types, depths, and structure. The growth of vetiver on five different soil types in Malaysia [18] was compared; and although growth of vetiver differed from one soil type to another, in all cases vetiver grew reasonably well. It was also demonstrated that vetiver can be established on ex-tin mining land, leading to the rehabilitation of such degraded land. In India, vetiver grows as strongly on the black vertisols as it does on the alfasols. Vetiver grows well on upland as well as wetland conditions, demonstrating its xerophytic and hydrophytic characteristics [18]. Vetiver's cold tolerance limit is around - 9.5° C [19], although some plants have survived short spells at - 15° C [20].

Rainfall is a constraint to the growth of vetiver. It grows in low rainfall areas of 300 - 400 mm, but requires greater management attention. Under these conditions it is more difficult to establish vetiver; and due to seasonal extremes, caused by overgrazing and periodic droughts etc. vetiver, like all other plants, suffers. However where ground water tables are high or irrigation is available vetiver will grow under zero rainfall conditions. At times of extreme drought, rainfall less than 50 mm vetiver has been recorded surviving 12 months without rain. As a rule of thumb vetiver will grow under most site conditions throughout the tropics and semi-tropics. It does best on well-drained soils. It will not grow in areas that have extreme cold during winter months, and where there are permafrost conditions. Except for the effect of temperature vetiver will grow at most altitudes. In Honduras [13] vetiver grows quite well at 2,800 meters. Vetiver hedges have been established [21] in western Ethiopia at 2,000 m. Vetiver has survived snow conditions at 3,000 meters in Lesotho [22]. Vetiver has high potential for growth in saline areas [23] in Australia, and was successfully used for the rehabilitation of the derelict sodic Ussar lands of northwest India.

More recent [24, 25] work by Truong *et al* shows vetiver to tolerate high levels of most heavy metals and toxic materials, well above threshold levels of most other plants. Researchers in China and Thailand have confirmed these findings. Combining its tolerance to heavy metals and its ability to take up excess phosphates and nitrates makes it an ideal plant for constructed and natural wetlands where there is a need to clean up polluted water, sewage and factory effluents. Paul Truong and his associates in Australia and Xia Hanping of China have led the research and demonstrations in this important area. See the Proceedings of the 2nd and 3rd International Vetiver Conferences found on the Vetiver Network website at:

Overall evidence points to vetiver tolerating a very wide range of site conditions, including those that may be considered extremely hostile to plant growth.

Vetiver grass is non-competitive with adjacent crops and Vetiver hedgerows are associated with crop yield increases.

Most evidence indicates that vetiver does not reduce significantly yield of adjacent row crops. Experiments [8] in Colombia indicate no yield loss reduction of cassava when grown with vetiver hedgerows, whereas there was a 33% reduction in yield with elephant grass (*Pennisetum purpureum*) hedges. The latter has wide spreading roots and is much more competitive with adjacent crops. Similar experimental results are demonstrated in Maharashtra, India [25] and Malaysia[17] and confirmed by farmers from South India to Fiji. Sugar farmers in Natal, South Africa[12] and Fiji [26] report production gains.

Experiments [27] over the period 1989 to 1991, at Akola, Maharashtra, India, on Lithic Ustorthent soils under an average rainfall of 840 mm. showed that crops grown in association with vetiver hedges had superior levels of production. Average total production was 17.1% and 32.3% higher for crops grown in vetiver-protected plots compared to crops grown in fields with graded bunds and across the slope cultivation respectively. Moisture Use Efficiency was the highest for vetiver plots, as was the level of residual nutrients. These researchers also compared the effectiveness of vetiver grass with other vegetative barriers. In all there were four comparisons - *Vetiveria zizanioides* (Vetiver Grass), *Leuceana leucocephala* (Subabul), *Cymbopogon flexuosus* (Lemon Grass), and *Chrysopogon martini* (Tikhada). Yield of seed cotton was 25.5% higher with vetiver than the untreated control, and compared to 24%, 15%, and 11% for leuceana, lemon grass, and Chrysopogon respectively. In all cases the highest mean soil moisture percentage, profile and available moisture storage were recorded for vetiver. Farmers in the Philippines indicated that corn and rice planted near a Mura (vetiver) hedgerow performed better [15].

