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The Role of Vetiver in Controlling Water Quantity and Treating Water Quality: An Overview with Special Reference to Thailand*

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Abstract

Water is one of the most important natural resources of mankind. Its importance can be appreciated from the following statements / events: His Majesty the King of Thailand's "Water is Life", International Conference on Water's "Year of Fresh Water", FAO World Food Day 2002's Theme, "Source of Food Security", Theme of International Year of Mountains, "Water Towers of the Earth", the Cause (Greenhouse Effect) and the Effect (El Nino and La Nina) of 'Global Warming'. Problems related to water are of two main types: quantity and quality. The former refers to too much water (normal and abnormal situations), and water shortage, while the latter covers prevention and remediation measures to keep the water clean and potable.

Prevention measures are to prevent pollutants or contaminants from entering a body of water. Currently two main methods of treating wastewater: Engineering and Biological are being used. The biological method consists of: land-irrigation, wetland, and hydroponic systems. Each system works through the removal or trapping and filtering out contaminants present either in the leachate or effluent. Remediation measures work through the removal of contaminants already present in the water, a process also known as 'water purification'. Three kinds of wastewater are known: contaminated water (containing waste products), polluted water (containing heavy metals, pesticide residues and other hazardous materials), and eutrophicated water (containing plant nutrients, especially N and PO_4).

This paper discusses how vetiver can control the quantity of water and treat water quality through simple methods, using low-cost technology.

Keywords: *Prevention, remediation, land irrigation, wetland, hydroponic, leachate, effluent, contaminants, water purification, wastewater, polluted water, eutrophicated water.*

1. Introduction

1.1 Importance of Water

Water is one of the most important natural resources of mankind. Its importance can be appreciated from the following events and statements:

1.1.1 'Water is Life': The development of water resources for crop cultivation, or irrigation project, is considered quite important and highly beneficial for the vast majority of people living in the rural areas, since water enables them to farm their lands throughout the year. At present, cultivated areas in most parts of Thailand are outside irrigated areas, thus they have to depend on rainwater, or water from other natural sources. This has led to an inadequate supply of water for crop cultivation. This is exaggerated by irregular rainfall, resulting in a poor yielding of crops. His Majesty the King attaches greater priority to projects related to the development of water resources than any other development projects. He recognizes the importance of the value of water and considers it to be 'life', as appeared in the following royal speech delivered at

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Chitralada Palace in Bangkok on 17 March 1986 concerning the importance of water:

"…The valid principle is that we must have water to drink, use and cultivate because 'life is there'. If there is water, we can survive. If there is no electricity, we can still survive. But if there is electricity but no water, we cannot survive…"

His Majesty's concerns on this issue ranges from supplying water to the areas where it is deficit, through drainage of excess water, to purifying wastewater.

1.1.2 The Year of Fresh Water: In the "International Conference on Water" held in Singapore in 2001, it was concluded that billions of people throughout the world are facing the problem of shortage of fresh water. This includes water for agricultural uses, for everyday household uses, and even for consumption and drinking! Of course, we still have plenty of water on the globe, but it is brine, too salty to be consumed. Fresh water will become scarce in many areas of the countries and in many countries of the regions, causing severe hardship, affecting the economy and security. The statistics of 1996 indicated that there were 600 million people in 31 countries that suffered from lack of fresh water. It was estimated that in the year 2026, which is only 30 years in the future, that the number of people suffering from the lack of fresh water will reach 3,000 million in 48 countries. However, it will get worst in 2050, when 4,000 million people in 54 countries will suffer from the same cause. This is really quite alarming. Fresh water will become an important asset of a country, providing opportunity for the well being of its people as it is the most important factor for sustaining life.

1.1.3 Source of Food Security: The theme of FAO's '2002 World Food Day' is, "Water: Source of Food Security", which states a well-known fact that water is the most important factor for food production. The limited availability of water for agricultural production is increasingly affecting the ability of the farms in every continent of the globe to produce enough food for the ever-increasing population, which now stands at six billion.

1.1.4 Water Towers of the Earth: It is not by coincidence that the UN is also commemorating its International Year of Mountains in 2002, as water and mountain are interrelated. More than half of the world's population relies on water that originates from the mountains, which acts as; "water towers of the earth". Denuded mountains, due to deforestation often result in landslides and mudslides after heavy rains, as were evident in the incidences that took place in Thailand in more recent times, such as; in the Kathun Sub-district, Pipun District, Nakhon Si Thammarat Province in 1991, and at Wang Chin District, Phrae Province in 2001. Thus, sustainable management of mountains and water- sheds are of particular interest and importance, otherwise, water-related catastrophes will occur.

1.1.5 Water - A Key to Sustainable Development: The goal of the International Fresh Water Conference held in Bonn, Germany in December 2001, was to develop solutions to global water problems. One fifth of the world's population do not have access to sufficient clean drinking water. Wastewater from around 2.5 billion people cannot be disposed of hygienically. Polluted drinking water is the number one cause of disease around the world. Climate changes, with its increasing floods and droughts, further aggravate these problems. At the same time, poor water supply reinforces poverty and gender inequality. The question was raised of how good governance, integrated management and new partnerships, capacity building and technology transfer can contribute to solving these problems. Consideration was also given to how additional financial resources, from the private sector can be mobilized, especially for poorer countries in order to solve the most serious problems (Truong, pers. comm.).

1.1.6 The National Policy on Water: The recently announced national policy of the present Government on "National Policy on Water", utilizing 200,000 million Baht to develop 25 river basins to solve the water deficient problem of the farmers should be congratulated. In the past, many Thai governments tried to implement huge water development projects, such as the 'Green I-san Project' to provide adequate water for agricultural development of the Northeast, the 'Khong-Chi-Mun Project' to divert water from

Mae Khong River to two main rivers of the Northeast, and the project on diversion of water from Salawin River in Mynamar to Thailand, all of which have not been successful.

It should be noted that two other international events related to water, i.e. the International Year of Fresh Water, and the Third World Water Forum will also be held in Japan in March 2003. All these international undertakings point to the importance of water for mankind, whether from its destructive or constructive roles. Fresh water has also been emphasized in these international undertakings.

1.2 Global Warming

1.2.1 The Causes: Global warming is a phenomenon arising from the burning of fossil fuels like petrol, coal, and natural gas, which have been buried underground for millions of years. Burning of these fossil fuels, together with additional burning of wood in the process of deforestation results in the release of large amounts of carbon dioxide (CO_2), which ultimately forms a layer in the atmosphere. Such layers act as a greenhouse effect, in not allowing the heat from sun to shine on the earth, which normally reflects back to the atmosphere, but instead bounds back to the earth. This raises the temperature of the earth by several degrees Celsius. This is known as the 'Greenhouse Effect'.

