Vetiver Grass System:
Potential Applications for Soil and Water Conservation in Northern California

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Abstract: The Vetiver System (VS) was first developed by the World Bank for soil and water conservation in India in the mid 1980s and it is based on the application of some extraordinary features of vetiver grass (Vetiveria zizanioides L). These include a massive and deep root system, tolerance to extreme climatic variations such as prolonged drought, flood, submergence, fire, frost and heat waves. It is also tolerant to a wide range of soil acidity, alkalinity, salinity, sodicity, agrochemicals and elevated levels of heavy metals in the soil.

VS is now being widely used for soil and water conservation in more than 100 countries including some states in southern U.S. Vetiver grass thrives under Mediterranean climate and in northern California, vetiver will grow for at least 6 months a year.

This paper presents the special characteristics of vetiver grass and its global uses for agricultural and environmental protection. Potential applications of the VS in northern California including soil and water conservation in sloping lands, flood erosion control, stream and levee bank stabilisation and offsite pollution control are discussed.

1 INTRODUCTION

The Vetiver System (VS), which is based on the application of vetiver grass (*Vetiveria zizanioides* L), was first developed by the World Bank for soil and water conservation in India in the mid 1980s. While this application still plays a vital role in agricultural land management, R&D conducted in the last 10 years has clearly demonstrated that, due to vetiver grass extraordinary characteristics, VS is now being used as a bioengineering technique for steep slope stabilisation and environmental protection (10, 11, 24, 28).

2 SPECIAL CHARACTERISTICS OF VETIVER GRASS

2.1 Morphological Characteristics

- Vetiver grass has no stolons, very short rhizomes and a massive finely structured root system that can grow very fast, in some applications rooting depth can reach 3-4m in the first year. This deep root system makes vetiver plant extremely drought tolerant and difficult to dislodge by strong current (26).
- Stiff and erect stems, which can stand up to relatively deep water flow (21)
- Highly resistance to pests, diseases and fire (4,30).
- A dense hedge is formed when planted close together acting as a very effective sediment filter and water spreader (7,12).
- New shoots develop from the underground crown making vetiver resistant to fire, frosts, traffic and heavy grazing pressure.
- New roots grow from nodes when buried by trapped sediment. Vetiver will continue to grow up with the deposited silt eventually forming terraces, if trapped sediment is not removed (21).

2.2 Physiological Characteristics

- Tolerance to extreme climatic variation such as prolonged drought, flood, submergence and extreme temperature from -22^{o}C to 60^{o}C (26, 33)

- Ability to regrow very quickly after being affected by drought, frosts, salinity and adverse conditions after the weather improves or soil ameliorants added (23).
- Tolerance to wide range of soil pH (3.0 to 10.5) (23)
- High level of tolerance to herbicides and pesticides (5,6,14,31).
- Highly efficient in absorbing dissolved nutrients and heavy metals in polluted water (18,34).
- Highly tolerant to growing medium high in acidity, alkalinity, salinity, sodicity and magnesium (19,22,23).
- Highly tolerant to Al, Mn and heavy metals such as As, Cd, Cr, Ni, Pb, Hg, Se and Zn in the soils (23,25).

2.3 Ecological Characteristics

Although vetiver is very tolerant to some extreme soil and climatic conditions mentioned above, as a C4 plant it is intolerant to shading. Shading will reduce its growth and in extreme cases, may even eliminate vetiver in the long term. Therefore vetiver grows best in the open and weed control may be needed during establishment phase. On erodible or unstable ground vetiver first reduces erosion, stabilises the erodible ground (particularly steep slopes), then improves its micro environment so other volunteered or sown plants can establish later. Because of these characteristics vetiver can be considered as a nurse plant on disturbed lands.

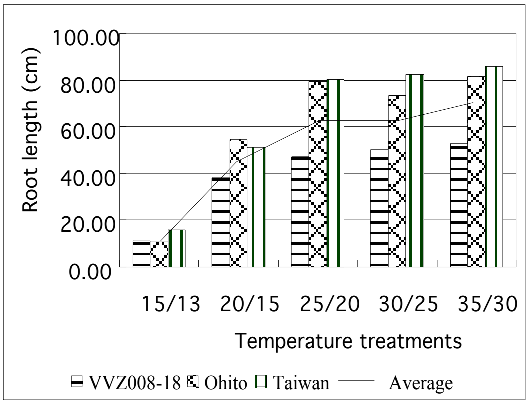
The summary of vetiver adaptability range is shown on Appendix 1.