Although in some instances there is evidence of competition with the crop row immediately adjacent to the vetiver barrier, most experimental results, and overwhelming farmer reports indicate that there are no negative yield changes, and that to the contrary, most crops show positive responses to vetiver barriers due mostly to its water conservation capacity. It should be noted that vetiver hedgerows use up less land than other barrier systems such as alley cropping, and thus (all other conditions remaining equal) the overall yield per unit area can be expected to be higher.

In recent years it has been demonstrated in South Africa that vetiver grass can be used as a biotrap which attracts stem borer to its leaves instead of crops, when grown in association with maize and sorghum, hence the incidence of stem borer attack on the crops is greatly reduced [28] without any detrimental effects to vetiver grass.

***Vetiver grass is not a weed, it is not invasive*.**

There is no evidence of vetiver being invasive under upland rainfed conditions [29]. There is some evidence of natural spreading under swamp conditions [30 and 31] Nowhere is it seen as a threatening weed (note this is not the case for other hedge species such as <u>Leuceana sp</u>. that can become a major weed if not managed properly). Its roots are not stoloniferous, some of the accessions originating from south India rarely flower, and if they do the seeds are mostly sterile. Vetiver, probably originating from Guatemala, now grown in Louisiana has at one site not flowered for 25 years [32]. Vetiver is propagated vegetatively. In Zambia vetiver hedges at Msamfu Research Station have remained intact for more than 60 years [33]. One of the main objectives of the National Research Council's review [29] of Vetiver was to verify whether vetiver might be a threat as a potential weed. The review found that in the majority of instances vetiver was not invasive, but it strongly recommended that only the non-seeding accessions be used. Evidence suggests that accessions from south India are less prone to seeding than those from north India. There are reports that accessions introduced from north India to ARS stations in Mississippi were very fertile and germinated strongly. This seems not the case of the Le Blanc accessions near Baton Rouge, Louisiana, nor those of Boucard [33] at Leakey, Texas. More research is required into the flowering habits of vetiver in relation to cultivar, climate, rainfall, and day length. Molecular diagnostics [35] linked with rigorous biometric analysis were used to identify relationships between different vetiver successions. DNA was extracted from young leaf tissue. It was found that the Boucard accession, and what is known as the Huffman accession (believed to originate in Guatemala) were essentially the same genotype, and they were very different from the three accessions received from India. There are believed to be over 20 accessions of vetiver grass introduced to the United States. Molecular diagnostics offers a means to identify different accessions and to correlate positive biological features relevant to the accession. This should result in a more scientific and controlled use of vetiver with potentially better results.

In Thailand [36] over 30 different accessions of Vetiver have been identified. These accessions often differ markedly in character and include six accessions of an upland species of vetiver identified as <u>*Vetiveria nemoralis*</u>. These accessions include some that flower, but produce sterile seed, and others that have seed that germinate more freely.

Recent work [37] in Australia and DNA [38] analysis of noninvasive vetiver accessions show very conclusively that *Vetiver zizanioides* originating from south India, and used in most countries for VGT technology is not invasive.

It is concluded that at most sites vetiver has rarely been recorded as invasive, and if germinated seedlings are present, they can be easily removed by cultivation or by the use of the herbicide – Round Up. There are clear differences in accessions and these differences need better identification so that in the longer term the most suitable accessions can be identified and matched to site and need. There are a number of accessions that are becoming well known to vetiver users. These include Huffman (US), Sunshine (US), and Monto (Australia). These all have essentially the same DNA and are indistinguishable. There are at least 50 other accessions around the world with similar genotypes (DNA analysed). None of them have invasive characteristics.

Vetiver grass is resistant to pests and diseases.