The situation is worsened with the release of chlorofluorocarbon (CFC), the air-conditioner chemical, which evaporates into the atmosphere and damages the ozone layer, resulting in the formation of a 'hole', which facilitates the penetration of solar radiation on to the earth and causing the rise in temperatures of the earth surface.

1.2.2 The Effects: The 'Greenhouse Effect' results in two related phenomena, *El Niño* and *La Niña,* both of which lead to extremes in heat waves, droughts, and floods. Both *El Niño* and *La Niña* are part of winds and currents that move back and forth in the equatorial Pacific, appearing every two to eight years. Normally, westward-blowing trade winds caused by the rotation of the earth, and conditions in the tropics push surface water across the Pacific toward Asia. The warm water piles up along the coasts of Australia and Southeast Asia, raising sea levels more than 30 cm above those on the South American side of the Pacific. When *La Niña* develops, the trade winds that normally push warm water toward Australia and Southeast Asia are stronger and faster. This results in the rise of moist air, and the decrease of atmospheric pressure, the end result of, which is the more frequent and intense rain falls in Southeast Asia.

It is not by coincidence, however, that the increased frequency of floods and droughts is significant over the last century, correlating with increased human usage of fossil fuels, and drastic land use changes from forest and grasslands, to cropland and urban development.

1.3 Problems Related to Water

Problems related to water are of two main types: quantity and quality. Their nature is described below, while the role of vetiver in controlling them will be discussed in the subsequent sections.

1.3.1 Water Quantity: In the second half of 2001, starting from August, many parts of Thailand, especially in the North and Northeast, suffered from severe floods. Hundreds of people were drown; similarly thousands of livestock also died of the same cause. The effect on crops was beyond comprehension. This causes a similar problem of the same factor, i.e. water quantity. At one time we have too much water; its destructive force running downhill, causes loss of property and lives of people living in such highland areas, as well as flood damaging the lowland areas. Then at another time, not so long from the first instance, we have drought scattered in large areas throughout the country from the North, the Northeast, the Central Plains, and even in the South, the region in which is supposed to be wet most of the year.

Both too much water and water shortages create problems to mankind. Too much water results in disasters such as: landslides, mudslides, fast running water, and floods that destroy houses and human property, as well as the lives of human beings and their animals. Water shortages result in hardships for the people, their animals, and their crops. People as well as other living creatures, can survive many days without food, but not without water!

1.3.2 Water Quality: Water quality signifies the absence of contaminants, which are waste products, pollutants and nutrients. Depending upon the usage, the presence of some contaminants in the water may be acceptable; e.g. water that is used for agricultural and other activities may not need to be pure. While that presence in a lake or other bodies of water should not be rich in nutrient, otherwise, a phenomenon of eutrophication will occur, resulting in algal bloom and the depletion of oxygen in the water, which results in the death of aquatic life. However, water for human consumption should be as clean as possible, i.e. uncontaminated with pathogens, nutrients, heavy metals, and other toxic or hazardous substances.

2. Vetiver and Water

Vetiver has a major role to play along with water, as can be seen from the following paragraphs:

2.1 The Theme of ICV-3

The theme of the Third International Conference on Vetiver (ICV-3) is "Vetiver and Water". This is most appropriate in the present circumstance, when water becomes the most important natural resource for mankind. Vetiver, a humble grass, has a big role to play along with this major natural resource. It is an essential tool in mitigating this pending water crisis.

2.2 Interdependence of Vetiver and Water

Vetiver and water are interdependent on each other. As other living creatures, vetiver depends on water for its growth and development. However, in terms of quantity and quality, the availability of water, depends to a certain extent on vetiver. As can be seen in subsequent sections, vetiver helps to regulate the amount of water. It conserves water when water is scarce. It helps to reduce surplus runoff rainwater by diverting it perpendicularly along the contour hedgerows, allowing much smaller amounts to pass through, while other amounts seep through the soil and retained by soil particles, while the surplus after saturation, is stored as underground water in the aquifer. It also helps to purify contaminated or polluted water.

2.3 Special Characteristics of Vetiver

Vetiver has many special characteristics that lend support for its uses in solving the water problem. According to Truong and Baker (1998) and Cull *et al.* (2000), these can be classified into morphological and physiological characteristics.

2.3.1 Morphological Features: Vetiver has:

- Stiff and erect stems that can stand up to high velocity flows and increase detention time.
- Thick growth forming living porous barrier that acts as a very effective filter trapping both fine and coarse sediments, as well as sediment-bound contaminants (e.g. heavy metals and some pesticide residues).
- Deep, dense and penetrating root system, that can reduce and prevent deep drainage, and improve bed stability and nutrient uptake.
- Finely structured and massive root system, which provides an environment that stimulates microbiological processes in the rhizosphere.

2.3.2 Physiological Features: Vetiver is:

- Highly tolerant to adverse climatic conditions such as frost, heat wave, drought, flood, and inundation. Highly tolerant to adverse edaphic conditions such as high soil acidity and alkalinity; saline, sodic, and magnesic conditions; and aluminum and manganese toxicities.
- Highly tolerant to elevated levels of heavy metals such as arsenic, cadmium, copper, chromium, lead, mercury, nickel, selenium, and zinc.
- Adaptive to be used in areas where too much water prevails, as it is able to consume high amount of water.
- Able to tolerate flood, making it ideal for use in ephemeral or permanent wetlands.

3. The Role of Vetiver in Controlling Water Quantity

3.1 Too Much Water

Too much water may occur in normal or abnormal situations as described below:

3.1.1 Normal Situation: This is the case where too much water is present as standing shallow water, or water-saturated topsoil, due to soil compaction and poor drainage.

3.1.1.1 Standing Shallow Water: This is the case of swamps, wetlands, bogs, marshes, etc., where standing shallow water is maintained throughout most of the year. As it can survive well in water, and together with its high rate of water consumption and tolerance to a high degree of water contamination, vetiver is ideal to be used to solve the problem of such a situation.

3.1.1.2 Water-saturated Topsoil: In certain areas, topsoil layer is quite shallow, as there is a hardpan layer underneath. This condition results in water saturation of the topsoil during the rainy season. As a result, plant growth is retarded. If vetiver is planted in such a soil, vetiver roots that allow water to percolate to subsoil layer penetrate the hardpan. In this way, excess water is drained downward in the wet season while water rises up through capillary force during the dry season. This stimulates the growth of crops growing in such a soil.