2.4 Cold weather tolerance of vetiver grass

Although vetiver is a tropical grass, it can survive and thrive under extremely cold conditions. Under frosty weather its top growth is killed but its underground growing points survived. In Australia, vetiver growth was not affected by severe frost at –11^{o}C (12 ^{o}F) and it survived for a short period at –22 ^{o}C (7.6 ^{o}F) in northern China (33). In Georgia (US), vetiver survived in soil temperature of -10 ^{o}C (14 ^{o}F) but not at –15 ^{o}C (5 ^{o}F) (13).

Recent research showed that 25^{o}C (72^{o}F) was optimal soil temperature for root growth, but vetiver roots continued to grow at 13^{o}C (55^{o}F). Although very little shoot growth occurred at the soil temperature range of 15 ^{o}C (day) and 13 ^{o}C (night) root growth continued at the rate of 126mm/day (5in.), indicating that vetiver grass was not dormant at this temperature (29) and extrapolation suggested that root dormancy occurred at about 5 ^{o}C (41^{o}F) (Fig.1)

Fig. 1 The effect of soil temperature on the root growth of vetiver



<u>Genotypes</u>: VVZ008-18, Ohito, and Taiwan, the later 2 are basically the same as Sunshine.
<u>Temperature treatments:</u> day 15 ^{o}C /night 13 ^{o}C

3 VETIVER GRASS GROWTH IN YOLO COUNTY

The average air and soil temperatures at Davis shown in Appendix 2 indicate that Yolo County has a relatively mild winter and warm summer. As vetiver roots continued to grow at soil temperature of 55

^{o}F (27), it is expected that vetiver will start growing by late March when minimum soil temperature is around 56 ^{o}F and continue until early November, when soil moisture permitted.

Vetiver produced on average 200 tillers after two years and up to 6 feet tall, with best growth occurs at ambient temperature of about 70 ^{o}F. Vetiver grass survived –8^{o}C (17 ^{o}F) for 10 consecutive days in the early 1990s. The plants were frost burnt to the ground but rebounded vigorously in spring (J. Eagan pers. com.).

4 VETIVER GRASS ON THE U.S. MAINLAND.

Vetiver grass was introduced to the USA early in the 19th Century (13). Its roots were used primarily as an insect repellent and its tops as mulch for garden crops; it was also a popular ornamental plant. More importantly in more than 150 years since its introduction (perhaps via Haiti) it has shown no evidence of invasiveness, in fact it is so "tame" that vetiver was promoted for soil and water conservation in the Gulf states and planting material could be found at sites where it had persisted without spreading since pre-civil war times. Vetiver has been grown commercially in Texas on one farm for aromatic oil production, but operations ceased as production prove uneconomic (Grimshaw pers.com).

USDA first introduced vetiver to California before World War II for testing at Indio and Lockeford and later at Pomona in southern California. There it has proven to survive extreme drought, for years without fertilisers, irrigation or other maintenance, following establishment with irrigation in the first year. In the past two years landscapers in southern California have started using it successfully for stabilising slopes that are prone to mud slides (Grimshaw pers.com). Vetiver has been used successfully to stabilise and rehabilitate a badly eroded embankment at Pomona. In addition, California Black Walnut seedlings established themselves in pockets of rich organic matter created by the vetiver hedges. Four years after vetiver planting, watered only by natural rainfall, lush green vetiver and young trees covered the embankment. At other two sites at the Spirit Mountain, vetiver has also been very successful in erosion control and water absorption (17).

