MANUAL

OF THE

INTERNATIONAL TRAINING COURSE

ON

THE VETIVER SYSTEM

ORGANIZED BY

OFFICE OF THE ROYAL DEVELOPMENT PROJECTS BOARD

IN COOPERATION WITH

THE CHAIPATTANA FOUNDATION

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Foreword

With financial support from the Heineken Breweries Co. Ltd., the International Training Course on the Vetiver System was organized during 19-30 November 2000 by the Office of the Royal Development Projects Board on behalf of the Chaipattana Foundation. There were altogether 31 trainees from 15 countries in all continents.

Although every trainee has received, during the period of instruction, a copy of all papers presented by the lecturers, yet they were still incomplete, due mainly to the lack of time to make them complete and to compile them in a bound volume. Moreover, very little editing has been done on the manuscripts. Yet they have served the purpose of good instruction since the trainees, many of whom have some English language difficulty, could follow the instruction quite well from the lecture notes given, without having to bother about writing down the lecture notes, thus could concentrate on the lectures alone. This was further facilitated by the PowerPoint presentations of all lectures with the idea to help the trainees to learn as much from the lecturers. By the end of the training course, each trainee received a set of CD ROM of all PowerPoint presentations as a gift from the Organizer. Time did not permit the Organizer, however, to compile all the lecture notes from different lecturers in a bound volume to present to them prior to their departure to their home countries since many of the lecture notes were still incomplete. It must be sympathized that all lecturers, in spite of being expert in their own fields, are all Thai national, whose English may not be fluent enough. Thus there is a need for some editing in order to make the Manual attains a high standard of publication.

The Editor, who is also the Course Director, takes full responsibility in the contents of this Manual, of which many mistakes may still be present, either typographical errors, English grammar, or scientific validity, as well as the different format of all the papers contained herein. Racing with time at all stages of preparation, this is the best he could do.

The Editor is thankful to all lecturers who were kind enough to prepare, on a short notice, their lecture notes, and to present them to the trainees. He also wishes to express his deep gratitude to the various vetiver experts around the world who had expressed concerns and gave valuable suggestions pertaining to the contents of this course. In particular, he is indebted to Dr. Paul V. Truong for giving the manuscripts of his lecture notes given at a training/workshop in the Philippines and the right to use them in this Manual. Special thanks are due to the staff of the Office of the Royal Development Projects Board who have worked so hard beyond the call of their duties to make this course one of the most successful and enjoyable ones.

Realizing that this is the first manual of its kind, it should be of some value to those people who are interested in the vetiver system. Thus, instead of presenting this bound volume of the Training Manual only to the sponsor of this training course, the lecturers and the trainees, it has been decided that it will also be distributed to all coordinators of the vetiver networks around the world as well as some vetiver experts who may wish to comment on the contents of this Manual in order to improve it, in case there is a chance for the Second International Conference on the Vetiver System in the future. Kindly send in your comments directly to the Editor by e-mail to <journal@au.ac.th>

Narong Chomchalow
Editor and Course Director
First International Training Course
on the Vetiver System

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1. INTRODUCTION

1.1 How Does This Course Originate?

The Heineken Breweries Co. Ltd. has decided to make a donation of $ 50,000 to the Chiapattana Foundation to promote the use and utilization of vetiver. Heineken has its green label image and is dependent upon sources of clean water for its products. So the company is interested in environmentally beneficial technologies, especially those that involve the conservation of clean water. The Office of the Royal Development Projects Board (ORDPB), the implementing arm of the Chaipattana Foundation, has decided to use this fund for two main activities: (i) training, and (ii) dissemination of technology. The topic of the training is the "Vetiver System" and is offered for both the international trainees from various countries and also for the Thai scientists and engineers working on vetiver. ORDPB, in cooperation with its various member agencies, is making preparation for both courses to be held in Thailand in November and December 2000, respectively. The main objective of this international training course is that after the training, the trainees will become familiar with the vetiver systems and the various technologies employed, appreciate what is being done in research, experimentation and application, and have concepts on how to promote the technology in their own environment.

1.2 What is The Vetiver System?

1.2.1 Definition of the Vetiver System: The Vetiver System (VS), originally known as the Vetiver Grass Technology (VGT), is *a low-cost, simple technology employing live vetiver plant for soil and water conservation and environmental protection.* VS is a very practical, inexpensive, low maintenance and very effective means of soil erosion and sediment control, water conservation, and land stabilization and rehabilitation. Being vegetative, it is also environmentally friendly.

1.2.2 Historical Background: The technology was first developed for the agricultural section by the World Bank for soil and water conservation, and later expanded to cover non-agricultural sector through bioengineering and phytoremediation for environmental protection such as slope and embankment stabilization, reclamation of wasteland, rehabilitation of contaminated land, water purification, pollution control, prevention or mitigation of natural disaster, etc.

1.2.3 Uses and Utilization of Vetiver: The main components of the vetiver system are the uses of live vetiver plant in agricultural (details in Chapter 6) and non-agricultural applications (details in Chapter 7), and utilization of dry vetiver plant which are by-products of vetiver grown for soil and water conservation in handicrafts, roof thatch, mushroom growing, animal fodder and feed stuff, industrial products, herbals, etc. (details in Chapter 8, also in Chart 1*)*.

1.3 How Does VS Work?

When planted in row, vetiver plant will form a hedge, a living porous barrier which slows and spreads runoff water and traps sediment. As the water 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 any eroded material is trapped by the hedges. Therefore, an effective hedge will reduce soil erosion, conserve soil moisture, and trap sediment on site.

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, particularly on sloping lands where this water is lost from the field. With the VS, not only this water is conserved but no land is wasted on the troublesome waterways.

Although most hedges can do that, vetiver plant, due to its extraordinary and unique morphological and physiological characteristics (see details in Chapter 4) can do it better than all other systems tested.

2. THE PERSPECTIVES

2.1 Vetiver: The Miracle Grass

2.1.1 Unique Root System: With its extensive fibrous root system which penetrates deep down into the soil at great depth (a specimen of 5.2 m was recorded, at the Doi Tung Development Project, Chiang Rai, Thailand during ICV-1, as the world's longest vetiver roots). Its roots were found to break through hardpan as thick as 15 cm. They were also found to have 'innate' power to penetrate a fairly thick layer of asphatic concrete. On slopes underlain with weathered rock, boulders or relatively hard layer, its penetrating roots will provide anchorage by root tendron action. Its action is comparable to a nail which could penetrate deep layers of soils whose texture may be quite hard, and at the same time it has the ability to hold soil particles together through its extensive fibrous roots, thus avoiding soil erosion due wind and water, making it well known among road engineers as the 'living nail'.

2.1.2 Unique Clumps when Grown as Hedgerows: The act of its clumps which are able to slow down the rapid movement of water and wind is really amazing. The direct benefits of this 'living wall' or 'living barrier' are: (i) increasing organic matter and moisture in front of the hedgerows, and (ii) acting as a sieve, and not allowing any debris to pass through but to accumulate in front of the hedgerow.

2.1.3 Unique Living Dam: The act of both the roots and clumps as a 'living dam' is also amazing. Their direct benefits are as follows: (i) adhere soil particles thus reducing soil erosion, (ii) increase the amount of organic matter collected in front of the hedgerow, (iii) increase moisture content in front of the hedgerow as the result of accumulation of organic matter and water, (iv) filter out toxic substances brought in by water and, after being absorbed in the plant tissues (see its tolerance later), these will slowly disintegrated, while clear and clean water is able to pass through this living dam.

2.1.4 Tolerance to a Wide Range of Environmental Stresses: The Vetiver System (VS) was first developed for soil and water conservation on the farmlands. While this application still plays a vital role in agricultural lands, vetiver's unique morphological, physiological and ecological characteristics, including its tolerance to highly adverse conditions, has played a key role in the area of environmental protection and land rehabilitation. These include tolerance to the following adverse conditions: (i) acidity, manganese and aluminum, (ii) salinity and sodicity, and (iii) heavy metals like arsenic, cadmium, copper, chromium, lead, mercury, nickel, selenium and zinc.

2.1.5 Ability to Absorb Toxic Substances: Not only vetiver can tolerate adverse soil conditions, but it can absorb toxic substances like pollutants, pesticides, and heavy metals into its biomass, thereby diluting such toxic substances in the soils and water, making them more safe in agricultural and non-agricultural activities. One such activity is the use of vetiver to purify eutrophicated water in the lake, leachate from garbage landfill, etc. It can also be used to absorb heavy metals from quarry, and such valuable metals can be recycled by extraction from the vetiver biomass.

2.2 The Initiatives

2.2.1 The World Bank's Initiative: VS has been practiced for more than 200 years by farmers in southern India (Karnataka) where it was used for soil erosion control and for the demarcation of farm boundaries. In other parts of India, it was used to stabilize rice bunds and inter-field channels (Orissa). It has also been used in the Philippines and Thailand to stabilize rice field bunds. The sugarcane industry which was booming during the turn of the century recognized its value for soil conservation; it was first used in the West Indies and South Africa, and later, in the 1950's, in Fiji, mainly on steep and erodible lands, based on the work of Mr. John Greenfield, who later, re-introduced the VS to India under the World Bank Project during the 1980's. Together with Mr. Richard G. Grimshaw, also of the World Bank, they developed the concept of Vetiver Grass Technology, which, after ICV-2 (18-22 Jan. 2000 in Thailand), has been changed to the Vetiver System (VS), into a viable system for soil and water conservation.

2.2.2 His Majesty the King of Thailand's Initiative: Since the day of His Majesty's accession to the throne in 1946, apart from his role as a king, His Majesty has also devoted himself to working hard to ease the people's hardship. He has initiated various development projects on water source, agriculture, health, career opportunity promotion, communication, and environment. "Soil conservation and development" is one of the environmental issues that His Majesty places great emphasis on, particularly in using vetiver for this particular purpose.

His Majesty recognized the problem of soil resource deterioration which aggravated rapidly day by day, and thus regularly conducted studies to find ways to solve the problem. It was in 1991 that His Majesty delivered the idea of carrying out an experiment on using vetiver for soil conservation. He kept track of the results, and periodically added more suggestions.

His Majesty's guidelines strongly focused on the development work in every field and subject. The ultimate objective is to care for the environment, especially in the conservation and development of natural resources in order to achieve sustainability and yield the most benefits. Loss of topsoil occurs in every region of Thailand especially in the North. His Majesty gave the ideas for starting the projects to conserve the topsoil using various methods, for example, planting big trees on steep slope and also as ground cover crop. However, the loss of topsoil still occurs because of deforestation which can very soon create environmental problem.

There is a wide range of usages of vetiver in Thailand under the Royal Initiative. His Majesty continually adds different benefits of vetiver on relevant several occasions to improve the environment, including soil, water, and forest resources.

His Majesty not only focused on the importance of vetiver by granting Royal Initiatives and advice, but also granted the King of Thailand Vetiver Awards worth $ 10,000. These awards were first bestowed in 1992, followed by the second one of the same amount at the occasion of holding the Second International Conference on Vetiver (ICV-2) in Thailand. These awards are for the outstanding works in two categories, one is for research, and the other for dissemination of the vetiver grass technology. In this instance, after having reviewed a total of 120 papers from various countries, the Committee on Development and Promotion of the Utilization of Vetiver Grass According to His Majesty the King's Royal Initiative selected six papers, three from each category to be eligible for winning the awards.

The use of vetiver grass which was introduced by His Majesty the King for conserving the environment can explain His Majesty's great concern for his subjects, as well as his remarkable recognition of the importance of protecting and solving the soil deterioration problem, by applying the concept of *"using nature to solve nature"*. This method is an economical means because vetiver is cheap and easily planted. Besides, farmers can apply on their own using the local wisdom. His Majesty also granted the principle of *"Self-sufficiency Economy"* for his people to adapt in their daily life, which would then lead to effective and sustainable management of the natural resources and environment, rendering benefits not only to Thailand, but also to the entire world.

2.2.3 The Royal Development Projects Board's Initiative: His Majesty King Bhumibol Adulyadej of Thailand has been dedicated to development work ever since the beginning of his reign in 1946. His Majesty has become familiar with the problems and real conditions of the people through constant visits to every region of the country, often accompanied by Her Majesty Queen Sirikit and other members of the Royal Family. It is during these many Royal visits to the rural areas that His Majesty has realized the need to initiate development projects that would directly benefit the people at the grassroots. Thus, the first Royal Development Project was launched in 1952 followed by numerous projects that currently reach the total of 2,700.

However, the implementation of the Royal Development Projects in the past lacked cohesiveness because each agency carried out the work on its own without coordinating with other concerned agencies. Therefore, in order to serve and implement the Royal initiatives through a consistently integrated system which allows the Royal Development Projects to run efficiently, the Thai government issued a "Regulation of the Office of the Prime Minister" which became effective on 9 September 1981. The Regulation led to the establishment of the Coordinating Committee for Royal Development Projects that later became the Royal Development Projects Board in 1993. The Board has the major task of directing, monitoring and coordinating the operation of government agencies and state enterprises concerning the Royal Development Projects. Moreover, it considers and approves projects, plans and activities as well as expenditures to be used in the operation of the projects. All of these tasks are supported by the Office of the Royal Development Projects Board (ORDPB), the secretariat of the Board.

With agriculture being the backbone occupation in the Thai society, His Majesty the King understood the vital need in preserving natural resources and therefore, initiated the vetiver project in Thailand. The project principally aimed to mitigate soil erosion, a distinct aspect of environmental deterioration in Thailand which needs to be managed properly, His Majesty recognized the potential of vetiver as a practical and inexpensive yet effective management and conservation tool to address the soil erosion problem. As a result, the Committee on the Development and Promotion of the Utilization of Vetiver (CODPUV) under His Majesty's Initiative was set up under the administration of the ORDPB in 1992 to look after all the Royally-initiated vetiver projects implemented in various parts of the country. This includes the Doi Tung Development Project in Chiang Rai, which is the venue for the organization of the First International Conference on Vetiver (ICV-1) on 4 to 8 February 1996 in Chiang Rai, Thailand. ICV-1 was co-organized by the Chaipattana Foundation and the Mae Fah Luang Foundation with the collaboration of the World Bank and the FAO. The main purpose was to commemorate the 50th Anniversary Celebrations of His Majesty the King's Accession the Throne.