The visit to the lime/guava orchard of Mr. Songsak Khieokhli of Tha Yang District, Phetchaburi Province during the ICV-2 technical tour had convinced visitors that vetiver really helped in improving his orchard's productivity. Due to the presence of shallow topsoil and a hardpan beneath it, excess rainwater could not penetrate downward. After vetiver was planted, his orchard turned out to be quite productive as excess rainwater could be drained downward, after the vetiver roots had penetrated through the hardpan layer. While during the dry spell, capillary rise of water from moist subsoil layer provided enough water to satisfy the thirst of lime/guava plants. The deep roots of the vetiver plants could also absorb enough water from the subsoil layer to satisfy their own needs during such a dry spell as well.

3.1.2 Abnormal Situation: This is the case when too much water is present as the result of a heavy of rains, which also ends up with several kinds of disasters such as landslides, mudslides, destructive fast-flowing currents, and damaging floods. 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 periods of rainfall. periods. Under natural conditions, deep-rooted trees in the forest provide structural reinforcement, but when deforestation occurs, this structural protection is lost. When this occurs, landslides often result. Mudslides are similar to landslides, except that the soil turns into mud when it is soaked with water for long periods of time. The effects of mudslides are worse than landslides, since mud can bury everything, including humans. Runoff water moving downhill at high speeds destroys everything obstructing its way.

The worst situation was seen at Krathun Subdistrict of Phipun District, Nakhon Si Thammarat Province, Thailand in 1989, where trees on the mountain were cut down and huge logs were left temporarily where they were cut. Unfortunately, with a heavy downpour of torrential rains, these logs were brought downwards along the current, and damaged the whole village at the base of the hill, which was later completely buried under sand and silt, which were also brought along the current downhill.

Planting vetiver hedges across the slope slows down runoff water, thus allowing more water to seep into lower layers of soil, instead of adding to the floodwater in the lowlands. In this way, more water is added to the depleted aquifer, which helps to make the soil moist. It also collects debris and other organic materials, making the soil more fertile. It not only reduces the velocity of running water, but also diverts it laterally, thus reducing the damage caused by the force of running rainwater. It has several beneficial features that lend itself to be used to reduce the effect of water-related problems in several situations, such as on the highlands and uplands, in the gullies, and flood plains.

In Australia, Dalton *et al.* (1996), and Dalton (1997), have provided evidence to demonstrate the effectiveness of vetiver hedgerows in the reduction of flood damage to cultivated lands on the Darling Downs of Queensland. On the experimental site, vetiver hedges that were established at 90m intervals provided a permanent protection against floodwater. It should be appreciated that during the period of five years with several major flood events, vetiver hedges proved to be very effective in reducing flood velocity and limiting soil movement, with very little erosion in fallow strips.

3.2 Water Shortage

As pointed out earlier, vetiver hedgerows planted on the slope contours allow more water to seep through the topsoil into the lower layer. In this way, the soil in front of the hedgerows becomes moist, and can supply moisture towards the dry season. In addition, debris and other organic matters carried by water and deposited in front of the hedgerows help to retain more moisture that facilitates the growth of plants growing in between the vetiver strips throughout the year.

Vetiver's massive root systems have the capability of punching through hardpan, thus the downward movement of water is increased. After saturation, water is retained as ground water in the aquifer, which provides a continuous supply of water to the soil above it throughout the year.

A good example can be seen from the project, "Check Dams to Retain Moisture", conducted by the Huai Hong Khrai Royal Development Study Center in Doi Saket District, Chiang Mai Province. Using vetiver as the main player, the project aimed at increasing soil moisture through simple, inexpensive, and effective means. There are two types of small checkdams; one retards stream flow and allows water to seep into the soil and increase soil moisture in the area. The other is the sediment control check dam that traps water-borne debris and soil particles carried along the water current. Both check dams increase and retain moisture, and create a hydrological cycle beneficial for effective forest conservation and rehabilitation. At the end, the forest that was once dried during the summer becomes evergreen.

Recharging of groundwater is an important feature of water resource planning. Groundwater not only supplies wells and springs, but also enhances the dry season flow of major river systems. Recharge will improve if rainfall runoff is reduced. Good vegetation cover is essential, trees, pasture, and crop covers all reduce runoff. Vetiver hedgerows also play an important role in groundwater recharge. Rainfall runoff is reduced by as much as 70% when vetiver hedgerows are planted across the slope and on the contour. This runoff reduction is due in part to the effect of the hedgerow in slowing down and spreading out runoff over a larger area, but also because its strong roots can penetrate hardpans that are off limits to many other plants, and thus significantly improve infiltration. "…We know from feedback in India (both in high and low rainfall areas) that where vetiver hedgerows are in place, water levels in wells are higher, springs do not dry up, and small streams run longer into the dry season…" (Greenfield, pers. comm.).

In addition, vetiver hedgerows are effective in removing excess nitrates and phosphates that may be in the runoff water, and there is some evidence that vetiver will remove excess pesticides as well. Thus, vetiver hedgerows have a dual function of increasing groundwater levels and improving its quality (see detail in Chapter 4).

Because vetiver hedgerows can do such a good job in reducing runoff, they are also very effective in flood control, both in the upper watershed catchments and on the floodplains. Flood control means a reduction in the volume of runoff rainwater and a slow down or delay in the release of floodwater. Because vetiver hedgerows slow down the movement of water, they are also reducing the rate of soil erosion, and are retaining the soil that is eroded in the areas adjacent to the hedgerows, forming natural terraces in front of the hedgerows, and not in downstream reservoirs, estuaries, etc.

4. The Role of Vetiver in Controlling Water Quality

Water may be contaminated through various activities: agricultural, domestic, or industrial. There are two main measures to keep water uncontaminated or clean, namely ‘prevention’ and ‘remediation’.

4.1 Prevention Measures

As in the case of human health, when dealing with the contamination of water, prevention is better than the cure. If at all possible, the vetiver system should be employed as a measure in preventing water body from being contaminated. It should be emphasized that this prevention measures work through the removal of liquid-borne contaminants *before* entering the water body, otherwise, the measure is considered ‘remediation’ (see detail in Section 4.2), which removes these contaminants *after* they have been present in the water body.

Currently two main methods of treating contaminated *water*, namely ‘*Engineering*’ *and* ‘*Biological*’*, are being used. The biological* method consists of *land-irrigation, wetland, and hydroponic systems.* Each system works through the removal or trapping/filtering of contaminants present either in: *(a) the leachates* (liquid leached from garbage landfill, quarry, farmland, etc.), or *(b) the effluents* (wastewater from septic tanks, city sewage treatment plants, plant nurseries, feedlots, cattle sheds, slaughterhouses, piggeries, etc.). *Note:* the terms, ‘leachates’ and ‘effluents’, are used here to mean any liquid containing contaminants prior to becoming the main water body. If the latter is the case, purification process is considered ‘remediation’.