In the last 7 years the US Army Corps of Engineers have conducted extensive trials using vetiver for the rehabilitation of the army training grounds in several states (VA, IL, MS, NC, GA, KY, AR, TX, MO, LA, OK and KS). Results so far indicated the vetiver is non-invasive, non-aggressive and does not like competition from native grasses. Vetiver can survive on infertile and sandy soil where even native plants do not grow at all, providing an excellent sediment filter and effective against erosion, while serving as a nurse plant for subsequent native plant establishment. However vetiver is not cold tolerant above latitude 40^{o} N (16). In Louisiana, Dr. Kittie Derstine (pers.com.) has used vetiver successfully for land stabilisation and erosion and sediment control on training ground at Ft Polk in the last 10 years.

5 GENETIC CHARACTERISTICS

There are two *V. zizanioides* genotypes being used for soil and water conservation, and land stabilisation purposes:

- The seeded north Indian genotype
- The sterile or very low fertility south Indian genotype.

While the seeded genotype is only used in northern India, the southern and sterile genotype is used for essential oil production around the world, and the latter is the genotype that being used for soil and water conservation and land stabilisation purposes. Results of the Vetiver Identification Program, by DNA typing have shown that of the 60 samples submitted from 29 countries outside South Asia, 53 (88%) were a single clone of *V.zizanioides*. These 53 samples tested came from North and South America, Asia, Oceania and Africa and among these 53 cultivars are: Monto (Australia) and Sunshine (USA) (1). Recent analysis have confirmed this distinction and shown a clear and replicable separation between the seedy and non fertile types (R. Adams pers.com.)

6 WEED POTENTIAL

It is imperative that any plants used for environmental protection will not become a weed. To comply with the very strict Australian rules on introduced plants, a sterile vetiver cultivar was selected (from a number of existing cultivars in Australia) and exhaustively and rigorously tested for eight years for its sterility under various growing conditions. The Queensland Department of Primary Industries has approved this cultivar for use in soil conservation and it was registered in Australia as Monto vetiver, which is identical to the Sunshine genotype used in the United States (1).

In Fiji where vetiver grass was introduced to the country for more than 100 years and it has been widely used for soil and water conservation purposes for more than 50 years, vetiver grass has not become a weed in the new environment (20).

In the US, although vetiver has been in Louisiana for more than 150 years, it has not become a weed. Today, vetiver can be found planted along the bank of many bayous and on old plantations where it has been essentially ignored since at least last century. There have been no reports of colonisation. Vetiver was also present in Florida for probably a century or more, it has never been reported as weed in cultivation (13).

As with all non fertile plants, vetiver can only be vegetatively propagated and planted. Planting materials are obtained by sub dividing the crown of a mature plant; they are supplied as slips or splits in various forms suitable for different applications.

Although vetiver grass is very resilient under the most adverse conditions it can be eliminated easily either by spraying with glyphosate herbicide (3) or uprooting and drying out by hand or farm machinery.

7 SOIL AND WATER CONSERVATION ON SLOPING LANDS IN YOLO COUNTY

As a living porous barrier vetiver hedge slows and spreads runoff water and traps sediment. As the flow is slowed down, its erosive power is reduced and at the same time allows more time for water to infiltrate to the soil, and the hedge traps any eroded materials (7). Therefore an effective hedge will reduce soil erosion, conserve soil moisture and trap sediment on site. When appropriately laid out these hedges can also act as very effective diversion structures spreading and diverting runoff water to stable areas or proper drains for safe disposal.

This is in sharp contrast with the contour terrace/waterway system which runoff water is collected by the terraces and diverted as quickly as possible from the field to reduce its erosive potential. All this runoff water is collected and concentrated in the waterways where most erosion occurs in agricultural lands, particularly on sloping lands and this water is lost from the field. With the VS not only this water is conserved but also no land is wasted on the waterways.

7.1 Runoff, Soil Erosion and Crop Yield

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 as much as 20%. The yield increase was attributed mainly to uniform *in situ* soil and moisture conservation over the entire toposequence under the vetiver hedge system (2). Table 1 shows that the implementation of VS significantly reduces soil loss and runoff on sloping land.