Immediately after ICV-1, a proposal was made by Mr. Richard G. Grimshaw, President of the Vetiver Network, to establish the Pacific Rim Vetiver Network (PRVN) in Thailand with the principal objective of serving as the center to collect and disseminate information on the use of vetiver grass in the form of newsletters, occasional publications as well as a homepage on the internet. His Majesty the King agreed with the proposal and commissioned the setting up of the PRVN under the supervision of the CODPUV, to be administered by the ORDPB. The PRVN then became active with the establishment of a working team on 6 May 1997.

2.3 The Vetiver Plant

2.3.1 Taxonomy: Eleven species of *Vetiveria* are recorded, with distribution in tropical Asia (including Pacific Islands and Australia) and Africa. Two species, *Vetiveria zizanioides* (lowland - wide distribution in tropical Asia), and *V. nemoralis* (upland - restricted distribution in mainland Southeast Asia) are used in the Vetiver System (i.e. use and utilization). The former has also been used in essential oil production and as traditional medicine.

2.3.2 Ecology: The two species are able to grow in various types of soils from sea level to 800 masl. Both species need bright sun with high temperatures, but cannot stand low temperatures. It is a tropical grass which can well adapt to different environmental conditions. In Thailand, this grass can be found growing in a wide range of areas, from highlands to lowlands. The dominant vetiver grass species grown in Thailand is *Vetiveria zizanioides*. It appears with dense clumps and is fast growing through tillering. When planted vertically across the contour on slopes, the clump which stands above the ground will produce tillers, forming a green hedge. This makes it capable of trapping crop residues and silts eroded by runoff, leading to natural earth terrace formation. With a deep, dense root system spreading vertically, rather than horizontally, vetiver can be tolerantly grown under adverse conditions.

2.3.3 Physiology: In natural habitat, both species can set seeds and the seeds can germinate and establish new populations in suitable growing areas. However, the selected ecotypes and varieties used in cultivation rarely set seeds. Seed sterility is required for cultivated type in order to avoid the chance of it being escape from cultivation and becomes a weed.

2.3.4 Genetics: Seed sterility is obviously genetically controlled although its mechanism has not yet been confirmed through genetic study. While the seeded genotype of *V. zizanioides* is only used in northern India, the southern and sterile genotype is the main vetiver used for essential oil production and this is the genotype that is being used around the world for soil and water conservation and land stabilization purposes because of its unique and desirable characteristics mentioned above. The wild type of *V. nemoralis* is somewhat seedy while those ecotypes (no breeding has been attempted in this species yet, thus no commercial variety exists) selected for cultivation rarely produce seeds. Unfortunately, no genetic study has been made on any other characters except for those used in essential oil type.

2.3.5 Biotechnology: Through the use of new technology known as biotechnology, vetiver has been subjected to two kinds of studies, namely tissue culture method of propagation and DNA finger printing to determine their variation.

The first approach is to have rapid mass propagation using the explants derived from the young shoots of young inflorescence, and grow them in aseptic condition to produce cell mass known as callus, which is then allowed to multiply until enough is produced. With the change of nutrient, callus differentiates of into root and shoot of the plantlet, which is still in aseptic condition until attaining a good size before it is transferred to be grown in the nursery.

The latter approach is to use the new DNA fingerprint method such as Random Amplified Polymorphic DNA (RAPD) or Single-Strand Conformational Polymorphism (SSCP) techniques to study the variation within the species or populations of vetiver.

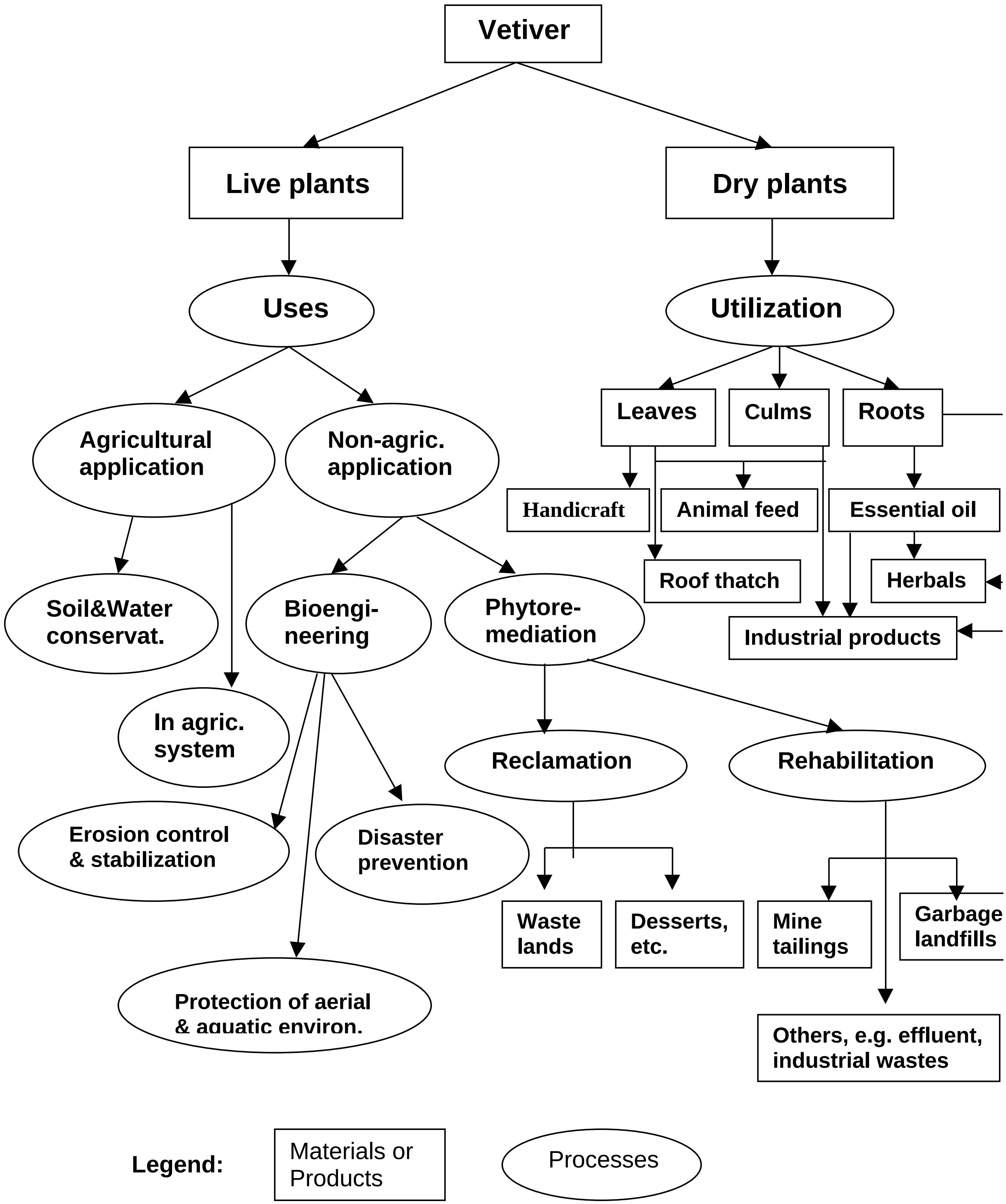
The RAPD technique is based on the amplification of genomic DNA with single primer of arbitrary nucleotide sequences. These primers detect polymorphism in the absence of specific nucleotide sequence information, and the polymorphism which functions as genetic markers, can be used to construct genetic maps. RAPD provide a simple, quick and reliable alternative to identify genetic variation whereas SSCP originally used as a quick technique to screen for nucleotide sequence polymorphism of the DNA mutation, has been developed to screen for genetic variants especially in nucleotide substitution at any position along a region of DNA. The SSCP is a simple method for detection sequence variations as small as single-base point mutations.

Kresovich *et al.* (1994) reported that genome of vetivers within the same clones generated stable RAPD patterns but were able to distinguish between various vetiver accessions. Srifah *et al*. (1996) investigated RAPD markers for detection among *Vetiveria nemoralis* A. Camus and *V. zizanioides* Nash.in Thailand. Adams and Dafforn (1999) found that 86% of 121 accessions of vetiver were appeared to be from a single clone (‘Sunshine’). The genomic relationships of 35 ecotypes of Thai vetivers and related taxa have been intensively studied by Srifah *et al* (2000) employing two different techniques of RAPD and SSCP methods. RAPD provided a simple, quick and reliable alternative to identify genetic variation whereas SSCP was used as to screen for nucleotide sequence polymorphism of DNA mutation. Although the ecotypic and phenotypic characterizations have been routinely used to identify vetivers in Thailand, the minor nucleotide variations may give rise to morphological, physiological and biological differences. The results showed that both SSCP and RAPD analysis of their DNA polymorphism are sufficient to distinguish each ecotype of *Vetiveria zizaniodes* Nash and *V. nemolis* A Camus.

2.4 The Vetiver System

2.4.1 Uses and Utilization of Vetiver: The main components of the vetiver system are the uses of live vetiver plant in agricultural (details in Chapter 6) and non-agricultural applications (details in Chapter 7), and utilization of dry vetiver plant which are by-products of vetiver grown for soil and water conservation in handicrafts, roof thatch, mushroom growing, animal fodder and feed stuff, industrial products, herbals, etc.(details in Chapter 8). *(See also Chart 1)*

Chart 1: Uses and Utilization of Vetiver



2.4.1.1 Uses of Vetiver: Involves any direct exploitation of live vetiver plant such as for soil and water conservation, slope stabilization, erosion control, environmental protection, etc. without having to change or process the vetiver plant into finished or semi-finished products. Application of vetiver in agricultural and non-agricultural systems, first developed by the World Bank for soil and water conservation in the 1980s. It is one of the most effective and low cost natural methods of environmental protection deriving from its tolerance to adverse soil conditions and heavy metal toxicities, and phyremediation, as well as in erosion protection and slope stabilization.

2.4.1.2 Utilization of Vetiver: Involves some kinds of processing of dead vetiver plants, including cut leaves, culms, roots, roots after essential oil extraction, etc. in the making roof thatch, for essential oil extraction, as a medium for mushroom growing, as raw material for handicraft making, as raw material for processing into industrial products (e.g. biodegradable nursery blocks or pots, construction materials, etc.). It does not include, however, the utilization of roots for essential oil extraction, since this requires the harvest of root mass which should be left in the ground to perform its main function in soil and water conservation.

2.4.2 Agricultural Applications: Traditionally, vetiver has been used for soil and water conservation in India for 200 years before the Vetiver System has been popularized in recent years. The basis of soil erosion and acceptance of soil conservation measures will first be discussed (in Section 6.1) in order to help the trainees to understand the principle of soil erosion and its consequences. The use of vetiver in soil and water conservation, including soil erosion and sediment control on sloping lnad and flood plain, flood erosion control and slope stabilization, etc., will then be discussed (in Section 6.2), followed by the works done by the Department of Land Development in northern Thailand on the use of vtiver in soil and water conservation in agricultural lands (in Section 6.3). The techniques of application of vetiver hedgerows on sloping farmlands will be discussed in Section 6.4 with demonstration of various apparatuses, to be held at the Chiang Rai Land Development Station during the study tour. Other benefits of growing vetiver like soil moisture conservation, watershed and catchment management, biological pest control, phytoremedial application, and trapping of agrochemical and nutrients will be discussed in Section 6.5.

2.4.3 Non-Agricultural Applications: It is undeniable that human activities are the main source of changes in the world geography and environment. Explicit examples of such acts include the explosion of mountains to build highways and railroads, drilling of mountains for mining, construction of dams across the rivers to build reservoirs, or the destruction of forest resources. Besides these, other causes include chemical changes in the atmospheres as a result of emission of gas or certain types of chemical substances, earthquakes, landslide and land subsidence, extinction of wild animal and plant species, as well as waves of extreme heat or drought which have occurred in several parts of the world. Undesirable and critical changes to the environment caused by man are now having impacts on human lives beyond control. Worst of all, one cannot anticipate the possible disastrous outcomes of this ongoing situation. Different methods including reliance of heavy machinery and cultivation of various crops have been attempted to resolve and prevent the problem. The use of vetiver in non-agricultural applications can be categorized as follows:

2.4.3.1 Bioengineering (prevention mechanism): Bioengineering is defined as the use of organisms, mainly plants, on its own in integration with civil engineering works, to address the problems of erosion and slope stabilization. In this regard, vetiver can be employed in the followings:

- ♦ Erosion control and slope stabilization
  - · Stabilizing soil and slope
  - · Trapping sediment
  - · Reducing runoff velocities
  - · Diverting flow
  - · Enhancing infiltration
  - · Protecting hard structure/soil interfaces
  - · Trapping agrochemicals and nutrients
- ♦ Erosion control and other stabilization
  - · Embankment stabilization
  - · Gully stabilization
  - · Catchment stabilization
- ♦ Protection of aerial environment
  - · Control of dust pollution
  - · Control of greenhouse gas

2.4.3.2 Phytoremediation (curing mechanism): The use of plants to clean up contaminated or intoxicated soils and water. Vetiver has been found to be quite efficient in the followings:

♦ Reclamation is the process of using certain methods, mechanical or biological, to reclaim deteriorated soils. The term is sometimes used synonymously with rehabilitation by many authors. In the present paper and in this training course, reclamation is used to make the deteriorated soils, which have been caused by natural phenomena or processes, suitable for crop cultivation. Such naturally-caused detriorated soils include:

- · Saline soil
- · Acid sulfate soil
- · Skeletal soil
- · Sodic soil
- · Sandy soil
- · Mangrove soil
- · Shallow soil
- · Steep-slope land

♦ Rehabilitation is the process of using certain therapy, mechanical or biological, to rehabilitate contaminated soils or water caused by human intervention. Thus, distinction can be made between reclamation and rehabilitation by the causes of such soils; if natural then the term reclamation is used; if man-made, then the term rehabilitation is used. However, sometimes, the term rehabilitation is used for such natural phenemena as "rehabilitation of cyclone-hit areas". Areas of land or water caused by human intervention which can be rehabilitated include:

- · Garbage landfills (where leachate is to be purified)
- · Mine tailings
- · Industrial waste dumping areas with heavy metal contamination
- · Effluent from aseptic tanks and piggeries, cattle and poulatry farms, etc.
- · Polluted water
- · Algal bloom in water body
- · Heavy metals in effluent disposal

2.4.3.3 Disaster prevention, mitigation and reclamation: A special phenomenon caused by natural phenomena such as storm, flood, runoff, etc. which result in disasters such as landslides, mudslides, collapse of infrastructures, dams, embankments, etc. Although can be discussed under bioengineering (as a prevention mechanism of disaster) and phytoremediation (as a curing mechanism of disaster), it is best to describe in a separate topic, which include:

- Storm mitigation
- Landslide prevention and mitigation
- Flood prevention and mitigation
- Stabilization of sand dunes

3. BASIC KNOWLEDGE ON THE VETIVER PLANT

3.1 Origin and Distribution

Vetiver belongs to the same group of the grass family[1/] as maize, sorghum, sugarcane, and lemongrass. Its botanic name, *Vetiveria zizanioides* (Linn.) Nash, has had a checkered history. At least 11 other names in four different genera have been employed in the past. Its generic name, *Vetiveria,* deriving from "vetiver," a Tamil word, meaning "root that is dug up", was given first by the great Swedish taxonomist, Carolus Linneaus, in 1771. Its specific epithet, *zizanioides*, means "by the riverside", reflects the fact that the plant is commonly found along the waterways.