4.1.1 Land Irrigation System: This system employs vetiver plants grown as a crop to dispose both the large effluent volume and to strip soluble elements (particularly N and P) or filter sediment-bound chemicals. Vetiver is currently being calibrated for application in Model for Effluent Disposal by Land Irrigation (MEDLI), a computer model being used in by the Environmental Protection Agency in Queensland, Australia, to regulate effluent disposal from various industries including sewage treatment plants, abattoirs and food processing plants. Results to date indicate that vetiver is at least twice efficient as Kikuyu and Rhodes grasses, the two commonly used species for effluent disposal in Queensland. Full results will be presented at ICV3 in October 2003 (Truong, pers. comm.).

4.1.1.1 Leachates: Many investigators have been able to remove or trap contaminants from agricultural, industrial, and garbage landfill leachates. These are discussed below:

(i) Agricultural Leachates: Modern cultivation of crops requires the application of fertilizers, growth substances, pesticides, etc. to promote crop growth and protect it from the attack of their enemies. The corps absorb not all substance Not all substance is absorbed by the crops, however. The surplus is leached from the farmlands. Sooner or later, it enters into the body of water. Residues of agricultural leachates, particularly pesticides, create a serious problem to the environment as they adversely affect flora and fauna in downstream aquatic ecosystems. Land irrigation system can be used to trap/filter nutrients, pesticide residues, and other toxic substances leached from the farms.

In His Majesty the King of Thailand’s ‘New Theory’ plots, there must be newly dug farm ponds to conserve water for use during the dry season, as well as to raise fish and other aqua-cultured creatures. To avoid the problem of their bank collapsing, vetiver was introduced, and it works! In addition, a few rows of vetiver hedges planted on the embankment of the pond help not only to stabilize it, but also to trap sediment-bound nutrients as well as residues of pesticides and other toxic substances carried along with them. As a result, only clear, clean water seeps through the thick vetiver hedgerows into the pond.

Another experiment conducted at the Huai Sai Royal Development Study Center, Huai Sai, Phetchaburi Province has proved that vetiver contour hedgerows planted across the slope form a living dam, while its root system forms an underground barrier that prevents water-borne pesticide residues and other toxic substances from flowing down into the water body below. The thick culms just above the soil surface also collect debris and soil particles carried along the water current and deposited in front of the vetiver hedgerows, thereby adding organic matter and moisture to the soil.

In Australia, experimental data obtained from sugarcane farms in northern Queensland indicated that vetiver hedges were highly effective in trapping particulate-bound nutrients such as P and Ca (Truong *et al.* 2000). The amounts of nutrients trapped varied with the cultural practices employed, ranging from 26 to 69% for P, and 51 to 56% for Ca. In order to retain these nutrients on site, these authors suggested the farm manager to establish vetiver hedges across drainage lines.

On cotton farms in central Queensland, vetiver hedges were effective in preventing herbicides (diuron, trifluralin, prometryn, and fluometuron), pesticides [organochlorine (□, □, and sulfate endosulfan) and organophosphate (chlorpyrifos, parathion, and profenofos)], and nutrients (N, P, and S) from leaving the farms (Truong *et al.* 2000). These authors have shown that during its first-year of growth, vetiver hedges were not very effective in trapping diuron herbicide, but fluometuron levels were greatly reduced. In the second year, the vetiver hedge trapped 48% of diuron.

As for pesticides, soil samples were collected at various distances upstream and downstream from the vetiver hedges grown on a cotton farm and analyzed for selected organochlorine (□, □, and sulfate endosulfan) and organophosphate (chlorpyrifos, parathion, and profenofos). During its first year of growth the vetiver hedges trapped 86% of total endosulfan in the sediment of runoff water and 67% of chlorpyrifos. In the second year, 65% of total endosulfan was trapped.

Similar to the results obtained in sugarcane farms, the vetiver hedges grown in the cotton farm trapped a significant amount of nutrients. During the second year, 73% of N in sediment was trapped as compared with 52% for P, and 55% for S (Truong *et al.* 2000).

Acid sulfate soils (ASS) are mechanically weak and the banks of farm drains in these soils are prone to collapse, dumping into drains eroded soil and sediments, which are highly acidic and loaded with heavy metals and nutrients. Vetiver was found to be highly effective in drain bank stabilisation in ASS, lower frequency of drain maintenance and reduce acidic loading by exposing less acid sulfate soil in the drain wall to oxidisation and leaching. The filtering effect of the vetiver grass on sugar cane farms will also limit the transport of sediments and cane trash into major waterways that should improve BOD and COD levels. A trial to test the use of vetiver to stabilize drain banks and trap sediment has been started at Pimpama, Queensland and will likely demonstrate the economic and environmentally effectiveness of vetiver grass in managing existing drainage networks. (Carlin *et al.* 2002.)

(ii) <u>Industrial Leachates</u>: 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. Similarly, leachates from the quarries also contain high amounts of several heavy metals. As these heavy metals are toxic to humans, their removal from the leachates must be done prior to their entering into the water body.

In Thailand, Roongtanakiat and Chairoj (2002) of Kasetsart University, conducted an investigation to determine the uptake potential of three ecotypes of vetiver grass, namely 'Kamphaeng Phet' (upland), 'Ratchaburi' and 'Surat Thani' (lowland). Varying amounts of Mn, Zn, Cu, Cd, and Pb were applied to one-month old vetiver grass in pots and harvested at 60 and 120 days after heavy metal application. The concentrations of heavy metals in the shoot and root of vetiver grass were determined by atomic adsorption spectrophotometry. It was found that the growth of vetiver plants was not affected by the application of heavy metals at the concentrations tested, and that heavy metal uptake by the three ecotypes of vetiver was inversely proportional to the concentration of heavy metals applied.

(iii) <u>Garbage landfill leachates</u>: This is a special type of leachates which may contain nitrates and phosphates as in domestic leachate, or pesticide residues as in agricultural leachate, and heavy metals and other hazardous substances as in industrial leachate, depending on what constitutes the garbage.

In many large cities, garbage is deposited as landfill to decompose. Such landfills produce leachates that contain various matters, including heavy metals and other toxic substances. One approach to use vetiver to trap these harmful substances is to grow in a strip around the garbage landfill. Strip of vetiver hedgerows would not only prevent seepage, but would act as a barrier to the movement of contaminants by wind or other means.