Table 1 Effects of the vetiver System on soil loss and runoff in agricultural lands
(Data extracted from papers presented at the International Vetiver Conference, Thailand, January 2 000) (15)

	Soil loss (t/ha)			Runoff (% of rainfall)		
Countries	Control	Conventional	VS	Control	Conventional	VS
Thailand	3.9	7.3	2.5	1.2	1.4	0.8
Venezuela	95.0	88.7	20.2	64.1	50.0	21.9
Venezuela (15%)*	16.8	12.0	1.1	88	76	72
Venezuela (26%)*	35.5	16.1	4.9			
Vietnam	27.1	5.7	0.8			
Bangladesh		42	6-11			
India		25	2			
		14.4	3.9		23.3	15.5

* Land slope

7.2 Soil Moisture Competition

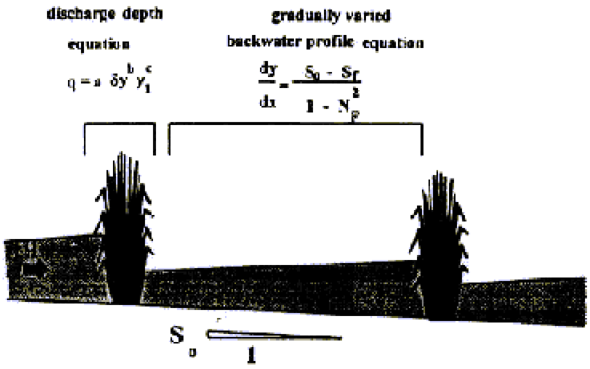
Research conducted on soil moisture competition between crops and vetiver hedges showed that no competition occurred under irrigation between vetiver and both shallow-rooted crop as bean and deep-rooted crop as sorghum. In rain fed farming, no competition occurred under average rainfall conditions, but vetiver hedges reduced sorghum establishment and yield in drought years. On vertisol soil, distance up to 1.5m (5 feet) from the hedge was affected (9).

In low rainfall regions of Asia and Africa, vetiver hedges when planted either in long rows or semi-circles around fruit trees have improved yield. In Thailand lychee yield improves by up to 20% by this water harvesting technique. Evaporation loss is also reduced when the trimmed tops are used to mulch fruit trees. In high runoff area, when planted on a gradient, vetiver hedges are also very effective in collecting and diverting water to storage dams.

8 EROSION AND SEDIMENT CONTROL ON FLOODPLAIN

When planted in row, vetiver plants will form a thick hedge and with their stiff stems these hedges can stand up to water flow at least 0.6m deep, forming a living barrier which slows and spreads runoff water. Hydraulic characteristics of vetiver hedges under deep flow are described in Fig.2 (8).

Fig. 2 Hydraulic model of flooding through vetiver hedges.



Where:

q = discharge per unit width y = depth of flow y_1 = depth upstream

S_o = land slope S_f = energy slope N_F = the Froude number

Based on the above model, VS has been used very successfully for flood erosion control on the floodplains of Queensland, Australia, where strip-cropping practice is generally used for this purpose. This practice relies on the stubble of the previous crop for erosion control of fallow land and young crops. On an experimental site of over 100 ha, vetiver hedges that were established at 90m intervals to provide a permanent protection against flood water. Results over the last several years, (including several major floods) have shown that VS has been very successful in reducing flow velocity and limiting soil movement, with very little erosion in fallow strips and the young crop was fully protected (8,9).

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 dry years particularly with low stubble producing crops such as cotton and sunflower. An added major benefit is that the area cropped at any one time could be increased by up to 30% (9).

9 STREAM, IRRIGATION CHANNEL AND LEVEE BANKS STABILISATION

Vetiver is highly tolerant to water logging condition; this in combination with its extensive root system vetiver provides a highly effective means of stream and levee bank, and irrigation channel stabilisation in Australia and South Africa (26).

Planting on the outside of a dam wall, vetiver stabilises the steep batter; planting inside the wall protects it from wave erosion.

10 OFFSITE POLLUTION CONTROL

10.1 De-eutrophication of polluted water

Algal growth in rivers and dams are major concerns around the world, 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 environmental friendly method of controlling algal growth.