3.1.1 Origin: The exact location of its origin is not precisely known. Most botanists concluded that it is native to northern India; some believed that it is native around Bombay. However, for all practical purposes, the wild plant inhabits the tropical and subtropical plains throughout northern India, Bangladesh, and Myanmar.

3.1.2 Natural Habitat: For a plant that grows so well on hillsides, vetiver's natural habitat may seem strange. It grows wild in low, damp sites such as swamps and bogs.

3.2 Botany of Vetiver

It is important to realize that vetiver are of two types; a crucial point, because only one of them is suitable for use around the world. If the wrong one is planted, it may spread and produce problems for farmers. These two types are:

· A wild type from North India. This is the original undomesticated species. It flowers regularly, sets fertile seed, and is known as a "colonizer". Its rooting tends to be shallow, especially in the damp ground that it seems to prefer. If get loose to other areas, it might become a weed.

· A "domesticated" type from South India. This is the vetiver that has existed under cultivation for centuries and is widely distributed throughout the tropics. It is probably a selection from the wild type. It is non-flowering, non-seeding (or at least non-spreading), and must be reproduced by vegetative propagation. It is the only safe type to use for erosion control.

It is not easy to differentiate between the two types, especially when their flowers cannot be seen. Over the years, Indian scientists have tried to identify distinguishing features. These include differences in:

- *Stems:* The South Indian type is said to have a thicker stem.
- *Roots:* The South India type is said to have roots with less branching.
- *Leaves:* The south India type apparently possesses wider leaves (1.1 cm *vs* 0.7 cm, on average)[2/]

[1/] *The actual family tree: Family Graminae (Poaceae), Subfamily Panicoideae (Andropogonidae), Tribe Andropogoneae, Subtribe_Sorghinae (BOSTID 1993)*

[2/] *Sobti and Roa 1977 (BOSTID 1993)*

- *Oil content. The South India type has a higher oil content and a higher yield of roots.*
- *Physical properties. Oil from the wild roots of North India is said to be highly laevorotatory (rotates the plane of polarized light to the left), whereas that from the cultivated roots from South India is dextrorotatory (rotates polarized light to the right).*
- *Scent. The oils from the two types differ in aroma and volatile ingredients.*

Whether these differences are truly diagnostic for the two genotypes is as yet unclear. However, at least one group of researchers considers that the two vetivers represent distinct races or even distinct species (CSIR 1976; BOSTID1993). Perhaps a test based on a DNA profile will soon settle the issue.

3.2.1 Taxonomy: Vetiver is a common name of the grass in the genus *Vetiveria* which consists of 11 species widely distributed in tropical regions of Asia, Africa, Pacific Islands, and Australia. These are:

Species	Distribution
1. *V. elongata* (R.Br.) Stapf ex C.E.	New Guinea, Australia
2. *V. festucoides* (Presl.) Ohwi	Japan
3. *V. filipes* C.E. Hubbard	New Guinea, Australia (Queensland)
4. *V. fulvibarbis* Stapf	Central and East Africa
5. *V. intermedia* S.T. Blake	Australia (Queensland)
6. *V. lawsonii* (Hook.f) Blatt. Et McCann	India
7. *V. nemoralis* (Balansa) A. Camus	Southeast Asia
8. *V. nigritana* Stapf	Central and East Africa
9. *V. pauciflora* S.T. Blake	Australia (Queensland)
10. *V. rigida* B.K. Simon	Australia (Queensland)
11. *V. zizanioides* Nash	Central and Southeast Asia

Of the 11 species of *Vetiveria,* all of which are coarse perennial grasses that are found in the tropics of the Old World which belong to the tribe Andropogoneae, only *Veteveria zizanioides* has proven ideal for soil and moisture conservation. Its numerous scientific names, of which the first one is valid, are as follows:

Vetiveria zizanioides Stapf.
Synonyms:
Andropogon zizanioides Linn.
Andropogon squarrosus Hack
Andropogon muricatus Retz.
Andropogon nardus Blanco
Andropogon nigritanus Stapf.
Andropogon festucoides Presl.
Andropogon echinulatum Koenig
Anatherum zizanioides Linn.
Anatherum muricatum Beauv.
Agrostis verticillata Lam.
Phalaris zizanioides Linn.

3.2.1.1 Taxonomic Position:

Family:	Poaceae (Gramineae)
Subfamily:	Panicoidae

Tribe: Andropogoneae

To find vetiver in a herbarium collection, it is necessary to check out previous given names. There has been a great deal of confusion over the naming of both the genus and the species. As recognized by the Kew Garden, *Vetiveria* species were distributed in the following countries:

Indochina:	*V. nemoralis* (poorly known, status doubtful)
India:	*V. zizanioides, V. lawsonii*
Japan:	*V. festucoides*
Australia:	*V. elongata, V. filipes, V. intermedia, V. pauciflora*
Madagascar:	*V. arguta*
Africa:	*V. nigritana, V. fulvibarbis*

There is an overall account of the genus at the Royal Botanic Gardens Herbarium, Kew, England, where most of the species have been described in one flora or another. Unfortunately these descriptions are not strictly comparable, and it would take some research to construct a reliable diagnostic key.

The lecturer personally believes that the specific epithet, *zizanioides*, from what we know about this grass, is inappropriate. He is fully aware that this name (meaning "by the river" - or "riverine") was given by the botanist who discovered the plant in India, where it was cultivated in the 'silty alluvium' of the river banks to make it easy to harvest the roots for oil. Two hundred years ago, nobody considered it an ideal plant for soil conservation. Thus, a more appropriate name for the species would be *V. ubique* - but that is up to the taxonomists.

3.2.1.2 Reference Data on* Vetiveria *spp.: A few other species of *Veiveria* have been recognized:

V. nigritana Stapf. = *Andropogon nigritanus*, Sahara, Sudan. The scented roots are used locally for perfuming clothes.

V. odorata Virey = *V. zizanioides* Stapf. = *V. odorata* = *Andropogon muricatus* (khus- khus, vetiver), tropical Asia, especially India, Sri Lanka and Myanmar. A heavy essential oil is distilled from the roots and is used in perfumery, mainly as a fixative. The roots are also used to make perfumed mats, baskets, fans, and so on. The plant is cultivated.(Greenfield 1995).

In Malaysia, D.H. Grist, writing in the Malayan Planting Manual No.2, "An Outline of Malayan Agriculture", refers to *V. odorata* as "a perennial grass, about four feet high (1.2 m)
with stiff erect leaves and aromatic roots. The essential oil is obtained from the roots by distillation and is used exclusively in perfumery on account of its fixed properties, as it prevents other essential oils from volatilizing too rapidly. This grass is propagated by <u>divisions of the root</u> *(this has been proven to be a wrong statement since the roots of vetiver cannot be used in propagation, see Chaper 5 – Ed.),* which are planted in rows three feet (0.91 m.) apart. The plants are ready for lifting after six to eight months, or just before flowering when the oil content is at its maximum."

"The yield of oil is highly variable and ranges from 0.5 to 3.3%, depending on the condition of the roots when lifted. With two crops per annum, each yielding about 1,000 lb (454 kg) of dry roots per acre (0.4 ha), and with an oil content of 2%, the yield of oil approximates to 40 lb per acre (45 kg/ha)".

"Owing to the ramification of vetiver roots, it is an expensive crop to harvest, and on this account, it is very doubtful whether its cultivation with paid labor would be a profitable undertaking under local conditions. The grass is of value for the purpose of holding up silt-pit bunds on steep and undulating land. The root system is very vigorous and assists materially in forming a compact bank of soil (a natural terrace)" (Greenfield 1995).

"Wealth of India" states: "*V. zizanioides*: A small genus of perennial grasses found in the tropics of the Old World. Two species are found in India, of which *V. zizanioides*, commonly known as vetiver, is the source of the well-known 'Oil of Vetiver', which finds use in medicine and perfumery. Vetiver oil was the original product making this an essential oil plant, but due to the extreme difficulty in digging up the roots, together with the cost of the operation, vetiver oil is not being produced in any quantity today".

World production was estimated at about 140 t, with Haiti, Reunion Island, and Indonesia (Java) as the principal producers. In general, the yield of oil is low, varying from 0.1% in India to a maximum of 2.0% in Indonesia. Interestingly, the oil (like the grass) is one of the most complex of the essential oils. Its chemistry is very complicated and not yet fully understood. Five kg of roots produce 25 to 50 g of essential oil (attar) (Greenfield 1995).

3.2.2 Species and Ecotypes of Vetiver Used in Vetiver System: Among 11 species of *Vetiveria,* only two are used in the vetiver system, namely *V. zizanioides* and *V. nemoralis.* The former has a broad distribution throughout the tropical regions while the distribution of the lattter is restricted to mainland Southeast Asia from Thailand, Lao PDR, Cambodia and Vietnam. In Thailand, the two species occur in open areas; *V. zizanioides* mostly in moist places, while *V. nemoralis* tends to be in drier area. Both species are naturally grown in a wide range of natural conditions, from the lowlands to the highlands, with the altitude from close to sea level to as high as 800 m.asl. A third species, *V.nigritana,* is native to southern and western Africa and its application is mainly restricted to the sub-continent. This species is a seeded variety, hence its application should be restricted to its homeland.

Vetiver is a tropical grass which can well adapt to different environmental conditions. In Thailand, this grass can be found growing in a wide range of areas, from highlands to lowlands. The dominant vetiver grass species grown in Thailand is *Vetiveria zizanioides*. It appears with dense clumps and is fast growing through tillering. The clump's diameter is about 30 cm with a height of 50-150 cm. The narrow, erect, and rather stiff leaf is about 75 cm long and 8 mm wide.

When planted vertically across the contour on slopes, the clump, which is raised above ground level, will produce tillers, forming a green hedge. This makes it capable of trapping crop residues and silts eroded by runoff, leading to natural earth terrace formation. With a deep, dense root system spreading vertically, rather than horizontally, vetiver can be tolerantly grown under adverse conditions. The roots densely bind together like an underground curtain or wall, enabling it to retain water and moisture (Nanakorn *et al*. 2000). Of course, as recognized that horizontal expansion of the vetiver root system being limited up to only 50 cm, it imposes no obstacle to the nearby plants, and is particularly considered being an effective measure for soil and water conservation. Vetiver hedgerows help retain soil moisture and surface soil and, at the same time, are suitable for combined cultivation along with economic crops. Growing vetiver grass is a simple and cost-effective method that has proved to be the most practical alternative in strengthening and sustaining the farming system in rain fed areas. Also, it can be adapted well to other areas for various natural resource and environmental preservation and conservation, such as along the banks of irrigation canals, reservoirs or ponds, along the roadsides and the approach of a bridge, as well as in forest areas (Nanakorn *et al*. 2000).

3.3 **Differences between *Vetiveria zizanioides* and *V. nemoralis***

3.3.1 *Vetiveria zizanioides* Nash: *V. zizanioides* is a kind of plant that can rapidly adapt to the environment. Most imported vetiver ecotypes, including those from India, Sri Lanka and Indonesia, are selected ecotypes, and planted under restricted conditions with careful manipulation to keep their original characteristics. For example, their leaves are regularly trimmed to accelerate growth of roots and tillering, as well as to prevent budding of inflorescence which minimizes the chance of cross pollination and mutation.

V. zizanioides that is commonly found in nature grows under various conditions and adapts well to those conditions. It produces a number of inflorescences and performs cross pollination every year. Cross pollination increases the genetic potential of plant in different aspects, i.e. tolerance to diseases and to critical climatic factors. However, it can also create variability, particularly in the roots that are used to extract its volatile oils, resulting in reduction or fluctuation of the quantity of volatile substances contained in the roots (Nanakorn and Chinapan 2000).

The leaf of *V. zizanioides* is 45-90 (100) cm long and 0.6-0.9 (1.2) cm wide. The upper surface of the blade is curved and the apex is flat and dark green. The texture is smooth and waxy. The lower surface of the blade is pale white. When holding the leaf against the sunlight, its septum can be clearly seen, especially at the base and middle of the blade. The midrib that is hidden in the blade is not clearly seen.

V. zizanioides grown for one year can produce the roots well above 1 m long. This some- how depends on the condition of the soil and physical condition of the grass itself. The roots will grow longest in loose sandy soil with good draining.

3.3.2 *Vetiveria nemoralis* A. Camus: *V. nemoralis*, the local *Vetiveria*, has a limited area of distribution. It is found only in the Southeast Asian region, i.e. in Thailand, Lao PDR, Cambodia, Vietnam and Malaysia. Moreover, there is no record of its uses.

V. nemoralis is commonly found in dry areas or in soil conditions with good draining in all regions of Thailand, especially in the dipterocarp forests, but hardly found in the South. This species grows well in the areas either with strong or moderate sunlight. The tip of the clump bends over the ground like lemongrass, not like that of *V. zizanioides*. At some places, the grass grows densely like a ground covering plant over a vast area, for eample at the Huai Kha Khaeng Wildlife Sanctuary in Uthai Thani province. *V. nemoralis* grown in dipterocarp forests is usually damaged by forest fires. Although the dry leaves serve as good fuel, the bottom of the clump is densely formed, thus preventing the grass from being totally destroyed. The grass is therefore capable of producing new leaves rapidly afterwards.

The leaf of *V. nemoralis* is 35-60 (maximum 80) cm long and 0.4-0.6 (maximum 0.8) cm wide, and is pale green. The upper surface of the blade flaps with a triangular ridge. The texture is coarse and a little waxy. The lower surface has the same color as the upper surface but somewhat paler. When holding the leaf against the sunlight, the septum is not distinctly seen. However, the midrib that is hardened and ridge-like structure can be clearly seen.