At one of the garbage landfill located at Kamphaeng Saen District, Nakhon Pathom Province, 90 km northwest of Bangkok, 5,000 tons of garbage are being dumped daily. A section has been allocated for the planting of vetiver to trap the leachate. After four months, it was observed that the plants were able to survive fairly well, despite the presence of leachate and toxicity normally expected of such a dumpsite (Hengchaovanich 2000). Parallel laboratory experiments were being conducted at Kasetsart University using conventional technique, and at Chulalongkorn University using radioactive technique to assess its performance. Both are discussed below:

Roongtanakiat (2002) conducted a field trial at Kamphaaeng Saen on domestic garbage landfill site as mentioned above, and laboratory experiment at Kasetsart University in Bangkok. Using ‘Surat Thani’ vetiver ecotype, she was able to demonstrate that vetiver plants could survive although their height was reduced, but with higher concentrations of heavy metals being absorbed into the shoot and root when fed with leachate of higher concentrations of heavy metals.

To investigate the growth characteristics and the uptake ability of vetiver grass for heavy metals in the soils and garbage leachate, Chayotha *et al.* (2002) planted vetiver on a garbage landfill at Kamphaeng Saen, 90 km northwest of Bangkok, and in pots as a parallel experiment in the laboratory at Kasetsart University in Bangkok. It was found that vetiver can be grown in polluted environment of organic decomposition derived from garbage leachate. Using Atomic Absorption Spectrophotometer technique, the investigators found that vetiver could absorb from the garbage landfill, the following amounts of heavy metals (mg/kg): Zn 54.6, Cu 9.9, Pb 4.0, Cr 2.6, and Ni 6.7.

Using X-ray fluorescence spectroscopy (XRF) and Instrumental Neutron Activation Analysis (NAA), which are very fast, highly accurate and non-destructive testing, Chanyotha and Nirunrat (2000) found that five toxic heavy metals, namely Pb, Zn, Cu, Ni, and Cr which were irrigated by industrial leachate/ wastewater and absorbed by vetiver could be analyzed by XRF. However, only Cr and Zn could be found when using NAA, due to the high sodium content in the sample. The amount of such heavy metal concentrations was mostly determined by XRF technique. The results showed that for vetiver irrigated by industrial leachate, more Cu and Cr were found in the shoot than in the root, while vetiver irrigated by industrial wastewater, less Zn, Cu, Ni, and Cr were found in the shoot than in the root.

Bannasak (2001) also conducted an experiment to study the ability of vetiver grass in up-taking Pb and Zn from Pb and Zn mine tailings. Vetiver was planted on two different tailing concentrations and was amended with different types of fertilizer. The concentration of Pb and Zn accumulated in vetiver grass was analyzed by using XRF technique. The results of vetiver planting on Pb tailings showed no difference among concentrations, but the results of vetiver planting on Zn tailings indicated that different levels of Zn concentration and types of fertilizer applied, had significant effect on the growth of vetiver grass.

Using ^{32}P isotope, Mahisarakul *et al.* (2002) were able to trace nutrients and heavy metals absorbed by the vetiver plants grown in cement cylinders (150 cm diam. and 150 cm high) on domestic garbage dump of Doi Tung Development Project in Chiang Rai Province, Thailand. It was found that vetiver roots were heavily distributed in the upper 30-cm depth, and the amount was reduced successively at the depths of 60, 90, and 120 cm. The amount of leachates and sediments (drawn from the garbage cylinder through a tube) were much less in the treatments with vetiver (100, 75, 50% of the area) than without vetiver at all stage of growth of the vetiver plants. The highest amount of the isotope was found in the roots at the depth of 90 cm. They concluded that vetiver can be used to grow on garbage landfill to help absorb the pollutants.

In China, Xia *et al.* (1998) studied the effects of vetiver in removing toxic substances from urban garbage leachate. It was found that of the seven parameters measured in the study, removal of ammoniac nitrogen was the highest, at the rate of 83-92%. Furthermore, vetiver was found to have strong absorption abilities to ammoniac N dissolved in water. In addition, vetiver showed a quite high removal rate for phosphorus (more than 74%). Results also indicated that vetiver was the best among the four grass species tested in terms of their removal abilities and their tolerance to high leachate concentrations.

Depending upon the contaminant levels in the leachate, land irrigation can also be used for its disposal. A project is currently underway in northern NSW, Australia to plant vetiver as a crop to treat a large volume of leachate from a landfill site (Truong, pers. comm.).

4.1.1.2 Effluents: Effluents are wastewater with certain amounts of contaminants. They are classified as: (i) domestic, (ii) agricultural, and (iii) industrial effluents. They usually contain high amounts of nitrates and particularly phosphates, which will cause environmental problem if they are drained into the body of water.

(i) Domestic effluents: There are two kinds of domestic effluents 'black' and 'grey' waters. The former is sewage of the toilets while the latter is washing water from kitchens and bathrooms.

If planted to intercept the flow of such effluents, vetiver would prevent the effluent from reaching the water body. In addition, vetiver would help dry up the effluent. Under these conditions vetiver will grow extremely well and will remain green throughout the year.

Truong and Hart (2001) have conducted a series of experiments on using vetiver to treat the effluent from the domestic sewage. Among these are:

- Vetiver was used to treat the effluent from a holiday camp on the shore of a lake, which provides raw water for making water supply for the city of Brisbane in Australia. Eight rows of vetiver were planted on a cut slope where the soil was very poor, to both stabilize the steep slope and to absorb the effluent. The first three rows of vetiver absorbed all the effluent, which previously ran down the slope. It was found that the first three rows grew luxuriantly, reaching almost 2 m in eight months. The next five rows down the slope, however, were less than 1 m tall showing nutrient deficiency symptoms, indicating that the absorption was so complete.
- At the Beelarong Community Farm in Brisbane, Australia, vetiver was used to dispose the discharge from a septic system on site. Vetiver was found to be more than 2m tall in a period of five months. A stand of about 100 vetiver plants in an area less than $50m^2$ has completely dried up the effluent discharge.
- A project is underway at Toogoolawah, a small town north west of Brisbane, to use vetiver to treat primary treated effluent from the town sewage treatment plant, instead of building a secondary treatment plant. This is very costly to build and maintain and not economical for a small town (Truong, pers. comm.).

(ii) Agricultural effluents: These effluents are produced from various agricultural activities. Plant nurseries, feedlots, piggeries, dairy sheds, chicken houses, slaughterhouses, etc., produce a large quantity of such effluents that are oozing onto nearby land and into streams and ditches. If vetiver grass were planted to intercept the flow of such effluents, it would do much to stop the effluent reaching water body and drying up the mess. Vetiver would grow extremely well and will remain green throughout the year.