Vetiver is extremely resistant to insect pests and diseases [18 and 19]. There is evidence from India [39] that when dead vetiver plant material is eaten by termites there may be an allelopathic reaction that prevents regrowth of vetiver from the center of the plant, and under severe drought conditions, new young shoots on the periphery of the plant are grazed out and the plant is killed. Alternatively, and most probably, the termite cast is too tough for the new young shoots to penetrate. Management by burning may eradicate this problem. Reports from Brazil [40] suggest that vetiver is resistant to *Meloidogyne javanica* and *M. incognita* race 1 (root knot nematodes), both serious root nematodes in tobacco. In China there have been reports that vetiver has hosted rice stem borer [19], and although this has not affected the growth of the vetiver, the latter might act as a host plant. However in Fujian (south east China), where vetiver has been grown in close association with rice for many years, this does not seem to be a problem. In most cases pests and diseases in vetiver can be best controlled through burning, and as will be noted later in this paper burning may have an important place in the general management of vetiver hedges. The fact that insect pests generally do not eat vetiver makes the grass a very useful thatch and mulch.

Evidence to date indicates that overall, vetiver is resistant to pest and diseases, and is not seen as a serious host plant. In fact evidence is growing that vetiver provides a preferred habitat for beneficial insects [30].

Vetiver grass is fire resistant and repels rodents and other animals.

Vetiver is well known for its resistance to fire. This resistance has resulted in its survival in sugar cane fields that are burnt prior to harvesting. In South Africa vetiver is used to protect forestry firebreaks from erosion [22], and that this method is accepted by the forest insurance companies. Young burnt vetiver (burnt as a result of a mass of cut and dried leaf) under Malaysian conditions recovered fully in four weeks [11]. Historically nomadic herdsmen in grazing the flood plains of the Niger River in Mali, West Africa, have burnt vetiver in order to get a quick flush of grass for grazing. Vetiver's resistance and quick recovery from burning is primarily due to its protected crown and from its deep root system and associated nutrient storage that enables quick recovery. It is these same characteristics that allows fire to be used as a maintenance system for vetiver in drier areas where large amounts of dry leaf material accumulates in vetiver hedges, burning "clears" out the hedge and reduces the incidence of termite infestation. Vetiver's quick revival after fire is particularly important in that by the wet season and erosive forces are at work the hedge is back up and doing its job.

There is conflicting evidence on vetiver's effectiveness to deter rodents and other animals. Farmers are continually reporting that rats appear to be repelled by vetiver and do not burrow into the root system. In fact on Nepal's irrigation schemes many farmers have planted vetiver on their inter-field bunds in order to reduce rat infestation [43]. Recently a forester in Papua New Guinea [47] reported that thus far (3 years), the notorious bush pigs have not up rooted vetiver grass hedges.

Vetiver grass requires minimum maintenance or management

Initially in the marketing of VGT the claim for minimum management was based on its use in higher rainfall areas such as Fiji and the West Indies. In these areas experience showed that on cultivated lands vetiver maintained itself well, the only maintenance being an annual cutting. Following its introduction to less favorable climatic conditions such as in the semi arid areas of central India (rainfall 500 - 600 mm.) it has been found that selection of quality planting material, planting at the correct time (under such climatic conditions the planting window is quite small), gap filling in the first year or so, planting via the use of polybags (container plants) under extremely difficult conditions, the use of fire as a management tool to eradicate excess dead plant material etc., and using different planting techniques to match different site conditions are all important management aspects that require good practical judgment. Experiments [18] have shown that management plays an important role in the level of success of vetiver hedges as an erosion control system. There is conclusive evidence that just "sticking the grass in the soil and forgetting about it" does not often lead to success, for that matter most technologies fail when this approach is taken.

Studies in Andhra Pradesh [48] and in the Philippines [15] show where farmers have understood the technology and apply and manage it properly the system is effective. When government undertakes the work on behalf of the farmer we find the farmer less committed to VGT; maintenance is not carried out and the hedge system degenerates. On the other hand VGT applied in Costa Rica [42] in a citrus orchard (free of livestock) showed no signs of deterioration with no maintenance after five years. Another study [49] shows that on very small farms (less than 0.5 ha.) farmers are loath to put any barrier across their land as they take up potential food crop production areas. In such cases we need to be more aware of farmer practices and encourage farmers to use VGT as a boundary demarcation as has been practiced for centuries by farmers in Gundalpet in south India, and by thousands of farmers outside the city of Kano in northern Nigeria.