At the same age, the roots of *V. nemoralis* are shorter than those of *V. zizanioides*. Generally, the roots of a one-year-old vetiver plant can be as long as 80-100 cm.

The inflorescence of local *V. nemoralis* appears in many different colors depending on the specific ecotype. In Uthai Thani and Nakhon Phanom, the color ranges from beige to reddish purple (Nanakorn and Chinapan 2000).

3.4 Comparing the Differences between *Vetiveria zizanioides* and *V. nemoralis*

Vetiveria zizanioides	*Vetiveria nemoralis*
Origin	
- In mid Asia, Presumably India - Generally used for planting and multiplication	- Southeast Asia: Thailand, Laos, Cambodia and Vietnam - Widely distributed in natural conditions, hardly cultivated
General Morphology	
- Clumpy with long, erect leaves - 150-200 cm tall - Capable of ratooning and aerial branching	- Tufted with leaves bending down like lemongrass, - 100-150 cm tall - Normally incapable of ratooning and aerial branching
Leaf	
- 45-100 cm long and 0.6-1.2 cm wide	- 35-80 cm long and 0.4-0.8 cm wide
- Dark green, curved upper surface, white lower surface white a septum, texture clearly seen when held against sunlight	- Pale green, upper surface flapped with a triangular ridge, lower surface paler than upper surface, septum not clearly seen when held against sunlight
- Smooth texture, with wax coated giving soft and waxy appearance	- Coarse texture, with thin coated wax, rough appearance
Inflorescence and Spikelet	
- 150-250 cm long	- 100-150 cm long
- Mostly purple color	- Color varies from creamy white to purple
- Most florets without awn	- Florets with awn
Seed	
- Relatively large	- Relatively small
Roots	
- Mild fragrance containing 1.4-1.6 % volatile oils in dry weight	- No fragrance
- Can anchor 100-300 cm deep	- Shorter roots, can anchor 80-100 cm deep
Uses	
- Roots are used to extract volatile oils to make perfume, soap, and other products like handbag, fan, cloth hanger, herbal medicine and closet insect repellent	- Leaves are used to make roof thatching in some rural areas

3.5 What are the Uses of Vetiver?

Two main parts of vetiver plant are being made use of, namely culm/leaf and roots. The former is considered as one part because the culm is indistinguishable, especially in young plant; while the leaf is most obvious. The latter part, the root, is underground and has to be dug.

3.5.1 Culm/Leaf: The above ground portion of the vetiver plant, collectively known as culm (or stem of grass), and the leaf have been used in various ways, viz.:

- trapping crop residues and silts eroded by runoff
- roof thatching
- as raw material for making paper
- making ropes, mats, hats, baskets, etc.
- as animal fodder for sheep, cattle, etc.
- mulching, covering the ground of animal stables
- as planting material for mushroom culture and for making compost
- etc.

3.5.2 Roots: The extensive fibrous roots pf vetiver are very useful in both soil and water conservation and other utilization of the essential oils and other components. These are:

- absorbing water and maintaining soil moisture
- absorbing minerals and nutrients
- decomposed as organic matters, thus making the soil friable
- absorbing toxic substances in chemical fertilizers and pesticides
- improving the physical elements of the soil
- making screens, blinds, fans, handbags, etc.
- making herbs and skin care substances
- extracting volatile oils for making perfume and aromatic ingredients in soaps
- as insect and rodent repellentsothers

(Nanakorn *et al*. 2000).

3.6 Where can Vetiver be found as a Source of Planting Material?

Vetiver can be found between the latitudes 22^{o} North and South, in most areas where there is a permanent water body, be it stream, lake, or swamp; it survives as a climax plant (Greenfield 1988).

If vetiver is unknown in your area, you may track down through your local herbarium (in a university, botanical garden, agricultural department, etc.). If they have a specimen, the specimen sheet should specify from where it was collected. The sheet should also specify the local name(s) of the plant. If the plant is unknown, check either with the Vetiver Information Network, or the Royal Botanical Gardens at Kew in London (Grimshaw 1990).

3.7 Can Vetiver Grass become a Serious Weed?

There are voices of concern that vetiver grass may become a serious weed like cogon grass *(Imperata cylindrica)*, Burmese grass *(Pennisetum polystachyon)*, or giant mimosa *(Mimosa pigra)*, when introduced into other areas. Generally, vetiver propagates by producing new shoots from the main stem just above soil surface, and by branching at the joint of a mature culm that start to have inflorescence. Most spikelets are not subject to fertilization and the seeds, which are sometimes produced, are very thin, and have a short dormancy period. This allows it limited opportunity to germinate and spread like weed. However. farmers can control and eliminate these seedlings of vetiver grass easily by digging them out or by plowing. It never appears that vetiver becomes weed in areas where it has been introduced (Nanakorn *et al.* 2000).

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3.8 Microbiology Associated with the Vetiver Plant

3.8.1 Introduction: The major determinants of agricultural productivity in the tropics are climate and soil fertility. A number of climatic zones can be identified and these change more with topography than with latitude. The fertility of soil in the tropics varies, being heavily influenced by the nature of the parent rock. Many tropical soils are derived from very ancient parent rock and are highly weathered and leached, with consequent problems of nutrient deficiencies, or of acidity and associated toxicities. Soils in the tropics are low in nitrogen and phosphorus levels, and yet they continue to support most of the world's rice, cassava, sugarcane, oil palm and rubber production with virtually no addition of fertilizer.

The discovery of associative nitrogen-fixation system in the tropical grass has changed, the view of plant and soil microbiology interaction. In many tropical countries, vetiver can grow and survive without nitrogen and phosphorus fertilizer application, especially in the infertile soil. What or where is the nutrient source for vetiver growth and development? It was believed that the soil microbes are mostly effective and are associated with vetiver. Many heterotrophic microbes have been found in the soil surrounding roots, known as the "rhizosphere soil", in which bacterial growth is stimulated. Microorganisms often invade the surface tissue of roots, where they may cause a number of plant link for nutrient transport between the plant and soil, while the roots excrete soluble organic carbon compound, "polysaccharide", for soil microbial metabolism and adaptation. The soil microorganisms associated with vetiver root are nitrogen-fixing bacteria, phosphate-solubilizing microbes, mycorrhizal fungi and cellulolytic microorganisms.

3.8.2 Soil Microorganisms Associated with Vetiver: Two major groups of microorganisms are found to be associated with vetiver. They are bacteria and fungi.

3.8.2.1 The Bacteria:

(1) Nitrogen fixing bacteria: Many heterotrophic bacteria found in the soil are capable of fixing nitrogen. N_2 fixation is a biological process that some microorganisms produce nitrogenase enzyme which reduces the atmospheric nitrogen to biologically useful combined form of N-ammonia. Thus, N_2-fixation carried out by associative and free-living microorganisms in the rhizosphere of vetiver has been recognized to play an important role in nitrogen nutrient of vetiver. Diazotrophs belonging to diverse bacterial genera such as *Azospirillum, Azotobacter, Acetobacter alicaligen, Bacillus, Beijerinckia, Enterobacter, Herbaspirillum, Klebsiella and Pseudomonas.* Most of the N_2-fixing becteria are present on the root surface, or are found in intercellular spaces, or in dead cells within the root.

(2) Plant growth-regulator bacteria: Plant growth regulators (PGRs) are organic substances that influence physiological processes of plants at a very low concentration. PGRs include bacterial metabolites that affect plant growth; examples of PGRs are auxins, gibberellins, cytokinins, ethylene and abscisic acid. Many plant hormones (phytohormones), or their derivatives, can be produced by N_2-fixing bacteria such as *Azotobacter, Azospirillum, Bacillus* and *Pseudomonas*. Beneficial effects of these PGR bacteria have been attributed to biological nitrogen fixation and production of phytohormones that promote root development and proliferation, resulting in efficient uptake of water and nutrient, also antagonism against pathogens.

(3) Phosphate-solubilizing bacteria: Several soil bacteria, particularly those belonging to the genera *Pseudomonas* and *Bacillus,* possess the ability to change insoluble phosphates in soil into soluble form by secreting organic acids, such as formic, acetic, propionic, lactic, glycolic, fumaric and succinic acids. These acids lower the pH and bring about the dissolution of bound form of phosphate. Tropical soils are generally low in phosphate which is readily available for plant growth. So the phosphate-solubilizing bacteria is very important for vetiver growth and development. Since plants utilize only inorganic phosphorus, organic phosphorus compounds must first be hydrolyzed by

phosphatase enzyme which mostly originates from plant roots, through the action of fungi and bacteria.

3.8.2.2 The Fungi:

(1) Phosphate-solubilizing fungi: This group of fungi, belonging to the genera *Penicillium* and *Aspergillus*, can change insoluble phosphates in soil into soluble form that affects plant growth.

(2) Mycorrhizal fungi: Mycorrhiza (meaning fungus root) is the term used to indicate the symbiotic association between plant roots and fungus. There are two primary types of mycorrhizal fungal association with plant root: ectomycorrhiza and endomycorrhiza. Mycorrhizal plant increases the surface area of the root system for better absorption of nutrients from soil, especially when the soil is deficient in phosphorus. Yet another class of endomycorrhiza is known as vesicular-arbuscular mycorrhiza (VAM), which possesses special structures known as vesicles and arbuscular, the latter helping in the transfer of nutrient from the soil into the root system. These fungi are classified on the basis of their spore morphology into five genera: *Glomus, Gigaspora, Acaulospora, Scherocystis* and *Endogone.* Benefits of VAM associations include: (i) improved uptake of macro- and micro-nutrients, (ii) increased tolerance of stresses, and (iii) beneficial alterations of PGRs. These benefits result from fungal-root interactions, which are complex and dynamic. Many depend on physical, chemical, and biological composition of the soil.

(3) Cellulolytic microorganisms: Dead and decaying parts of plants and animals contribute to the primary source of organic matter in the soil. In order of abundance, the insoluble chemical constituents of organic matter are cellulose, hemicellulose and lignin, while the soluble constituents are composed of sugars, amino acids, and organic acids. Other constituents are fats, oils, waxes, resins, pigments, proteins, and minerals. Soil microbes can utilize the ingredients of organic matter in the soil by feeding readily on soluble resources and rather slowly on insoluble forms. Residues of younger plant with more soluble nutrient materials are more easily metabolized than branches of old tree with relatively higher woody tissue containing lignin. The nutritional composition of the substrate to be composted is a selective factor in that nutritional requirements vary greatly among different organisms. Many bacteria prefer amino acid and other N-containing substrates, whereas many fungi and actinomycetes prefer carbohydrates. Bacteria can utilize C/N ratio of 10:1 to 20:1, whereas fungi can utilize a wider ratio of 150:2 to 200:1, or even higher for wood decay fungi. So the cellulolytic microorganisms which surround vetiver root are of great importance to build up or decrease the organic-matter content in tropical soil.

(4) Antagonism fungi or fungi killer: Composted materials can also be benefited in the suppression of pathogens of horticultural and agricultural crops by microbial antagonism. In composted hardwood bark, the establishment of large population of *Trichoderma hamatum* and *T. harzianum* were strongly suppressive against damping-off caused by *Rhizoctonia, Pythium* and *Phytopthera.*

3.8.3 The Basic Research to Soil Microorganisms Associated with Vetiver in Thailand: Sunanthapongsuk *et al.* (2000) reported the study on soil microbial biodiversity in the rhizosphere of vetiver grass. The results revealed that the total soil microorganisms and cellulolytic microbes were in the range of 106 to 108 cells/g of dry soil. The amount of non-symbiotic nitrogen fixing bacteria and phosphate-solubilizing microorganisms varies from 101 to 104 cells/g of soil. The endomycorrhiza were 2.5 to 25.5 spores/100 g of soil. Most of microorganisms appeared in the areas of rhizosphere of the vetiver root. Soil pH and organic matter percentages affected soil microbial population.

Siripin *et al.* (2000c) concluded that 35 isolates of N_2-fixing bacteria could be screened from the vetiver root. Each strain has different potential in N_2-fixing ability and has difference in physiology and morphology of the colonies and the cells. N_2-fixing bacterial inoculation increased vetiver growth and development, particularly by increasing lateral root number, root dry-weight, number of tiller, plant height, branch-root number, root dry-weight, culm dry-weight, and total plant dry-weight. N_2-fixing bacteria produced PGRs which are similar to IAA, IBA, and GA, and affected lateral root number and total biomass. The inoculated vetiver with mixed strains of N_2-fixing bacteria showed the highest N_2-fixing ability; 30 to 40% of N_2 in vetiver plant were derived from the atmosphere by using ^{15}N isotope dilution method for measurement of N_2-fixing ability.

Patiyuth *et al.* (2000) revealed that the N_2-fixing bacteria *(Azospirillum)* produced plant growth hormone, idole-3-acetic acid (IAA) at 30-40 ug/ml in the broth media. *Azospirillum* grew well outside and inside the vetiver root.

Techapinyawat *et al.* (2000) reported that VA mycorrhiza inoculated to vetiver significantly increased plant biomass and the nutrient uptake.

3.8.4 Conclusion: Soil microorganisms which are associated with vetiver exhibited diversity among bacteria, fungi, etc. All soil microbes share their survival and adaptation with vetiver. Thus, soil microbes associated with vetiver do not only produce nutrient sources for vetiver growth and development, but also induce plant growth hormones that affect vetiver directly. We need to know more answers about these associations.

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4. SPECIAL FEATURES OF VETIVER

4.1 Morphological Characteristics

In its general aspect, a vetiver plant looks like a big, coarse clump grass, not very different from pampas grass, citronella grass, or lemongrass. It can, however, grow to be very tall. Under favorable conditions, the erect stems (culms) can reach heights of 3 m.