Effluents from plant nurseries create environmental problems, as they contain high amounts of nutrients from both surface and drip fertigation. One of the largest flower nurseries near Brisbane, Australia faced with the problem of disposing a large volume of effluent runoff from the nursery floor and potting sheds (Truong and Hart 2001). An area of 320 m^2 was planted with vetiver at the density of 8 plants/m^2. Under the rich source of nutrient and plentiful supply of water, vetiver reached the full size of over 2 m in height after five months. This area of vetiver could absorb all the effluent generated by this nursery, even during the rainy season.

(iii) Industrial effluents: Using the MEDLI model mentioned above, vetiver is being trailed to treat 2.2 million litres of effluent (160mgN/L and 55mgP/L) discharged from an abattoir near Brisbane. A total area of up to 64ha is anticipated to be used for vetiver planting on this site (Truong, pers. comm.).

At a gelatine production plant, vetiver is also being considered to dispose of 2 million litres of effluent (300mgN/L and 5mgP/L) discharged from the factory. A total area of up to 231 ha is anticipated for use in vetiver planting on this site (Truong, pers. comm.).

With the potential of removing very high amounts of nitrates and phosphates, and very rapid growth, the vetiver system can be used both to reduce the volume, and to remove nutrients in effluent from septic tanks, plant nurseries, feedlots, slaughterhouses, piggeries, and other agro-industrial factories.

4.1.2 Wetland System: Wetlands are low-lying areas with water and aquatic plants growing. There are two types of wetlands: natural and constructed. Natural and constructed wetlands have been shown to be effective in reducing the amounts of contaminants in runoff from both agricultural and industrial lands. The use of wetlands for the removal of contaminants involves a complex variety of biological processes, involving microbiological transformations and physio-chemical processes such as adsorption, precipitation, or sedimentation.

Vetiver grown in the constructed wetland can be used to remove or trap contaminants from leachates and effluents.

4.1.2.1 Leachates: Vetiver has been used by various investigators in many countries to remove contaminants from domestic, agricultural, industrial, and garbage landfill leachates.

(i) Agricultural leachates: Contaminants contained in agricultural leachates include fertilizer and pesticide residues.

Cull *et al.* (2000) undertook a glasshouse trial in Australia to assess the potential for using vetiver and three wetland species in constructed wetlands, which receive agricultural leachates containing varying concentrations of two commonly used herbicides, atrazine and diuron. It was found that vetiver could reduce residues of both herbicides while its growth was not adversely affected by application of both herbicides at the rates up to 2,000 □gL^{-1}.

Wetlands are also popularly used in reducing the amounts of pesticide residues in the leachates.

(ii) Industrial leachates: Currumbin Sanctuary is a small native animal sanctuary on the Gold Coast of Australia. Its intensive feeding program produces highly polluted runoff to the local environment. A wetland system using vetiver is being established to treat this leachate (Truong, pers. comm.).

(iii) Garbage landfill leachate: Leachate from the Likeng landfill site in Guangzhou, China was found to contain high concentrations of pollutants, well above the effluent limits, which could be harmful to flora and fauna in the surrounding environment (Xia *et al.* 2000). Among the four plant species tested vetiver grass was the least affected by high (HCL) and low (LCL) concentration leachates. The tolerance to garbage leachate was ranked as vetiver > alligator weed > Bahia grass> water hyacinth. Of all seven pollutants measured ammonia N was found to be most effectively absorbed by vetiver, at about 80% in HCL and nearly 90% in LCL. Vetiver also showed a quite high absorption rate for P, over 74%.

4.1.2.2 Effluents: Wetlands are used to remove or trap contaminants from agricultural, domestic, and industrial effluents.

(i) Domestic effluents: At the Toogoolawah treatment site mentioned above, in wet weather the excess effluent runoff from the vetiver plot will be diverted to a wetland down slope and further treated with vetiver to comply with EPA requirement (Truong, pers. comm.).

(ii) Agricultural effluents: Wetlands are particularly suitable for use to treat agricultural effluents, especially from livestock sheds.

Effluents from livestock sheds contain high amount of waste products. Of all livestock sheds, piggeries created the severest problem to the environment, as they are present in large numbers, many of which are concentrated in small areas. The case of piggeries in China can be cited.

Liao (2000) conducted a study on purification of piggery effluent through the use of constructed wetlands with vetiver and 11 other species. It was found that vetiver and *Cyperus alternifolius* were the two best species on the basis of plant growth in piggery effluent and effective decontamination.

(ii) Industrial effluents: Trials are also being carried out in Australia to use vetiver in the treatment of effluent from the expanding wine industry (Truong, pers. comm.).

4.1.3 Hydroponic System: Using a floating platform, vetiver can be grown hydroponically in the water with its root immersed in the water. Hydroponic system can be used to remove contaminants from leachates or effluents, which are drained into the pond. The advantages of this system using platform method is that vetiver tops can be harvested easily for use as livestock feed, mulch, mushroom growing, etc., while its roots can also be removed for essential oil extraction or used as crude pesticide to control termites.

4.1.3.1 Leachates: Due to practical difficulty in draining leachates into a pond, there has so far been no attempt to use vetiver growing on the floating platform to remove nutrients, heavy metals, or toxic substances from the leachates of various sources.

4.1.3.2 Effluents: In theory, vetiver grown on floating platforms can be used to remove nutrients, heavy metals, or toxic substances from effluents of various sources. However, only domestic effluents have been attempted.

To determine the efficiency of vetiver in improving the quality of domestic effluent, a hydroponic trial was conducted using a mixture of black and grey waters (Truong and Hart (2001). Their results confirm the Chinese research in that vetiver could remove most soluble N and P in effluent over a very short period of time, and thus eliminating blue-green algae in the eutrophicated water.

Research is also being conducted to treat black and grey effluent discharged from a motel in Australia by Vetiver Modules. Full results will be presented at ICV3 in October 2003 (Truong, pers. comm.).

4.2 Remediation Measures

Remediation is defined as "the process of remedying or cleaning up deteriorated, contaminated or intoxicated soil and water". If microorganisms are used to remediate, the process is called 'bioremediation'. The use of plant to clean up deteriorated, contaminated or intoxicated soil and water is called 'phytoremediation'. However, the term 'remediation' is generally used even when plants are used to clean up contaminated water.

4.2.1 Kinds of Contaminated Waters: In the case of a body of water, which has already been deteriorated, contaminated or intoxicated (from here on, only the term 'contaminated' will be used to save space), purification can be done by removing contaminants from the body of water. Many terms have been used in the literature to describe the nature of liquid-borne substances that contaminate the water, such as wastewater, polluted water, and eutrophicated water. There is a little difference in the meaning of these terms and many authors used them interchangeably. In this paper, however, attempts has been made to distinguish them, as given below:

4.2.1.1 Wastewater: Wastewater is one that contains the liquid-borne *waste products* (organics, solids, and nutrients) of domestic, agricultural, and industrial or manufacturing activities. It is similar to eutrophicated water (see later), especially in the presence of plant nutrients such as N and PO_4 which favor the growth of algae; however, wastewater can also contain other organic and solid matters. Apart from the odor, the health risks created by this waste are enormous and include the source of typhoid and dysenteric diseases as well as breeding grounds for mosquitoes. Most of these 'residential' areas have no drains, no potable water, and no paving. Water and sewage stagnates adding to the misery of living conditions (Grimshaw, pers. comm.).