Vetiver grass can be used as a fodder.

Where there are other more palatable grasses vetiver grass is normally ignored by livestock, this is an important feature if the grass hedge is to remain intact for many years. There has been limited research carried out on the management and feed value of vetiver as a fodder. It has been observed on many occasions, under farm conditions, that if the hedge is managed correctly, regular harvesting of young leaves is possible, and that these young leaves provide a "maintenance +" ration. In Malaysia sheep will not eat vetiver in the field when there is an abundance of other more palatable species, but cut tops when fed to penned sheep were readily consumed. In China and Malaysia vetiver has been successfully fed to grass carp. In eastern Indonesia, under very dry conditions, cows and horses ate vetiver. Under good management young vetiver leaves have a nutritive value similar to napier grass with Crude Protein levels of about 7.0 to 12%%. Under good conditions high volumes of green leaf are available. In Texas [34] under irrigated conditions, production of dry matter at more than 100 tons per ha. per annum, equivalent to about 350 tons of fresh leaf, has been achieved. Reports [41] from China indicated mulch production from vetiver of 11.4, 14.7, and 17.8 tons of green weight per 100 sq. meters of hedgerow over three consecutive years. Note 100 sq. meters in this case was equivalent to 230 linear meters of hedge. There is little doubt that with some improved management vetiver would make an adequate dry season fodder, particularly if combined with high protein forage. Farmers at Gundalpet, India, have been using vetiver for centuries as a field boundary, and for fodder, where during the peak growing season it is cut once every three weeks. Reports for its use as a fodder come from many other countries including China, Guatemala, Honduras, Niger, and Mali. Some accessions are known to be more palatable - i.e. the so-called "farmer" cultivar from Karnataka, which had been selected by farmers over decades as a softer and more palatable cultivar.

In areas where there are more palatable species of forage grass or where livestock are absent, users who require an inert grass that can be developed with minimum management should look to vetiver. There are excellent examples of this application demonstrated in Costa Rica [42] for the protection of mango orchards on steep slopes.

The most recent analysis [43] from China indicates high crude protein levels of 11-14% when cut young and regularly. Even the more mature plants showed CP levels in the 5-6% range. We have evidence of vetiver's extreme drought tolerance; therefore it might prove a very useful forage crop when irrigated (using an abundance of brackish water?) in the Middle East.

Vetiver grass can be used for structural strengthening of earth embankments, drainage lines, roads, gully rehabilitation and control.

There is worldwide evidence to support the use of VGT for embankment stabilization [2, 3, 11, 12, 22, 44]. Vetiver has been used successfully in Brazil, Central America, China, Ethiopia, India, Italy, Malaysia, Philippines, South Africa, Sri Lanka, Venezuela, Vietnam, and the West Indies for stabilization of roadsides. Vetiver has been used in conjunction with geotechnical applications for embankment stabilization in Nepal and South Africa. It has been used successfully [22] to stabilize gold mine slag heaps in South Africa. It has been used to stabilize flood embankments, river and canal embankments in Bangladesh, China, Madagascar, Vietnam, Zimbabwe amongst others. Because it's great strength and capacity to absorb shock vetiver has potential in the stabilization of canal banks against the force and shock of boat wash and wind created waves. The Vetiver Network has received positive reports of vetiver being used to reduce erosion in small dam spillways in Zimbabwe [40], gullies in Fiji [26], and drainage ways in Guatemala, South Africa, Malaysia, and Nepal [11, 12, 42, 44]. VGT is being used for the protection of building sites when located on sloping land [22].

VGT can be used effectively for the stabilization of irrigation channels [45]. Experiments using irrigation channels with vertical side slopes compared vetiver on unlined slopes and vetiver on polyethylene lined slopes. The side slopes planted with vetiver in the polyethylene lined channels remained vertical, and nearly so in the unlined slopes. The results indicated the high ability of vetiver to bind the soil (a sandy loam), and the potential for designing channels with much steeper slopes with the resultant saving in land area.