For purposes of erosion control, vetiver has a number of singular architectural and anatomical features:

- *Habit:* The plant has an erect habit and keeps its leaves up off the ground. This seems to be important in allowing the hedge to close up tight, and it also allows crops to be grown next to the plant.
- *Resistance to Toppling:* Unlike many grasses, vetiver is "bottom heavy." It shows no tendency to fall over (lodge), despite its very tall culms.
- *Strength:* The woody and inter-folded structures of the stems and leaf bases are extremely strong.
- *Year-Round Performance:* Although vetiver goes dormant during winter months or dry seasons, its stems and leaves stay stiff and firmly attached to the crown. This means that the plant continues stopping soil, even in the off-seasons or (at least for some months) after death.
- *Self-Rising Ability:* As silt builds up behind a vetiver plant, the crown rises to match the new level of the soil surface. The hedge is thus a living barrier that cannot be smothered by a slow rise of sediment. Like dune grasses at the beach, it puts out new roots as dirt builds up around its stems.
- *Underground Networking:* Vetiver is a sod-forming grass. Its clumps grow out, and when they intersect with neighboring ones they intertwine and form a sod. It is this that makes the hedges so tight and compact that they can block the movement of soil.
- *Clump Integrity:* For all practical purposes, vetiver has no running rhizomes or stolons[5/] This, too, helps keep the hedge dense and tight. The clumps do not readily die out in the center. Unlike most other clump grasses, even old vetiver plants seldom have empty middles.

4.1.1 Crown: The crown of the plant is generally a few centimeters below the surface of the ground. It is a "dome" of dead material, debris, and growing tissue, much of it a tangled knot of rhizomes. These rhizomes are very short - 1 cm or less - and are often turned back on themselves. It is apparently for this reason that vetiver stays in clumps and does not spread across the land. *(The statement that vetiver has short rhizomes has been proven to be wrong since vetiver, unlike some other plants, has no rhizome at all (see Chapter 5). The tillers grow from the base of the stout stem in all directions and finally form dense mass of the crown after the tillers produce more tiller-offsprings – Ed.)*

To separate the tillers for planting, the massive crown is cut apart. It is sometimes so huge that it has to be pulled out of the ground with a tractor and cut up with axes. In the nurseries, however, young tillers are easily separated.

4.1.2 Leaves and Stems: It is, of course, the leaves and stems that are crucial in this living-hedge form of erosion control. Vetiver leaf is somewhat like that of the sugarcane, but narrower. Although the blade is soft at the top, the lower portion is firm and hard.

On some vetiver types, the leaves have edges sharp enough to cut a finger. Actually, this is due to tiny barbs. There is a lot of variability, however. Some plants are fiercely barbed, some not. The ones used for oil and erosion control tend to be smooth edged. Topping the plants is an easy way (at least temporarily) to remove the troublesome of the barbs.

The leaves apparently have fewer stomata than one would expect, which perhaps helps account for the plant withstanding drought so well.

It is the stems that provide the "backbone" of the erosion-control barrier. Strong, hard, and lignified (as in bamboo), they act like a wooden palisade across the hill slope. The strongest are those that bear the inflorescence. These stiff and cane-like culms have prominent nodes that can form roots, which is one of the ways the plant uses to rise when it gets buried. Throughout their length, the culms are usually sheathed with a leaf-like husk. This possibly shields them from stresses; salinity, desiccation, herbicides, or pestilence, for example (National Research Council 1993).

4.1.3 Flowers: The flowers are borne in inflorescence, and the seed-heads are very large, up to 1.5 m long. Both are brown or purple in color. The flower's male and female parts are separated. As in maize, florets in the upper section are male and produce pollens; in vetiver, however, those below are hermaphrodite (both male and female).

4.1.4 Roots: Perhaps most basic to this plant's erosion-fighting ability is its huge spongy mass of roots. These are not only numerous, strong, and fibrous, they tap into soil moisture far below the reach of the roots of most crops.

They have been found at depths below 3 m and can keep the plant alive long after most surrounding vegetation has succumbed to drought.

The massive, deep "ground anchor" also means that even heavy downpours cannot undermine the plant or wash it out. Moreover, because the roots anchor steeply downwards, farmers can plow and grow their crops close to the line of grass, so that little cropland is lost when the hedges are in place.

The roots can grow extremely fast. Tilllers planted in Malaysia produced roots 60 cm deep in just 3 weeks.

It can be concluded that vetiver has special features in its morphological characteristics as follows:

♦ Vetiver grass has no stolon (unlike cogon grass which has). It has a massive finely structured root system that can grow very fast. This deep root system makes vetiver plant extremely drought tolerant.

♦ Stiff and erect stems which can stand up to relatively deep water flow.

♦ Dense hedges are formed when planted close together and form a very effective water spreader, diversion barrier and sediment filter.

♦ New shoots emerge from the base, helping it to withstanding heavy traffic and heavy grazing pressure.

♦ New roots are developed 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.

4.2 Physiological Characteristics

Like its relatives, maize, sorghum, and sugarcane, vetiver is among the group of plants that use specialized photosynthesis. Plants employing this so-called C_4 pathway, using CO_2 more efficiently than those with the normal (C_3 or Calvin Cycle) photosynthesis. For one thing, most C_4 plants convert CO_2 to sugars using less water, which helps them thrive under dry conditions. For another, they continue growing and "fixing" CO_2 at high rates, even with their stomata partially closed. Since stomata close when a plant is stressed (by drought or salinity, for instance), C_4 plant tend to perform better than most plants under adversity.

The vetiver plant is insensitive to photoperiod and grows and flowers year-round where temperatures permit. It is best suited to open sunlight and will not establish easily under shady conditions. However, once established, plants can survive in deep shade for decades. They tolerate the near darkness under rubber trees and tropical forests, for example (National Research Council 1993).

4.2.1 Physiology of Vetiver Seeds: In a study on the development stages from inflorescence to florets and seeds, the result indicated that, in optimum condition, seeds can germinate but vitality is very short. In normal conditions, disarticulation of mature seeds is gradually falling off and seeds able to germinate only in appropriate condition. Vetiver seeds are sensitive to environmental factors, hence, easily loose viability. So, there is no need to be concerned about their rapid distribution and turning into weeds. Due to low viability of vetiver seeds, the germination percentage is low.

4.2.1.1 Inflorescence: Vetiver has a straight tuft inflorescence, with the main axis plumose and quite long. The inflorescence and main axis are about 100-150 cm. However, in healthy individuals it can reach 200 cm. Inflorescence is about 20-30 (maxium 40) cm long, 10-15 cm broad; the color is purple or violet, which is rather common for the Thai vetiver.

In the Poaceae, the character of inflorescence is very important for identification, but in vetiver, the traits are easily confused, especially the length, width, and color. Actually, the inflorescence varies in shape and color according to its developmental stage. There are three stages as follow:

(1) Anthesis Stage: From emergence from the flag leaf to full blossom, it takes approximate 4-5 days. At this stage, the main axis elongates very fast. All parts of the inflorescence are full of water, nutrients, and plant hormones. The gland at the base of rachis is swollen; when fully turgid, it pushes the rachis to expand. The stamens are reflexed, hanging out from the spikelet, ready for anthesis.

(2) Post-Anthesis or Embryo-Development Stage: When the spikelet has been fertilized, the metabolism within inflorescence is decreased gradually. Basal glands will flatten and the inflorescence will become narrow again. Apical part of the inflorescence is fertilized prior to the basal part. This stage takes 8-10 days.

(3) Seed-Maturity Stage: The fertilized and fully developed spikelets are becoming larger, and stick together longitudinally along the main axis. This stage, the inflorescence is smaller and paler, and the embryo has developed into a seed. This stage takes 10-12 days. When the seeds are fully mature, they, together with the glumes, disarticulate with only the rachis left.

The total duration of the three stages from anthesis to disarticulation is approximately 20-28 days.

In each inflorescence, rachises are arranged in approximately 8-12 whorls at different levels. Each whorl consists of 6-18 rachises. Each rachis contains 10-20 spikelets. The total amount of spikelets varies between 600 and 1,500, depending on different factors, such as environmental, genetic, etc. (ORDPB 1995).

4.2.1.2 Spikelets: Vetiver spikelets are in pairs, and similar in appearance. Each pair consists of sessile spikelet and pedicelled spikelet, except at the terminal end of rachis which is usually ternate. Sessile spikelet is on the lower portion and is hermaphrodite, while pedicelled spikelet is on the upper portion, and is staminate. Each spikelet consists of 2 florets, normally reduced or abnormal. Only single floret appears while empty floret is with glume.

Vetiver spikelets are conical shape, oblong, ovate, with cuneate apex; size of spikelets is 1.5-2.5 mm broad, 2.5-3.5 mm. long. Upper surface coarsely spinulose, especially at the edge which is clearly seen with hand lens, while the lower surface is smooth (ORDPB 1995).

4.2.1.3 Seed and Seedling: When vetiver spikelets are fertilized, the sessile spikelet, which is hermaphrodite, sets seed. Seed has brownish color, conical shape, smooth, and round, 1-1.5 mm broad, and 2.5-3 mm long. Seed has thin exocarp, glutinous endosperm which is rich in starch and oil.

Vetiver seed has viability within a specific period of time. A mature seed can be observed by a narrowing of the inflorescence that tightly holds in conical shape. This is the resting stage for the embryo to be fully developed. If the seeds were harvested at this time (before the disarticulation), and cultured in the laboratory, it will germinate at the rate of more than 70 %. If the seeds were left for 3 days, germination will decrease to 40 %; and for 7 days, will decrease to only 10%. Vetiver seedling develops in the same manner as those of other grasses, starting with the radicle emerges from the seed, then the cotyledon emerges at the opposite side. Seedling elongates very fast, straight up about 2 cm within 3 days, and produces true leaf, green color, clearly with spine, in the first week.

In natural condition, mature seeds are attached to the inflorescence, and gradually fall off. Most seeds have lost their viability after falling unless they happen to fall on the site of optimum condition. Vetiver seeds are sensitive to environmental factors; thus they easily lost their viability upon exposure to drought, wind, and bright sunlight, even for only a short period.

In this connection, the technical staff of the Land Development Department has studied the viability of vetiver seed. It was found that the selected ecotypes of vetiver (which have been selected for soil and water conservation purpose) have low germination percentage. When treated with GA at the concentration of 250 ppm for one night, some seed still germinate, indicating that vetiver seed has a short period dormancy (ORDRB 1995).

4.3 Ecological Characteristics

4.3.1 Ecological Climax: Vetiver is an ‘ecological climax’ species. It outlasts its neighbors and seems to survive for decades while (at least under normal conditions) showing little or no aggressiveness or colonizing ability (National Research Council 1993). Vetiver can survive months of drought or up to 45 days of flooding. It can be grown at temperatures as low as - 9^{o}C and as high as 45^{o}C. It thrives in sea-level marshes and on mountain 2,600 m high. It flourishes in both acidic (pH 10.5 in India) or alkaline (pH 4.5 in Ethiopia) soil, despite salinity, low fertility, and even aluminum toxicity. Vetiver has positive effect on crops in its vicinity. Because it is virtually sterile, it never becomes a weed or spreads out of control. It has almost no enemies. Snake, rats and other pests dislike it. But what happens if it is grazed to the ground by starving cattle, or burned to ash in a bush fire? No problem! Like the proverbial phoenix, *vetiver rises again*. How does it stop erosion? When planted correctly, vetiver forms a dense, erect, cheap, easy to establish, permanent hedge at the ground surface that slows the velocity of rainfall runoff to nearly zero, thus greatly increasing both the amount of rain infiltrating the ground and farm productivity. Tests in Malaysia found that vetiver hedges reduced water run- off 75% and soil erosion 93%. Vetiver was planted in Fiji, in 10 m-deep erosion gullies decades ago; now the gullies are no more (Technology 1991).

4.3.2 The Effect of Arbuscular Mycorrhizal Fungi on the Growth of Vetiver: Inoculation of the roots of vetiver grass with mycorrhizal fungi improves the growth significantly. Note that while some of the fungi were better than others in promoting biomass production, even the least successful of the fungi still improves the growth. The association between the roots of a plant and the vegetative part of a fungus, known as 'mycorrhiza', helps the plant to take up nutrients and soil water more efficiently; this is very important under condition where nutrients and/or moisture are limited. It was found that by inoculating vetiver roots with certain fungi, early growth and establishment of vetiver were much better. If we establish plants with the right mycorrhiza to rehabilitate and stabilize degraded lands, then the fungi can benefit other crops that will eventually be grown there. Mycorrhizal fungi occur in nearly all soils on earth and form mutualistic symbiosis (an association beneficial to both) with the roots of most terrestrial plants. The arbuscular mycorrhizal fungi (AMF) are present over the widest ecological ranges and are commonly found in association with most of the important agricultural and horticultural crops.(Grimshaw 1991). Study on soil microbial biodiversity in the rhizosphere of vetiver grass in degrading soil indicates that the total soil microorganisms and cellulolytic microbes have increased from 10^6 to 10^8 cells/g of dry soil. Meanwhile, the endomycorrhiza increased from 2.5 to 25.5 spores/100 g of soil. Increasing the amount of soil microorganisms had also corresponded with the amount of some nutrients in the soil. The quantities of released phosphorus, potassium, calcium, magnesium, and sulfur increased from 2.2, 51, 375, 353; and 0.82 to 4.7, 148, 495, 537, and 1.63 ppm, respectively. The pH of soil has changed from 5.0 to 5.8. Furthermore, the amount of soil organic matter was raised from 0.50 to 0.90% (Sunathapongsuk *et al*. 2000).

4.4 Genetic Characteristics

In the DNA-fingerprint analysis of genetic diversity of the vetiver, it appears that only one *Vetiveria zizanioides*, genotype, 'Sunshine', accounts for almost all germplasm used in soil and water conservation outside South Asia. Additional RAPD analyses revealed, however, that several other non-fertile accessions are distinct genotypes. This germplasm uniformity holds promise for reducing the vulnerable genetic uniformity in what is now essentially a pantropical monoculture of an economically and environmentally important plant resource. Analysis of vetiver cultivars and putative *Vetiveria nemoralis* from Thailand has suggested that *V. nemoralis* is, in fact, a distinct taxon (Adams 2000).

Cytological data play a very important role in understanding the phylogeny and supporting classification in plant taxa. Vetiver has very specialized adaptations enabling them to grow in various habitats. As a result of hybridization, there are many intermediates occurring in the nature. Variation in chromosome number within a single species is also common in the Poaceae. The study on chromosome number reveals that *Vetiveria* spp. have base number, x = 10, and 2n = 20 (2x) and 40 (4x) (Namwongprom *et al.* 2000). *Vetiveria filipes*, which is one of the Australian species, is of special botanical interest because its morphology is intermediate between vetiver and lemongrass. One accession was found to have a 2n chromosome number of 40 (=4x), which is twice of that normally found in the genus.