Chinese researchers have shown that:

- Vetiver has a very high capacity to reduce soluble P, up to 99% after 3 weeks, and 74% of soluble N after 5 weeks (32,34).
- Vetiver could remove dissolved nutrients and reduced algal growth within two days under experimental conditions (34)

10.2 Trapping and Decontaminating Agrochemicals and Nutrients

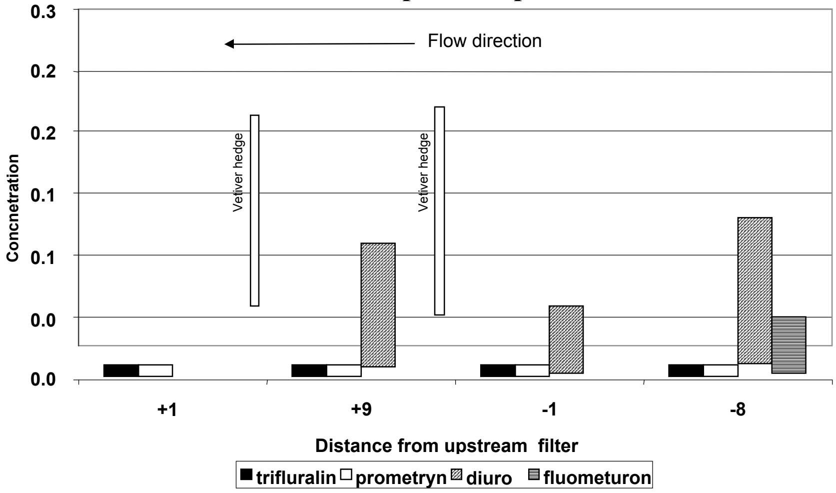
Sediment and runoff analyses associated with the monitoring the quality of water in tropical Queensland have indicated that, in general, greater than 95% of the nitrogen and phosphorus lost in the runoff are associated with the particulate fraction. Therefore the key in controlling off-site pollution by nutrients and agrochemicals is to control sediment movement. If the sediment could be effectively trapped at source, the degree of downstream pollution would be greatly reduced. Vetiver hedges have been shown to be a very effective and low cost means *of* retention and decontamination of particle-bound agro-chemicals, especially pesticides and nutrients in runoff water from agricultural lands.

- In Thailand vetiver hedges captured and decontaminated pesticides such as carbofuran, monocrotophos and anachlor used in cabbage crops, preventing them from contaminating and accumulating in the soils and crops (14,18).
- On pineapple farms in Queensland, vetiver hedges filtered out both bed and suspended load of runoff water. Sediment load was reduced from 3.94g/L to 2.33g/L after passing through the hedge, and similarly, electrical conductivity was reduced to half (263uSm/cm to 128uSm/cm). The high dose of diuron used did not affect vetiver growth (5). These results were later confirmed by a simulated wetland trial (6).
- On sugarcane farms, vetiver hedges were highly effective in trapping particulate nutrients such as P and Ca. As expected, the hedges had little effect on soluble forms of nutrients such as N and K. The effectiveness of vetiver hedges varied with soil surface treatment and fertiliser placement, being most effective when fertilisers were applied on the soil surface (27).
- On cotton farms, when vetiver was planted as filter strips across drainage lines, soil samples collected at various distances upstream and downstream from the vetiver hedges, showed that during its first year of growth, for pesticides the vetiver hedges trapped 86% of total endosulfan in the sediment of runoff water and 67% of chlorpyrifos. For herbicides, during its second year the vetiver hedge trapped 48% of diuron. (Fig.3). For nutrients, similar to the results obtained in canelands, a significant amount of nutrients were trapped by the vetiver hedges (27).
- The high concentration of endosulfan in the trapped sediment resulted in higher endosulfan content in vetiver tops. While the vetiver shoot of the first hedge contained on average 0.43 $mgkg^{-1}$ endosulfan, the shoots of the next hedge down slope only have 0.03 $mgkg^{-1}$. That is a 14 times reduction (27)

11 ARTIFICIAL WETLANDS

The use of wetlands for the removal of pollutants involves a complex variety of biological processes, involving microbiological transformations and physio-chemical processes such as adsorption, precipitation or sedimentation. The ability of vetiver to tolerate flooded soil conditions and to absorb and decontaminate high levels of agrochemicals and nutrients makes it very suitable for use in ephemeral or permanent wetlands. Its dense stands of stiff, erect stems can reduce flow velocity, increase detention time and enhance deposition of sediment and sediment-bound contaminants. Furthermore, vetiver dense and finely structured root system can improve bed stability and nutrient uptake, and provide an environment that stimulates microbiological processes in the rhizosphere.