In more recent times there have been many studies carried out on VGT for embankments stabilization, the most important [46] of which demonstrates that vetiver roots have an average tensile strength of 75 MPa and improve the shear strength of soil by as much as 30%. These findings led to a great interest in the use of VGT by engineers and a major expansion of vetiver for these types of applications. In recent years China has taken the lead in the use of VGT for major highway and railroad embankment stabilization. Probably the best summaries of this work are available on TVN's website at: http://www.vetiver.org/TVN_ICV3_proceedings.htm

VGT has been used in many countries as a very effective means for gully control. Because of its strength vetiver can withstand high velocity water flows that are normally associated with gullies, and can grow up and through deep deposits of sediment that are formed behind vetiver hedges established in gullies. As a result natural steps are formed in the gullies. Where gabbions are used to stabilize gullies and waterways, vetiver, if planted in association with the structures will help stabilize them.

Vetiver grass is a low cost and economic technology for bio-engineering

An economic analysis [48, 49] compared establishing vetiver grass hedges at less than $30 per ha. with more than $500 per ha. for conventional engineered systems. Economic rates of return for the latter are around 20% compared to more than 90% for vetiver. The costs of establishing vetiver hedges vary from site to site and country to country, depending on the labour cost. On gentle sloping lands vetiver hedges may be established 50 meters apart, and thus only 100 meters of hedge per ha. of protected land is required. On steep lands of 60% the distance between hedges may be 4 meters or less, requiring 2,500 meters of hedge per ha. The cost of planting material varies depending on how it is produced. It will cost more if propagated by hand in a commercial nursery, less expensive by mechanized methods, as done by the Boucard brothers in Texas, and even less if existing farm hedges are divided for replanting as new hedges. In India a farmer can dig and plant 200 meters in a day - cost US $3 per day. "Commercial" vetiver nursery enterprises in India were paid in 1987 about US 1 cent per 3 planting slips. At three slips per hole planting material would cost about Rupees 300 (US $ 10 per km. of planted hedge). In Thailand good quality bare rooted "slip producers" are paid in 1993 US$ 2,600 per ha. which at 1.25 million slips per ha. is equivalent to US 0.2 cents per slip or US$ 60 per km. In Thailand polybag vetiver is produced and planted at US 62 cents per meter. The mechanized cost [32] of planting of vetiver, including cost of planting material, is estimated at about US $175 per mile. In the USA protecting 1 ha. of land on a 4% slope would, using six lines of hedgerow, cost about US $ 90. Because of the variation in planting density according to slope and labor costs probably the best way of quoting cost is cost per linear meter planted.

Benefits from using vetiver grass hedges are less easy to determine. In most instances soil loss is quickly and permanently reduced, reductions of erosion losses from 143 tons to 1.3 tons per ha. in one year are not uncommon [6]. Short-term yield gains have been demonstrated in India [25] resulting in estimated Benefit Cost ratios of more than 2:1. Some farmers in India have reported no crop loss in drought years when using vetiver, whilst their neighbors have lost their unprotected crops. Other benefits that should be quantified include the value of vetiver as a mulch (in China US 2 cents per kg), as a fuel (vetiver has an energy value of about 55% of that of coal), and as a fodder. Indirect benefits include value of otherwise lost soil and soil nutrients, value of increased ground water recharge, its value in upper catchment flood protection and reduced maintenance cost of embankments. If one assumes the benefits between engineered systems and vetiver grass to be the same (which they are not - vetiver's being superior) then the low cost of vetiver compared to engineered systems (about one fifth) should rank VGT as a priority technology. Detailed costs of vetiver hedge development [48] show its superiority over other systems, including engineered structures, in terms of benefit cost ratios.

Other than soil conservation a general rule of thumb is that the application of Vetiver System is about 20% of the cost of engineered applications. Ultimately one has to carry out individual cost analysis for each site and application. Generally the technical parameters of VGT is known and reasonably accurate, all other factors are country, design and site specific.