Depending on the origin, three kinds of wastewaters are known, namely:

(i) Domestic wastewater: This is the water derived from human domestic activities, such as water from toilet (also known as 'black water'), sink, shower, and kitchen flows; and water used in washing or flushing (also known as 'grey water').

(ii) Agricultural wastewater: This is the water derived from agricultural activities, mainly from fertilizer application and secretion and disintegration of plants and animals, and excluding those that contain harmful pesticide residues.

(iii) Industrial wastewater: This is the water derived from industrial or manufacturing activities, mainly of organic origin, and excluding those that contain harmful substances of inorganic origin.

4.2.1.2 Polluted Water: Polluted water is water contaminated with *harmful* substances resulting from agricultural and industrial processes. Such substances include (i) heavy metals, e.g. Pb, Hg, Cu, Cd, Cr, As, (ii) pesticide residues, e.g. insecticides, fungicides, herbicides, (iii) other harmful compounds. Upon entering into water body, elevated concentrations of these toxic substances pose a significant risk to human and animal health. Depending on the origin, polluted water can be classified into domestic, agricultural and industrial polluted water.

4.2.1.3 Eutrophicated Water: Eutrophicated water is one which is rich in mineral and organic nutrients that promote a proliferation of aquatic plants, especially blue-green algae consuming nearly all the oxygen, especially during warm weather, choking the fish, and often causes the extinction of other organisms. The characteristic of eutrophicated water is the promotion of algal growth due to the presence of high amounts of N and PO_4. Depending on the origin, it can be classified into domestic, agricultural, and industrial eutrophicated water.

It should be noted that these three terms are closely related and can be used almost synonymously. Another term that is used to include all three is 'contaminated water', which implies impurity of the water without specifying the kind of contaminants, whether they are waste products (wastewater), harmful substances (polluted water), or nutrients (eutrophicated water). However, some wastewater, like leachate from garbage landfill, may also contain harmful heavy metals. Similarly, eutrophicated water may also contain harmful pesticide residues. Thus, these terms should not be used strictly. Their usage in the present paper is to provide clear understanding of the main constituents of the contaminated waters.

As vetiver thrives in wetlands, it is highly suitable for the wetland system to remove waste products, pollutants, or nutrients from wastewater, polluted water, or eutrophicated water, respectively. The process of removing contaminants from contaminated water is known as 'purification'. Purification of each type of contaminated water is discussed below:

4.2.2 Purification of Contaminated Waters: Vetiver has been experimentally shown to be able to absorb elements and nutrients from wastewater, polluted water, or eutrophicated water.

4.2.2.1 Purification of Wastewater: In Thailand, Jatiyanikornkul (1986) investigated the possibility of using vetiver in purifying domestic wastewater. She employed five varieties/ecotypes of vetiver, namely: 'Brazil', 'Sri Lanka', Ratchaburi', 'Surat Thani', and 'Indonesia'. The treatments included mixtures of wastewater and fresh water of five levels, viz.: 0, 25, 50, 75, and 100% of wastewater. It was found that at the mixtures of 75 and 100%, the height, culm size, and biomass of the vetiver plants were significantly different from employing fresh water alone. Furthermore, the 'Brazil' variety was found to absorb high amounts of N, K, Ca, and Mg; the 'Indonesia' variety could absorb higher amount of P than other ecotypes/varieties; and the 'Brazil' variety could absorb high amounts of Pb and Cd. In addition, the 'Indonesia' variety could absorb as high as 4.9 ppm of Pb in the culm.

Sripen *et al.* (2000) used five vetiver ecotypes, namely 'Ratchaburi', 'Surat Thani', 'Indonesia', 'Sri Lanka', and 'Brazil' to treat three kinds of wastewaters, namely domestic, milk-industrial, and agricultural, found variable amounts of N, K, Ca, Mg, Pb and Cd deposited in the shoot and root of vetiver grown in the three wastewaters. They concluded that vetiver can be used as a biological wastewater treatment.

Chantkaeo *et al.* (2002) did 'constructed wetland' experiment using 'Indonesia' and 'Sri Lanka' varieties of vetiver to purify domestic wastewater. In their experiments, two systems were employed; one with wastewater drained into the wetland (5x100 m) for five days and allowed the wetland to dry for two days; the other was to supply wastewater continuously to the wetland and allow it to overflow through the wetland with one day standing. It was found that in the first system with five-day standing and two-day dry, a total volume of wastewater passed through the system per cycle of seven days was 232.5 m^3 with the waste of 4.13 kg BOD. The second system with overflow wastewater with one-day standing water in the wetland, a total amount of wastewater is 59.99 m^3/day and wastewater of 0.93 kg BOD/day. It can be seen that the amount of wastewater passed through the first system (5-day standing and 2-day dry) was higher as the system was allowed to dry, and when more wastewater was added, a volume was penetrating the cavities of the dry soil, thus consuming more water. However, considering the period of water standing, the second system with overflow consumed more wastewater.

In Australia, vetiver was used very successfully as an integral part of a water purification program in removing waste products from septic tank effluent (Truong and Hart (2001).

4.2.2.2 Purification of Polluted Water: Experiments conducted in Thailand on polluted water indicated that vetiver had the ability to uptake heavy metals and accumulated in the shoots and roots. Sripen *et al.* (1996) found that vetiver can absorb substantial quantities of Pb, Hg, Cd in polluted water.

Vetiver can tolerate very high level of As in the water, but most of the As absorbed remained in the roots (90-95%). Such an approach is used in Australia to rehabilitate gold mine tailings, which are very high in As and stock can safely graze it (Truong, pers.comm.).

4.2.2.3 Purification of Eutrophicated Water: As soluble N and particularly P are usually considered to be key elements responsible for water eutrophication which normally leads to blue-green algal growth in rivers and lakes, the removal of these elements by vetiver is a most cost-effective and environmentally friendly method of controlling algal growth.

With intensive farming adjacent to these water bodies, the quantities of N and P are bound to increase. Removal of these elements can be achieved by: (i) 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 occurred, and (ii) growing vetiver hydroponically on floating platforms which could be moved to the worse 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 (Truong and Baker 1998).