One of vetiver's great benefits, of course, is that once it is planted, it stays in place. It is therefore, not pestiferous, and seldom spreads into neighboring land.

Actually, though, seeds are often seen on the plant. Why they fail to produce lots of seedlings is still unknown. Perhaps they are sterile. Researchers who examined spikelet and pollen fertility in 75 clones collected from widely different geographical locations within India found that 5 clones failed to flower. Of the remaining 70, female (pistillate) sterility ranged from 30 to 100%; male (pollen) sterility ranged from 2 to 100%. Some, notably those of South Indian origin, could be maintained only by vegetative methods because they produced no seed under natural pollination or under hand pollination, despite high pollen fertility. These data were obtained under New Delhi conditions. Perhaps, they may be fertile, but the optimum conditions for germination are seldom present. Or perhaps people just have not looked hard enough!

Under certain conditions, some seeds are indeed able to germinate. These conditions seem to be most commonly found in tropical swamps. There, in the heat and damp, little vetiver seedlings spring up vigorously all around the mother plant (National Research Council 1993).

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4.5 Hydraulic Characteristics

The situation being considered is the use of vetiver hedges in line of structural (water diversion) measures, say > 5%. In doing so, we should remind ourselves that the original natural forest system was a vegetative system that successfully controlled erosion. The aim is to produce an alternative system that combines erosion control with agricultural production. Substantial soil movement is most certainly going to occur. The aim will be restricted to the location of this soil movement, as far as possible, to between the hedges and minimize the amount of soil lost from the slope. The end point of the process will be a sequence of stable natural terraces with the steep batters stabilized by the hedges, as following schematic definition sketch of the vegetative barrier system (Smith 1996).

W1	=	design width of barrier, m
W2	=	design width of cropped strip, m
Ws	=	W1+W2 = barrier spacing
S0	=	initial land slope steepness, m/100m
S1	=	future barrier back slope steepness, m/100 m
S2	=	future steepness of cropped interval, m/100 m
Hs	=	step height of mature vegetative barrier, m.

Trials aimed at a quantitative description of the hydraulic characteristics of vetiver hedges are described. Three hedges were planted across a large outdoor flume, perpendicular to the flow. Trials were conducted at various discharges and depths, and the discharges and depths upstream and downstream of each hedge were recorded. From these data, an empirical hydraulic relationship was developed between the depths and the discharge. This relationship was used to calculate the maximum vetiver hedge spacing required to control soil erosion on a cropped flood plain of low slope subject to deep erosive overland flows. Finally, an appropriate hedge spacing was calculated for a field site on the Darling Downs of Queensland, Australia. Hedges were planted at the appropriate spacing and flow retardant and sediment trapping were monitored.

The flow of water through a hedge can be described by a simple equation relating discharge to the depths upstream and downstream of the hedge, with upwards of 90% of the variation in discharge described by the equation. Secondly it appears hydraulically feasible to use vetiver hedges to control flood flow and erosion on a cropped flood plain (Dalton *et al.* 1966).

5. PROPAGATION OF VETIVER

5.1 Propagation *vs* Multiplication

There are a few terms commonly used to describe the mode of reproduction of vetiver. The two most common terms are 'propagation' and 'multiplication', which are used interchangeably by some authors. Others use the term 'propagation' to mean any means of reproduction of vetiver, irrespective of the ultimate goal, while the term 'multiplication' is used to solely increase the number of individuals of vetiver plants, without having the objective of planting them in the field. Some authors, however, use the term 'propagation' in place of 'multiplication', and *vice versa*.

In this manual, 'propagation' is defined as *"any means of reproduction, either for increasing the number of individuals or for subsequent planting out in the field"*, while 'multiplication' is *"any means of reproduction solely to increase the number of individuals"*. It is implied that 'propagation' is used as a general term of reproduction of vetiver; it also includes 'multiplication' through various means to increase the number of individuals. The ultimate goal of 'propagation' is to grow individual vetiver planting materials in the field, either through the process of 'multiplication' first, or directly growing the propagules in the field.

5.2 Vetiver Parts Used in Propagation

Vetiver plant in cultivation rarely produces seeds. Thus, only asexual reproduction will be treated in this manual. In the vetiver literature, several terms have been used, sometimes indiscriminately, to designate the parts of the vetiver plant that can be used in propagation. In this manual, all these terms are being compiled, and, to avoid further confusion, their definitions which are based on: (1) Webster's New World Dictionary, Third College Edition, 1993, written in italics; (2) www.dictionary.com, underlined; and (3) the lecturer's own, specifically for vetiver, in italics and underlined, are provided together with their explanations. They are given below:

5.2.1 Tiller:

(1) A shoot growing from the base of the stem of a plant
(2) <u>A shoot, especially one that sprouts from the base of a grass</u>
(3) <u>*A shoot sprouts from the base of the stem of a vetiver plant*</u>.

Tiller is the most popular part of the vetiver plant used in propagation since it is available in large quantity, employs simple technique, and gives good result.

5.2.2 Slip:

(1) A stem, root, twig, etc. cut or broken off a plant and used for planting or grafting; cutting; scion
(2) <u>A part of a plant cut or broken off for planting; a cutting</u>
(3) <u>*A shoot cut off from a vetiver clump used for planting*</u>.

Many authors used this term synonymously with tiller. Some (e.g. National Research Council 1993) even called it a 'root division'. In vetiver, the structure from which the slip grows is the base of the stem, not the root. As it is a rather confusing term, and the fact that the term ‘tiller’is more appropriate, the present paper will not use this term to avoid further confusion.

5.2.3 Culm:

(1) A stalk, stem; the jointed stem of various grasses, usually hollow
(2) The stem of a grass
(3) The above-ground part of the stem of a vetiver plant.

The culm of the vetiver grass is strong, hard, and lignified, having prominent nodes with lateral buds that can form roots and shoots upon exposure to moist condition. Laying the cut pieces of culms on moist sand, or better under mist spray, results in the rapid formation of roots and shoots at each node.

5.2.4 Cutting:

(1) A slip or shoot cut away from a plant for rooting or grafting
(2) A part of stem removed from a plant to propagate new plants, as through rooting
(3) *Vetiver culm cut into sections with at least one node each used to propagate new plant.*

Although commonly used as propagating material in horticultural crops, ‘cutting’ is rarely used in vetiver. This term is probably synonymous with *‘cut culm’* or *‘culm-cutting’* (as referred to by Yoon 1991).

5.2.5 Culm-branch:

(1) There is no definition of such a term in Webster’s Dictionary
(2) There is also no definition from www.dictionary.com
(3) *A branch developed from the lateral bud of a culm.*

It is a term derived from similar structure in bamboo and other ramified grasses. It was Yoon (1991) who used this term in vetiver literature for the first time to mean a branch developed from a lateral bud of a culm of more than three months old whose main culm has been repeatedly cut down to induce tillering.

5.2.6 Clump:

(1) A cluster, as of shrubs or trees
(2) A thick grouping, as of trees or bushes
(3) A cluster of tillers developed originally from a mother plant of the vetiver in all directions.

In vetiver, a clump is formed when a plant has been grown for a certain period and produces numerous tillers in all directions.

5.2.7 Ratoon:

(1) A shoot growing from the root of a plant (esp. the sugar cane) that has been cut down
(2) A shoot sprouting from a plant base as in the banana, pineapple, or sugar cane
(3) *A shoot (tiller) sprouting from the base of the vetiver plant that has been cut down to induce sprouting.*

As vetiver (or even the sugar cane!) does not seem to re-sprout from the *root* when the clump is cut down to the ground, but rather from the base of the stem, thus the re-sprouting structure is actually a ‘tiller’ which has been induced to sprout by cutting down the top part. This term will not be used in this paper to avoid further confusion.

5.2.8 Tissue-cultured plantlet:

(1) There is no definition of such a term in Webster’s Dictionary
(2) There is also no definition from www.dictionary.com
(3) Differentiated tiny plant developed from explant through tissue-cultured technique.

Unlimited number of plantlets can be produced in aseptic condition from the explants deriving from shoot tip, lateral bud, young inflorescence, etc. Upon attaining a good size, these ‘plantlets’ can be transplanted in the containers or in the fields similar to tillers, although much smaller in size. Tissue-cultured plantlets can be produced within a relatively short time with reasonable expenses. They also have certain advantages over other planting materials in that they are small in size, easy to transport, and free from pathogen (as they are grown, and still remain, in aseptic condition) which makes them safe for international movement, especially across the countries with strict plant quarantine system.

Of all these parts, only the first and the last are used extensively in most vetiver-growing countries to propagate the vetiver plant, simply because they are the convenient parts to be used in propagation. Besides, the cost of their production is relatively lower than that of the other parts while the success is higher. Of the remaining structures, culm (including cutting and culm-branch) and clump are also used in propagation to some extent while the rest are either not used for practical reason, or do not exist.

5.3 Techniques Commonly Employed in Vetiver Propagation

5.3.1 Planting Bare-Root Tillers in Cultivated Land for Multiplication: This traditional method of planting vetiver has been done since the old days when people started to grow vetiver for erosion control in India some 200 years ago. It was the most convenient method so far practiced in those days when no polybags were available and no other parts were used. This method is still in use even nowadays in many countries.

For multiplication purpose, tiller can also be planted directly on cultivated land. In Thailand, this is normally employed in the government-owned vetiver multiplication centers, such as the Land Development Department’s stations, or multiplication plots of other agencies. These are normally located near the area where vetiver will be transplanted. Depending on the kind of cultivated land used in multiplication, this type of planting can be separated into three categories, viz.:

5.3.1.1 On Upland Fields: Large-scale vetiver multiplication requires a large to number of tillers well suited government agencies, or large-scale plantations or companies. The system is suitable for non-irrigated areas. After land preparation, tillers whose shoots are trimmed to 20 cm and roots to 5 cm are planted when soil is moistened. Two or three tillers are used in each hole at a spacing of 50 x 50 cm. However, to make it easier for caring and best time for the operation is mid-rainy season (between mid-June and mid-August). In this method, each 4-5 month-old tiller can generate an average of 50 new shoots per clump during the period of multiplication of about six months.

5.3.1.2 On Raised Beds: This method should be applied in area where there is a good watering system. Under proper cultivation practice, this system is highly productive. Moreover, tillers can be produced on a year-round basis. The tillers used in planting are obtained from the selected clump, and then trim the top to 20 cm and the roots to 5 cm. After that, the shoots are separated and bound together in bunches. The roots are soaked in water for four days, after which they start to grow. This will give more than 90% survival rate. Tillers are then planted on prepared raised beds of 1 m width with a walk path of 1 m. On each bed, the tillers are planted in double rows at a spacing of 50 x 50 cm. Watering after planting to maintain soil moisture is necessary. At one month, each tiller should receive approximately one teaspoonful of 15-15-15 fertilizer. Each clump will generate 40-50 new shoots after 4-5 months, and one ha of land can yield 750,000-975,000 new shoots.

5.3.1.3 In Paddy Fields: This practice is done in the paddy fields with good drainage or other areas having good watering and draining system. The same procedure of the above methods can be applied in this method.

5.3.2 Planting Tillers in Polybags and Transplanting Them in the Field: This is a technique that has only recently been developed when vetiver has been popularized to be grown for soil and water conservation as the result of promotional campaign of the World Bank in the late 1980s.

5.3.2.1 The Technique: Individual tillers are separated from the clump. The shoot is cut off to about 20cm and the root to about 5cm in length. Each tiller is inserted into a small polybag filled with planting medium, normally composed of burnt rice husk, manure, coir dust, and some topsoil. The techniques of propagation of vetiver employed in various countries differ somewhat. For example, in Thailand, the tillers are planted in polybags for 45 days or more before field planting. The medium used is one part topsoil and one part compost. The best time to transplant is at the beginning of the rainy season. Survival rate is expected to be more than 90%, especially if the rain falls normally (Chalothorn 1998). In Malaysia, Yoon (1991) planted tillers in polybags with sizes of 7” x 15” and 10” x 20”. One nugget of Kokei (6 g) of slow release fertilizer (N, P, K, and Mg) was applied into each bag and a drip-dry irrigation system was used. Plants were divided as soon as they are bag-bound. At four months, the small bags had 17.1 $\pm$ 1.1 tillers/plant and the larger bags 25.5 $\pm$ 1.6 tillers/plant.

5.3.2.2 Problems in Polybag Propagation: Polybag propagation is by far the most popular technique in vetiver propagation. However, it has many drawbacks such as:

- *Expensive:* This includes the costs of polybag, medium (topsoil and compost), nursery, water, labor and transportation.

- *Problems in Maintenance:* A large area of the nursery is needed for keeping the vetiver in polybags for the period of 45 days or more. Watering the young plant everyday requires labor and installation inputs, and a good source of water supply.

- *Environmental Problem:* The disposal of a large number of polybags during field planting is always a problem since most laborers do not pay attention to collecting the polybags after removing the young vetiver plant out for planting. Instead, the polybags are left in the field, thus creating environmental pollution.

- *Demand-Supply Problem:* In many cases, the demand for vetiver planting material does not match the supply. Sometimes a large number of polybags with vetiver is available at the multiplication center while the demand for them is much less. As a result, most of them are to be disposed of, since they are no longer good for planting a few months after their optimum period (of 45 days). In other occasion, there is not enough planting material at the time of need.

- *Labor Intensifies:* Starting from procurement of medium (topsoil, burnt rice husk, coir dust, and compost), cutting the corner edges of the polybags, filling the medium into the polybag, preparing the tillers, inserting the tillers in the polybags, laying the polybags in the nursery, watering and other maintenance, transporting the polybags to the field, removing the polybags, digging holes for planting, placing the vetiver plants in the hole, covering the holes with soil, collecting used polybags, etc., all are quite time- and labor-consuming.

Even with all the above drawbacks, planting tiller in polybag is still popularly employed in vetiver propagation in most vetiver-growing countries, as it is the most practical method of propagation.

5.3.2.3 Types of Polybag Propagation: Planting vetiver in the polybags is both clean and easy to maintain; however, it requires proper tools for watering and caring. Depending on the objective, two sizes of polybags are used: small polybags for field planting, and large polybags for multiplication.

- *In Small Polybags for Field Planting:* This method is appropriate to be used under various development projects in the initial stage of operation. It is very convenient in terms of distribution and providing services or support to various agencies and interested public for further multiplication or other purposes. It is easy to develop and keep a record of the number of bags and tillers needed to meet the demand.