Fig. 3 Herbicide concentration in soil deposited upstreamand downstream of vetiver filter strips



11.1 Tolerance to Agrochemicals in Wetlands

Results of a study set up to explore the potential for expanding the application of VS for use (as a vegetative buffer or in shallow wetlands) in the treatment of runoff and other waste waters, particularly agricultural runoff, confirmed the ability of vetiver to establish and grow well in a shallow wetland environment. Importantly, the results also clearly demonstrated that growth and performance of vetiver were not affected by exposure to the herbicides, atrazine and diuron, at concentrations likely to be found in agricultural runoff or water bodies downstream. Indeed, vetiver was shown to be unaffected by either herbicide at concentrations as high as 2000 □g L^{-1}; levels which are likely to be encountered in the environment only in situations of accidental spillage, or direct application to waterways (Fig.4,5), (6).

Fig. 4 Mean effect of 3 levels of atrazine and diuronon the whole plant dry weight of vetiver at harvest

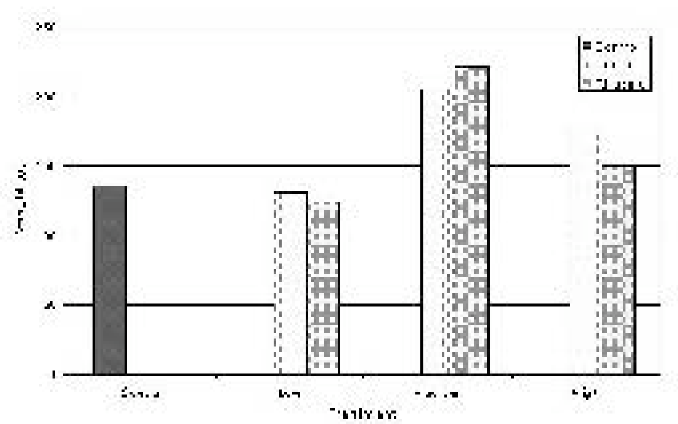
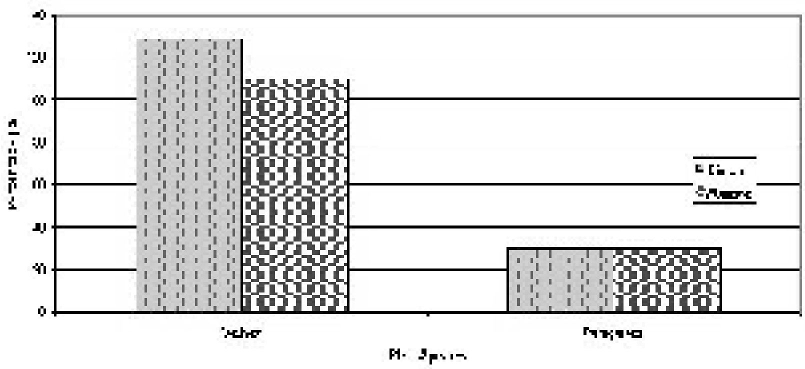


Fig. 5 Whole plant biomass (as a percentage of controls) of vetiver and phragmites at the high rates of herbicide application.



11.2 Reduction of Agrochemical level in Wetland

Results of a comparative study conducted to determine the ability of iris (*Iris pseudacorus*), common club-rush (*Schoenoplectus lacustris*) and vetiver to enhance the removal or degradation of atrazine in a simulated wetland environment, show that iris and vetiver were far more effective than club-rush in lowering the atrazine levels in the soil. This was attributed to firstly the ability of both plants to absorb large quantity of atrazine and secondly to the enhanced activity of micro-organism in the rhizosphere of these two plants. While iris translocated most of its absorbed atrazine to its tops, vetiver retained it in its extensive root system (31).