Research in China has shown that the vetiver system can be used to remove high soluble N and P concentrations in eutrophicated river water (Zheng *et al.* 1997). It was found that vetiver can reduce soluble P up to 99% after three weeks and 74% of soluble N after five weeks. The authors were of the opinion that the vetiver system has the potential of removing up to 102 tons of N and 54 tons of P/yr/ha.

From another experiment in China, it was found that vetiver, which was grown along the edges of the streams, or in the shallow parts of the lakes to first filter off the chemicals, and then grown hydroponically in water along banks, can effectively remove N and P. And, the water became more transparent after treatment (Xia *et al.* 1998; Zheng *et al.* 1998). These Chinese researchers and workers indicated that vetiver could remove dissolved nutrients, and reduced algal growth within two days under experimental conditions. Thus, vetiver can be used very effectively to control algal growth in water infested with blue-green algae.

5. Discussion

The unique advantages in employing vetiver as a means of controlling quantity and quality of water is its simplicity, low cost and minimal maintenance. This paper mainly deals with the role of vetiver in solving the problems related to water quantity and quality.

5.1 Advantages

5.1.1 Simplicity: "Make it simple" is His Majesty's frequent advice for all of his development initiatives, including those concerned with water resource. His Majesty favors simplifying complex situations, making confusing issues comprehensible, and using common sense to solve problems. The methods of using vetiver in controlling quantity and quality of water are quite simple.

5.1.2 Low cost: Application of the Vetiver System in wasteater treatment costs a fraction of the conventional methods such as chemical or mechanical means. In additon to appropriate design initially it only involves readily available locally produced planting materials and labor.

5.1.3 Minimal maintenance: When proprely established VS requires practicaly no maintence to keep it functioning. This is in sharp contrast to other means which need regular costly maintenance and a skilled operator, often an engineer, to operate it efficiently (Truong, pers. comm.).

5.1.4 Additional benefits: In treating effluent with vetiver, ultimately VS is a '*recycling plant*', not a treatment plant. In this application, by absorbing essential plant nutrients such as N, P and cations, vetiver will not only purify the wastewater but it will also store them for other applications. In Australia with large scale planting, for example 321ha at one site as mentioned above, this *recycling plant* is anticipating to provide high nutrient materials for animal feed, mulch for gardens, manure for organic farming, organic source for composting just to name a few (Truong, pers. comm.).

5.2 Water Quantity

Thailand is a country that repeatedly suffers from lack of water, not just fresh water, but any water for use in agriculture and consumption. The most recent situation in the early part of 2002 was one of the severest due to the El Nino effect. More than 50 provinces were affected, some very severely. The selling price for drinking water was more than that of oil, which was also expensive, as we had to import almost all amounts of oil.

Warning of water scarcity may sound strange at a time when many parts of the country, as well as many countries in all contents, are suffering from severe floods, many of which resulted in a great toll of human lives, their animals and their properties. However, there is a Thai saying, "Flood is better than drought!". This is true in normal situations, since Thailand usually suffers from drought more than flood. In most cases, it is only a matter of time before the flood recedes and soil becomes dry again. It is not surprising that drought has repeatedly occurred in many provinces of Thailand, especially in the Northeast. The successive floods and droughts in these provinces show the uneven distribution of water through the year, with most of the waterflow in the big rivers confined to just a few weeks. With not enough reservoirs to hold excess water, floods frequently occur during the heavy rains, followed by droughts afterward, as there is no regular supply of the water during the dry months.

As a tropical country in the humid region of the world, Thailand has enough rainfall, although its distribution is not regular in recent years due to the deteriorating environment, especially from deforestation.

Most of the suggestions to solve the problem of water quantity are difficult to implement. These include the halt of deforestation, massive reforestation, the construction of reservoirs and dams, setting up an alarm system, etc. The author wishes to suggest as an alternative approach; i.e. plant hedgerows of vetiver across the slopes in a newly established reforestation project. Most of the advantages of such an operation have been mentioned earlier. The only thing that remains to be brought into attention is its ability to reduce the greenhouse effect.

The extensive root system of the vetiver plant can absorb a large amount of carbon dioxide (CO_2). Although no direct measurement was made on the amount of CO_2 absorbed by a vetiver plant, a comparable study by two CIAT scientists can be cited. They claimed that two grass species in the savannas of South America might remove as much as two billion tons of CO_2 from the atmosphere annually. One of these grasses is *Andropogon guyanus*, a closely related species of vetiver. These CIAT researchers reported in the 'Nature' magazine, that the two grasses store as much as 53 tons of CO_2, as organic matter per hectare per year. This is because the extensive roots of this grass deposit the organic matter as deep as one meter in the savanna soil.

Just imagine with vetiver, whose roots are much more extensive and deeper than those two grasses, how much more CO_2 will be removed from the atmosphere and fixed in their root systems. If a hectare of deep-rooted grass absorbs 53 tons of CO_2, a square meter will absorb about 5 kg of this greenhouse gas during a year of growth. Comparable to these grasses, a full-grown clump of vetiver would absorb at lease 5 kg of CO_2 annually. If we could plant just a million clumps of vetiver, they will absorb 5,000 tons of CO_2. The Doi Tung Development Project in Chiang Rai alone, used to plant 100 million vetiver plants per year; that means that it alone has provided 500,000 tons of 'atmospheric cooling' benefit. By CIAT calculations, that is as much as CO_2 emitted by 100,000 cars, each driven 20,000 km. As the annual global increase in atmospheric CO_2 is estimated to be about 20 billion tons a year, we only need to plant 4,000 billion vetiver plants to absorb all this gas and we probably don't need air-conditioning to cool down the air round us (Vietmyer 1997; Enoch 1998).

Vetiver is truly a miracle grass, as it can do miracles, including the mitigation of disaster caused by destructive heavy rains, in addition to several other well-known benefits to agricultural and non-agricultural activities.

5.3 Water Quality

The information presented above clearly demonstrates that the VS are a very efficient and low-cost method for treating effluent and leachate from both domestic and industrial sources.

In the modern Thai community, we are now facing the ever-increasing problem of declining water quality, mainly due to contamination of various substances in the water, making it unsuitable for consumption.

Although there is a law in Thailand prohibiting the drainage of domestic and industrial contaminated waters into streams, rivers, lakes and oceans, reinforcement is not effective enough to stop such practices. Wouldn't it be better to treat such waters through land disposal that is more environmentally conscious. Besides, such waters can also be used to irrigate agricultural and recreational areas.

This paper has cited a number of cases, both in Thailand and abroad, where vetiver can be used in various systems, namely land irrigation, constructed wetland, and hydroponic, to purify domestic, agricultural, and industrial wastewater.

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