The size of the polybags is about 5 cm wide and 15 cm long, with a diam. of 7 cm when filled with soil. Many other sizes have also been used in several countries. They are suitable for direct transplanting on land or specific areas for soil and water conservation purposes, such as in hedgerows on roadsides and road shoulders, at pond edges, and on paddy buns to hold the soil in dry, impoverished and saline conditions. Planting vetiver tillers propagated in small plastic bags ensures a better survival rate and faster establishment of the vetiver grass than conventional bare-root planting.

- *In Large Polybags for Multiplication:* The large polybag is made of black polyethylene, about 10 cm wide and 25 cm long, with folding at the bottom. When filled with planting soil, the bag will have a diameter of 15-20 cm. Propagation of vetiver tillers in large polybags can produce a large number of new shoots. These shoots are collectively called clump and can be kept in the polybags for an extended period of time. Hence, these vetiver clumps are suitable for further multiplication or for separating into individual tillers (bare root) for large-scale transplanting.

5.4 Innovative Techniques in Vetiver Propagation

As planting vetiver for soil and water conservation is getting popular, many new innovative techniques of its propagation have been developed to obtain better result in a shorter period of time with less expense. Among these are:

5.4.1 Tissue-Cultured Technique: As micropropagation through tissue-cultured technique is quite well developed in many vetiver-growing countries, such technique has now been adopted in these countries to mass produce vetiver planting material. This method is appropriate because it does not promote mutation; besides, vetiver plantlets, which are relatively small as compared to conventional tiller in polybags, make it easy for transporting large quantities to other areas (Charanasri et al. 1996).

In Thailand, a number of laboratories such as at the Doi Tung Development Project (Charanasri *et al.* 1996), Kasetsart University (Namwongprom and Nanakorn 1992), and the Land Development Department (Sukkasem and Chinapan 1996) have been involved in such techniques. These are discussed below:

5.4.1.1 Plant Materials (Explants) Used in Tissue Culturing: In principle, any meristematic tissues of the plant can be used as starting material in tissue culturing. As for vetiver, those from young shoot and young inflorescence are preferred.

- *Young Shoot:* The Botany Department, Kasetsart University has experimented with tissue culturing of young shoot derived from lateral or terminal buds and found that 70% of the plantlets survive which renders the method effective (Namwongprom and Nanakorn 1992). The Department has been producing tissue-cultured plantlets as a service to other government agencies as well as for their own experiments, e.g. to select for salt or toxic substance resistant clones (Na Nanakorn *et al.* 1996).

- *Young Inflorescence:* The Doi Tung Development Project was successful in propagating vetiver plantlets using meristematic tissue of the inflorescence and culturing it under aseptic condition (Charanasri *et al.* 1996).

5.4.1.2 Transplanting Plantlets: Plantlets can be transplanted to various containers and fields:

- *On Nursery Beds:* After the plantlets have been fully developed in the culture medium, they are removed from the bottle and transferred to the nursery beds. Raised beds of 1 m wide and 5-10 cm high should be prepared in the nursery with proper shading using saran (70%) or any other materials available in the locality such as banana or coconut leaves. Watering facility should be available to provide sufficient amount of water for the growing young plants. The nursery should receive full sunlight at least 6-7 hours per day.

Immediately after removing from the bottle, the plantlets should be planted in the nursery bed to avoid desiccation. The bed should be watered just before transplanting. Place the plantlets into the holes of the nursery bed at 1 cm depth, and at the spacing between plants of 1-2 cm, and between rows of 7 cm during the dry season and 10 cm during the rainy season. Press the moist soil firmly around the plantlets and water again. During the entire period of growth in the nursery beds, keep the soil moist by watering twice a day. Weeding should be done regularly. Fifteen days after transplanting, replace any dead plants and remove the shade to allow the plantlets to be exposed to sunlight; this will promote hardening of the young plantlets. Fertilizer (manure or chemical fertilizer) should also be applied to the young plantlets at this time. When the plantlets are 20-30 cm tall, they are ready to be transplanted in the field.

- *In Polybags:* The plantlets can also be transplanted into the polybags, using the same technique of polybag propagation described earlier. These are to be kept in the nursery during the first 15 days, after which the shade is to be removed to allow the plants to expose to full sunlight and fertilizer be applied to promote growth and development of the plantlets. When they are 20 cm tall or 60-90 days old (after transplanting from the bottle), they are ready to be transplanted in the field.

- *In the Field for Multiplication:* The 60-90 days old plantlets grown in the nursery beds or in the polybags are ready for field planting for further multiplication, using the same techniques described earlier.

▪ *In Other Containers:* Similarly, the 60-90 days old plantlets can also be transplanted in strips, dibbling tubes, or nursery blocks (see later). In fact, plantlets obtained from tissue culture technique have an advantage over tillers as they are small in size that fit well in small structures of the dibbling tubes and nursery blocks.

5.4.2 Planting Specially-Treated Bare-Root Tillers Directly in the Field: A new technique in vetiver propagation has been developed by Chalothorn (1998) at the Huai Sai Development Study Center by using bare-root tillers planted directly in the field. The procedure includes digging up the well-developed vetiver clump, chopping the shoot to 20 cm and the roots to 5 cm, then split the clump into individual tillers, tie them together into bundle, and keep them in shallow water for four days (to induce new root formation) before planting. This method is quite efficient, especially if operation is done in the rainy season after the soil has been sufficiently moistened. The survival rate is promising with this method. It is quite convenient and economic since it does not require polybag, medium, nor maintenance, and also save a lot of labor. As compared to the polybag method, transportation cost to the site of planting is much less.

A further improvement has been invented by Jirasathaworn and Sutharuk (1995, cited by Inthapan and Boonchee 2000) who submerged bare-root tillers in humic acid solution for three days until they produced new roots. They were found to grow faster after transplanting in the field (in the middle of May to the end of June) than tillers grown in polybags.

5.4.3 Planting Tillers in Strips for Field Planting: The Khao Hin Son Royal Development Study Center (1998) has developed a new propagating technique by making a long strip which would facilitate transportation and planting. It is a labor-saving practice with high survival rate since the roots are not disturbed as in the case of using polybags. It is also environmental friendly because no waste material (used polybags) is left in the field.

The materials employed include two rows of cement blocks (each is 20 cm high, 30 cm long and 4 cm thick) placed at a distance of 1.3 m apart and any length depending on the length of the area. Steel rods or bamboo stakes are placed 5-6 cm apart across the width of the cement blocks to support plastic sheet. With a piece of stick, push the sheet down and fill the cavity with planting medium (soil mixed with compost). Plant vetiver tillers along the length of the cavity at the spacing of 5 cm. After two months, the roots will form a closely tight net such that the whole strip can be lifted up without damaging the root system. Normal nursery practices such as watering and shading are given.

No watering is given to the young vetiver plants seven days prior to field planting to reduce the weight of the strips in order to facilitate transportation. In field planting, a grove is made in the soil along the contour of the slope to place the strip in it. Press the soil along the strip tightly. Since the whole strip (of 1 m length) is planted together in one operation, no damage is caused to the root mass; thus every plant starts to grow immediately after planting.

5.4.4 Planting Tillers in Dibbling Tubes: During the 1970's the author introduced the use of dibbling tubes to grow fast growing nitrogen-fixing trees with considerable success. He recently advised the scientists at the Thailand Institute of Scientific and Technological Research to conduct an experiment on propagating vetiver in a dibbling tube, which is a cylindrical plastic tube of the size of 12 cm long and 3 cm diameter, with a 1 cm diameter opening at the lower end to allow excess water to pass through (Anusonpornperm *et al.* 2000). The tube is made of durable black polyethylene with three groves along its length to prevent coiling of the roots. The tube is filled with nutrient-enriched medium (compost mixed with slow-released fertilizer) and placed on aluminum tray with 80 holes to hold the tubes vertically. Each tray has four legs of 15 cm long at the corners. Thus the lower end of the tube is 3 cm above ground. This 'air pruning' effect makes it difficult for the roots of the young vetiver plant to reach the soil below, but remain stagnant until they actually reach the soil after field planting.

Vetiver tillers of the size of around 20-30 cm high are preferable since they are still small enough to be inserted in the opening end of the tube but large enough to produce roots from accumulated nutrient in the plant tissues. Tissue-cultured plantlets can also be used, especially after being established in a nursery for a few weeks. Normal nursery practices, such as shading, watering, and liquid fertilizer spray, are given to the vetiver tillers for about 8-12 weeks at which time the root mass will fully occupy the medium in the tube. When they are ready for transplanting in the field, sprinkle water to add moisture to the medium; this will also facilitate the separation of the root mass from the tube. When pulling it up, the whole mass (consisting of the medium and the root mass) comes up as a single, tightly-held piece in the shape of the tube. This can be packed in a carton of corrugated paper with plastic sheet lining and transported to the field site for transplanting.

Field planting is done by inserting a hole-maker into the ground. The apparatus is made of steel with three iron rods of the shape and size of the tube, spaced at 5 cm apart. When the hole-maker is pressed by foot into the soil, it makes three holes in one operation. Each hole is 12 cm deep. Such a depth is a perfect fit for the root mass of the tiller grown in the 12 cm-long tube to be in touch with the soil. In practice, one person makes the holes along the line while another person simply inserts root mass of the tiller into the hole. Once the root mass touches the soil in all direction, each root quickly grows in the soil. Survival rate is close to 100%, especially if grown in the wet season.

This method is highly recommended for areas which are difficult to reach such as on steep slopes since materials to be carried up there are light-weight cartons of vetiver root-mass (about 80 per carton) and the hole-making apparatus. After planting, there is no used polybags to collect and bring back. Corrugated cartons are reusable for several times; they can be folded flat to save space.

5.4.5 Planting Tillers in Other Containers and Biodegradable Nursery Blocks: A number of used containers such as soft drink cups, cans, etc. have been tried to hold medium for vetiver growth. It was found that although the growth of the vetiver planted in such containers was good and the cost of the containers is negligible, but there was a problem in transport of vetiver plants still in the containers as well as in pulling the whole mass in the containers up before planting in prepared hole; such operation is likely to damage the root system, causing death or poor growth of the newly planted vetiver tillers. This has led the Doi Tung Development Project in Chiang Rai and the Highland Land Development Office in Chiang Mai to try an alternative approach by producing biodegradable blocks from vetiver biomass (mainly leaves and culms). The blocks are made by a simple machine using manual labor or a small engine. They come in various shapes and sizes; the most common ones are cylindrical and cube. Important features include solid nature of the block with small hole at the top to facilitate insertion of the tiller in place. Once the vetiver plant is ready for planting, the whole block with vetiver plant is then placed in the prepared hole without having to pull the vetiver plant out from the block. The block, which contains considerable amount of nutrient and moisture, nourishes the vetiver plant both in the nursery and in the field. This approach is very adaptive to planting in critical areas such as on side slope of the highway or rail road, along the newly compressed ridged of the farm ponds or reservoirs, since the block slowly disintegrates while releasing plant nutrient to the growing vetiver plant. Such biodegradable block is also ecological friendly since it is made mainly of organic matter; and no ‘garbage’ of any kinds is left in the field as compared to polybag technique**.**

5.4.6 Planting Tillers in Pots Made from Vetiver Leaves: Thiramongkol and Baebprasert (2000) experimentally produced pots from clay, dry vetiver leaves and binder (polyvinyl alcohol or ‘Poval’). In one of their trials, they planted vetiver tillers in such ‘vetiver’ pots after the latter had been hardened for a while. These tillers in the ‘vetiver’ pots were placed across the slope of the plantation area of the Doi Tung Development Project, Chiang Rai, Thailand. All vetiver planted in this way has grown successfully. This work has demonstrated that it is possible to recycle the vetiver grass through the ‘vertiver’ pot to the vetiver grass again.

5.4.7 Using Growth Promoters in Tiller Propagation: Ho *et al.* (2000) tested three commercial brands of growth hormones and two levels of auxin plus minerals in shortening the growing period of vetiver. By soaking the tillers for 15-20 min in growth hormone solutions and immediately planted in the polybags, the growth rate of the vetiver tillers was found to have increased considerably and can potentially reduce the growing period by as much as 50%. The gain in shoot and root length in just three weeks was almost double that of the control (water). An auxin level of around 0.34 ppm was preferred since this amount did not appreciably inhibit root growth and yet produced a good enough shoot growth.

Bernal (2000) used bencil adenine purine (BAP) and naphthalene acetic acid (NAA) to induce adventitious bud development of vetiver cuttings. It was found that BAP at 500 and 1,500 ppm gave better result than the control treatment, while 10 cm cuttings with 500 ppm NAA and 20 cm cutting without NAA were the two best combinations. When different concentrations of NAA were combined with applied time, it was found that 500 ppm for 60 min gave the best result.

5.5 Guidelines to Choose the Techniques of Vetiver Propagation

The above document provides up-to-date information of the various techniques of vetiver propagation employed in Thailand as well as in some other countries. It is up to the manager of the project to select which one he wants to employ in his project, and how it is accomplished to obtain the best result. The following paragraphs provide the guidelines in choosing the techniques to be used in propagating vetiver and also the ultimate goals in vetiver propagation.

The various techniques of vetiver propagation presented above are an asset for those who are working on the transfer of technology of planting the vetiver grass to the farmers or other users. The followings are the guidelines for the users to choose which one they want to employ:

- Availability of the mother plants
- Availability of the facility
- Availability of the techniques
- The demand of vetiver planting material
- The distance to transport
- The terrain in which the transplanting is to take place.

5.6 Goals in Vetiver Propagation

Vetiver is easy to propagate at a relatively low cost. Under normal conditions, propagation by using tillers grown in small polybags will give satisfactory results. However, it has certain disadvantages such as being labor intensive, high weight per plant ratio, and may create environmental problem if polybags are not collected after field planting. Thus other alternative techniques of propagation, e.g. using bare-root tillers, growing tillers in other types of containers, or using tissue-cultured plantlets, may be of some advantages. Non-conventional parts may also be used in propagation in certain special conditions. These methods are by far much cheaper than if they were to be multiplied by tissue culture method. However, once the principal source for multiplication is established, the normal method of tiller planting should suffice. It is therefore very important to set the goals in propagating vetiver before the operation is started. The following goals are the criteria for the manager of the project to choose appropriate techniques for vetiver propagation.