However, although iris outperformed vetiver in the removal of atrazine from the soil under wetland environment, iris showed sign of stress throughout the experiment. On the other hand vetiver growth was not affected, indicating that in the long term vetiver may be a better plant for this application.

12 WEED AND FIRE BARRIER AND WINDBREAK

When fully developed vetiver forms a very thick barrier, which can stop stoloniferous or creeping grass such as Bermuda grass spreading. The thick growth of the vetiver hedges also provides excellent windbreak for young tree and vegetable crops.

Even in a very dry state vetiver top does not burn readily and remains green during summer so vetiver is being used in South Africa as a fire barrier protecting forest plantation from creeping grass fire.

13 APPROPRIATE DESIGN AND MANAGEMENT

The success of all the applications mentioned above depends on the proper design and application of the VS. To ensure success appropriate management practices have to be developed for each region and each application. Practices that promote good establishment and growth during summer months are most important during establishment phase and those encouraging early regrowth in spring need to be developed for each region.

14 CONCLUSION

As vetiver has been successfully established and thrived in northern California and global experience proves that VS is a very effective, low cost and simple-to-manage soil and water conservation practice, the Vetiver System will provide a great potential to this region for agricultural productivity improvement and environmental protection.

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Appendix 1 **Adaptability Range of Vetiver in Australia and other Countries**

Adverse Soil Conditions	Australia	Other Countries
Acidity	pH 3.0	pH 4.2 (with high level soluble aluminium)
Aluminium level (Al Sat. %)	Between 68% - 87%	80%-87%
Manganese level	> 578 $mgkg^{-1}$	
Alkalinity (highly sodic)	pH 9.5	pH 10.5
Salinity (50% yield reduction)	17.5 $mScm^{-1}$	
Salinity (survived)	47.5 $mScm^{-1}$	
Sodicity	48% (exchange Na)	
Magnesicity	2 400 $mgkg^{-1}$ (Mg)	
Heavy Metals		
Arsenic	100 - 250 $mgkg^{-1}$	
Cadmium	20 $mgkg^{-1}$	22 $mgkg^{-1}$
Copper	35 - 50 $mgkg^{-1}$	174 $mgkg^{-1}$
Chromium	200 - 600 $mgkg^{-1}$	
Nickel	50 - 100 $mgkg^{-1}$	
Mercury	> 6 $mgkg^{-1}$	
Lead	> 1 500 $mgkg^{-1}$	3 123 $mgkg^{-1}$
Selenium	> 74 $mgkg^{-1}$	
Zinc	>750 $mgkg^{-1}$	3 418 $mgkg^{-1}$
Latitude	15^0S - 37^0S	41^0N - 38^0S
Altitude		2 800m
Annual Rainfall (mm)	450 - 4 000	250 - 5 000
Frost (ground temp.) (soil temperature)	-11^0C ($12\,^oF$)	-22^0C ($7.6\,^oF$) -10^0C ($14\,^oF$)
Heat wave	45^0C (113^oF)	60^0C (140^oF)
Drought (without effective rain)	15 months	
Fertiliser		
Vetiver can be established on very infertile soil	N and P (300 kg/ha DAP)	N and P, farm manure
Palatability	Dairy cows, cattle, horse, rabbits, sheep, kangaroo	Cows, cattle, goats, sheep, pigs, carp
Nutritional Value	N = 1.1 % P = 0.17% K = 2.2%	Crude protein 3.3% Crude fat 0.4% Crude fibre 7.1%

Appendix 2 **Air and Soil Temperature at Davis, Yolo County**

Month	Air (^OF)		Soil (^OF)		
	Max	Min	Max	Min	Average
Jan	57	40	49	46	46
Feb	58	43	55	48	51.5
Mar	67	43	62	52	57
April	71	44	72	89	65.5
May	79	48	83	69	76
June	85	52	90	77	83.5
July	87	54	96	81	88.5
August	88	55	95	79	87
September	89	54	87	73	80
October	81	49	75	65	70
November	65	44	58	52	55
December	61	34	49	44	46.5