Vetiver Systems

As background VS was first used for soil and water conservation purposes probably by Indian farmers in Mysore District of India's southern state of Karnataka. There it had been used for centuries for conservation purposes. Likewise it has been used (in this case Vetiveria nigritana) for more than 100 years in Nigeria's northern city of Kano as a boundary demarcation for household plots and as a windbreak. Its first modern use for conservation purposes was probably in the West Indies (St. Lucia, St. Vincent) and then in Fiji where John Greenfield introduced the technology to protect steep hillsides that were being planted to sugar cane. The current vetiver initiative, developed by John Greenfield[i] and myself, at a time when we were working in India during the latter part of the 1980's, in the beginning focused primarily on soil and water conservation.

Vetiver grass has been used for millennia for the extraction of an aromatic oil, oil of vetiver, from its roots, prior to 1985 most of the research on vetiver had focused on vetiver oils. Indian research stations (G. Bharad) were the first to undertake serious soil conservation related work from 1987, closely followed by Malaysia's Rubber Research Institute (P.K/Yoon) and Thailand's Royal Project's Development Board at the insistence of the King of Thailand. By this time research was moving into new areas including vetiver's use from highway stabilization, water quality improvement, disaster mitigation, mineland rehabilitation and handicrafts. In the early 1990's Paul Truong (Australia) researched aspects relating to flood mitigation, heavy (toxic) metal tolerance, water quality improvement, and constructed wetlands. Chinese researchers headed by Xia Hanping followed up on Truong's work and carried out extensive research on the use of vetiver for water quality improvement and at the same time undertook large scale applications of VGT to highway, railroad and landfill stabilization. Currently a new and large vetiver program is developing in Vietnam for a wide range of applications focusing on disaster mitigation and backed by research and data collection.

India, Malaysia, Thailand, Australia, China and Vietnam have been or are currently important centers of research and development. Even so there are other initiatives taking place that are important in other parts of the world. Today over 100 tropical and subtropical countries around the world are fairly serious users of vetiver. In addition special niche environments such as California and some Mediterranean countries are developing techniques to use Vetiver Systems to mitigate problems that impact their infrastructure. Some of this is backed by local research, but much of the VS development is undertaken on the basis of research done elsewhere, and the use of vetiver grass cultivars that are related to those non-invasive types from south India. Such cultivars include: Karnataka, Sunshine, Hoffman, and Monto. Combine the two and one can expect good results if applied correctly.

The Future

VS is still not widely known despite efforts of TVN and others. This is particularly so in South America. South American countries support climates that are conducive to the growing of vetiver grass and in such cases VS could be highly applicable in meeting the needs of these countries, specifically in mitigating against increased natural disasters (flooding and land slides) and increased land degradation resulting from deforestation, mining, and industrialization. As mentioned earlier its use is not dependent on new and time consuming research. Fortunately there are a number of South American countries that are starting to use the technique including Venezuela, Chile, Columbia, and Peru. There is a huge potential in Brazil for VS application covering a wide range of needs. Most Central American countries have used VS quite effectively and their experience should be harnessed.

Although much research has been carried out over the past 20 years additional research is needed to understand the basic plant physiology, and in the ways it might be bred for such characteristics as cold tolerance, root variation for different applications, and water submergence tolerance. Additionally with the high cost fossil fuels vetiver grass has potential as a bio fuel, either as a biomass for burning in modern and efficient boilers, and or as ethanol. Vetiver, because of its massive root and leaf volume makes an excellent carbon dioxide sink. Research into these potential applications would be most valuable.

Conclusions

In order to take advantage of VS it is recommended that country and sub-regional workshops are organized embracing interested parties from all the sectors that might be interested, including: agriculture, public works, health, urban, mining, and water authorities. Both public and private sector agencies should be involved, including NGOs. These workshops should use experienced vetiver resource persons to conduct the workshops. Past experience shows that this is one of the most effective ways of introducing VS.

The vetiver Network is the custodian of most of the important reports, papers and documents relating to the world wide initiative on VGT. In particular we hold the Proceedings of the past International Vetiver Conferences that cover all the foregoing topics and more. They can be accessed via the Vetiver Network homepage: http://www.vetiver.org/TVN_archive.htm. In addition 10,000 pages of vetiver documents are available on CD-ROM.

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