5.6.1 Quality of Planting Materials: One of the major goals in propagating vetiver is to produce only high-quality planting material. Remember that only high-quality planting material should be used in transplanting in the field. High quality includes healthy and vigorous growth. Poor-quality planting materials will result in slow growth or even death of the transplanted tillers. Even re-planting may be possible at a later date, this will not be as good as when every tiller survives and performs its function the moment it was transplanted.

5.6.2 Low Cost: Efficient nursery management will reduce extra cost of propagating vetiver. However, from a planning perspective, high input approach should be aimed at,
especially to produce good quality planting material mentioned above. Nevertheless, especially in large-scale propagation, economic consideration should be of prime importance. The economies of scale and inputs will help to solve the problem considerably since the bigger the operation the cheaper the unit cost of production. The returns to production for a given input will often more than pay for themselves. Input and material savings can be tremendous. However, being a living organism, vetiver needs some inputs like water, nutrient, light, etc. It will not grow if no water is provided. Similarly it cannot grow well if it has no nutrient upon which to draw. It cannot compete with weeds or animal grazing. It also needs subdue sunlight for its early growth in the nursery, and brighter sunlight at a later stage, especially during the hardening period (see later).

5.6.3 Hardiness: By its nature, vetiver is a tough plant. However, during its early stage of growth as propagating material grown in any form of containers, it is rather weak, especially when subject to long transportation through rugged terrain in the hot sun before being transplanted. Thus planting material should be durable in the sense that it will withstand such conditions without severe setting back. Since such material is aimed at planting in the field exposing to strong sunlight, a young propagating plant kept in shady nursery for a long time, for example, will not be able to withstand exposure to strong sunlight immediately after transplanting. A period of hardening or acclimatization, i.e. exposure to sunlight, prior to field planting is needed.

5.6.4 Being Easy to Transport: Containerized-planting material is considered most practical. However, it would be quite difficult during transportation if the container is large, and planting medium is bulky and/or heavy. Trays to hold polybags or other containerized planting materials should also be lightweight, small volume and easy to handle. A one-way transport, like the use of strip planting, biodegradable nursery blocks, dibbling tubes (tubes removed and retained), etc. has the advantage in that no containers and other materials are to be collected and returned to the nursery for re-use or throwing away.

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6. AGRICULTURAL APPLICATIONS OF THE VETIVER

6.1 Soil Erosion and Acceptance of Soil Conservation Measures

Soil erosion is a natural phenomenon that has been occurring since the early part of geologic time scale. What we see now as broad valleys and wide delta areas have been the results from soil erosion processes; the same being the denuded hills and aweful gullies and river canyons. Such kind of erosion can be called *geologic erosion*. With the evolution of human beings and their aquired knowldge of agriculture - that is a departure from 'hunting and gathering' way of life - erosion by man began. The latter kind of erosion is called *accelerated erosion.*

In fact, this accelerated soil erosion did not happen at once when man started to grow their crops and tend their animals. At first human beings would do cropping in patches at a small extent. Only when the world population increased to a much higher number that soil erosion and other kinds of land degradation, such as saline soils, acid soils, would occur. Examples abound; one historic episode that may be cited is the rise and fall of civilizations in the Mesopotamia area since several millennia ago. In such case, forest clearing has caused vast land areas to be denuded of trees and soil salinity came into play, which made cropping fail and the land could not supoort its population any more. In a worldwide scale, soil erosion is considered the most severe form of land degradation.

6.1.1 Mechanisms Causing Soil Erosion: It can be simply described that the soil erosion process involves three steps, i.e. detachment, transportation, and sedimentation. *Detachment* occurs when soil particles or soil clods detach from the land through any kind of force, such as raindrop impact, flowing water, animal tramping, and even the earth gravity. *Transportation* occurs when there is a means, such as water flowing on the land as runoff and in streams or rivers. *Sedimentation*, being the final stage, happens when the force that brings soils particles or soil clods decreases and the materials drop and stay in a new place. Good understanding of these three stages will make the correction or alleviation of soil erosion easier and the goal will be successfully achieved.

6.1.2 Extent of Soil Erosion: Studies on soil erosion and its countermeasures have started since a century ago. Investigators in USA, Russia, and many advanced countries were the first to study about it, in order to know what has caused it, what impacts it has caused, and how to alleviate it. The estimation of Pimentel *et al.* (1995) states that, worldwide, *75 billion tons of soil* are being lost from all continents in each year, causing a combined damage of approximately *$400 billion*. The paper mentions that average soil loss from land in Asia, Africa and Latin America is around 40 t/ha/yr, while in North America and Europe the figure is 17 t/ha/yr. Studies in many countries show differing amounts of soil erosion, the largest being approximately 200 t/ha/yr, and even more in certain locations.

6.1.3 Impacts: Impacts from soil erosion are numerous. *Decline in agricultural yield* is the most prominent. The loss of topsoil with its high organic matter content and rich soil fauna and flora essential for being a 'productive soil' is considered a big loss that the original conditons cannot be easily returned. One inch of topsoil that may need several hundred years to form may be lost within one or two years after the land is cleared and put for cultivation. Such *on-site* impact is the matter that many governments are covering in order to improve agricultural productivity in respective countries. Another kind of impact is of the *off-site* nature. It deals essentially with the sedimentation of soil particles in various streams, rivers, lakes, reservoirs, and estuaries and renders either a large budget for improving existing infrastructures or shortening of their useful life. This is a matter that needs much consideration when planning for soil conservation projects.

6.1.4 Measures to Counter Soil Erosion: Soil conservation was started over a century ago. This kind of work is basically to counter the effects of soil erosion. It has been recorded that a soil conservation service was established as early as 1907 in Iceland, and later in 1937 in USA where much work, both research and implementation were implemented countrywide and has become a blueprint for Australia and several African countries. The work in Thailand started in 1963 with help from the USA when the Land Development Department was established, and now covers all provinces of the country.

When working in soil conservation several kinds of measures have been devised, including physical structures, vegetative methods, agronomic measures and management methods. In the ealy part the physical structures were thought of as effective in retarding soil loss, but later on it was found to have many obstacles that made them not well accepted by the farmers. This subject will be dealt with in the next part in this paper.

6.1.4.1 Implementation of Soil Conservation: Implementation of soil conservation in countries all over the world was influenced by techniques from North America up to the 1970s, when the measures were largely of structural nature. Vegetative and agronomic measures started to gain attention from that point onward, due to the fact that they would be better accepted by farmers because of several reasons. There was not much interest in knowing if any project or program has succeeded since it was a general understanding that soil conservation is one part of rural development that will benefit both people and land. Only until the 1980s when several workers in this field noted that those conservation measures implemented by projects had not stayed long or land users in the project areas were not interested in working in their fields to protect their soil, that there started to find out that the maintenance of those measures was at a low level, which means that the project has not succeeded. For example, Hudson (1991) reported only 25% success of FAO funded projects which started in the 1970s, and the rate improved somewhat for those initiated later. Lack of success has prompted workers in several areas of developing world to devise methods, loosely called 'participatory approaches', which would hopefully lead future projects to higher rate of success.

For projects, to achieve success means to have those recommended measures accepted and adopted by land users. Since the early to mid-1980s, workers in this field started to talk about success and failure of projects and they looked for the way to improve the success rate through several participatory mechanisms as earlier mentioned.

6.1.4.2 Definitions and Theories of 'Adoption': The so-called Roger's model (Rogers 1962) puts the 'adoption process' in include altogether five stages, i.e. awareness, interest, evaluation, trial, and adoption. Enters (1997) mentioned that, " … change, i.e. adoption of a new idea or innovation, can take many forms and without outside intervention is based on traditional knowledge and/or on-farm experiments. Most of the soil conservation measures being employed now are the mixture of those based on traditional knowledge and on research. The dissemination of research results has been the main objective of extension. Until recently the task of extension was viewed as educating farmers or to teach them better land management and the application of soil conservation measures within their fields. This top-down approach is still more common than most of us would like to think. But there is now a broad agreement that extension workers should instead assume the role of facilitators of change and communicators between farmers, researchers, project implementers and policy makers. It is their role to assist farmers in the practices, providing the necessary information and assisting in the evaluation of potential soil conservation practices. The extensionists must also participate in on-farm research and help farmers to make their decision on how to adjust their farming systems in order to reduce land degradation and improve crop yields, thus improving their standard of living."

Sombatpanit (1993) on the other hand proposed adoption to comprise four major steps, corresponding to the states of mind as perception, attitude, acceptance, and adoption. They may be defined briefly like this:

- *Perception (or Acknowledgement):* Becoming conscious/aware of or having the knowledge of
- *Attitude:* Having manner/feeling toward a person or thing
- *Acceptance:* Acknowledgment or recognition as appropriate, permissible or inevitable
- *Adoption:* Act of taking over into general use especially with little or no change in form

On the other hand, Willcocks and Critchley (1996) put the adoption process in the following pattern:

Identification
Evaluation 1 (preliminary)
Evaluation 2 (technical and socioeconomic monitoring)
Dissemination and extension
Adoption

Recently, Erenstein (1999) suggested that there was a step-wise adoption in his work on no-burn, reduced till and mulching criteria. Moreover, there are several words related to this, such as, disadoption, non-adoption, etc.

6.1.5 Why Farmers do not Adopt?: While success stories are rare, failure (or non-acceptance/non-adoption) saga abound. Fujisaka (1991) studied six projects in Southeast Asia and found as many as 13 reasons why farmers did not adopt recommended practices. They are:

- Absence of problem
- Inappropriate innovation
- General unawareness
- (Lack of?) facility of the innovation
- Incorrect identification of adoption domain
- Appropriateness of farmers' practice
- Adverse off-site effects
- Non-adoption due to problems from innovation
- Non-adoption due to cost
- Lack of extension
- Insecure land tenure
- Farmers may be 'mining resources'
- Negative social connotations

Undoubtedly there must be much overlapping among them. More systematic study about reasons for non-adoption is needed. However, we have to accept the fact that that farmers do not accept innovations they are not unreasonable; they are mostly rational.

What Fujisaka has cited above have in fact corresponded with what Hudson (1982) has earlier described about problems of implementing soil conservation in developing countries. Such problems cover political aspects (political policy, state land and state forests, land allocation, legislation), social features (land ownership and land tenure, land fragmentation, social significance of cattle, reluctance to move, reluctance to change), and economic constraints (element of risk, time scale of soil conservation, who should be the one to pay).

Many project which have not found satisfactory success might have a stumbled on one or more problems mentioned above. As example, Laing and Ashby (1993) describe the case of the Paute Watershed in Ecuador, which was the problems of a top-down regulatory approach which has no built-in incentives and which does not motivate farmers to mobilize local resources of labor and cooperation. The same author also cite the example from the Eastern Province of Zambia where soil conservation and agroforestry were promoted but failed due to ineffectiveness of camp officers, inappropriate extension methods (T&V), lack of communication in government hierarchy and major transport problems.

6.1.6 Examples of Adoption in Soil Conservation:

6.1.6.1 Autonomous Adoption: Erenstein (1999) described about adoption of soil conservation measures that were done without any influence from extension officers by using the term "autonomous adoption". Examples of these are mostly indigenous conservation measures such as cut-off drain, contour trashline, and various kinds of bench terrace that were executed through local wisdom since centuries ago. Ifugao rice terraces in the northern part of the Philippines and ancient Inca terraces at Machu Picchu in Peru are good examples of the practice. It is, however, evident that the original purpose of building such structures was not for conserving soil; conservation of water and facilitating the work in the field were what inspired to shape their terraces, and facilitation of everyday life was the purpose of those at Machu Picchu. But these structures have served the purpose as the prototypes of modern soil conservation measures such as bench terraces, small terraces for rubber, intermittent terraces for horticulture, hillside ditches, and so on.

This kind of adoption is also called 'spontaneous adoption'. Laing and Ashby (1993), moreover, describe an example of reforestation in Nepal where land users understand the value of trees and grow them voluntarily on 'bare' land (outsloping upperslope rainfed terraces) without any intervention from outside agencies.

6.1.6.2 Adoption through intervention: This is the adoption of soil conservation measures that find favor with farmers, though sometime it needs certain strategies such as financial assistance in the form of incentives in order to induce initial adoption. But once farmers get used to and become aware of those measures, they will continue maintaining them almost without any more assistance. Following are examples of this kind of adoption.

(1) Small bench terrace for rubber in Southeast Asia. There has been a program to assist rubber farmers in Thailand (and other SE Asian countries) in felling old rubber trees and plant new varieties on the contour. The agency gave money enough for implementing the whole process within the period of five years. Aligning contour lines and putting up a small terrace has to be done in the land preparation process. When farmers get used to bench terracing, including having been facilitated by such kind of structure while working in the plantation, such practice has become a way of life that, when they replant rubber even outside the program, they would try to do the same. After all, they find it very useful when traversing in the farm.

(2) Sloping Agricultural Land Technology (SALT). The Mindanao Baptist Rural Life Center (MBRLC) in the Philippines has devised the SALT technique comprising growing contour hedgerows (using leguminous shrubs such as *Leucaena leucocephala, Cajanus cajan,* etc.) on sloping upland and planting cash crops between the rows, and

extend it to farmers in Mindanao and other regions of the country (Palmer *et al.* 1999). The technique has grown far and wide, so that the extension programs in Thailand, Nepal, Sri Lanka and some other Asian countries recommend this technique to their farmer cooperators and got accepted reasonably well comparing with other soil conservation measures, especially the structural ones. Surprisingly, such technique has also been independently developed in West Africa around the mid-20th century (Rattan Lal - Pers. Comm.) and was further promoted in that part of the world.

(3) No-tillage system in south Brazil. The no-till method is an efficient way to reduce soil loss up to 90% or more (Calegari 2000), while farmers can economize through the saving of fuel and machine maintenance costs. But to implement this technique it requires special kinds of farm machine and application of herbicide, plus new know-how and sufficient courage of farmers who might not be familiar with. After struggling with the reduced tillage since the 1960s, the states in south Brazil, including Parana, Santa Catarina, and Rio Grande do Sol, have been successful in using no-tillage crop cultivation in a total area of12 million hectares, or around the size of England. This success story cannot be considered an accident; a lot of efforts must have been exercised by officers and farmers alike, while the resulting saving of 90% of soil might have been lost to the stream and ocean is indeed encouraging.

(4) Landcare movement in Australia. There is a highly successful program in getting rural as well as urban people in all states and territories of Australia to involve in caring for the land, rivers, shorelines, native vegetation, etc. While the government coordinates and stimulates the forming of Landcare groups and their implementation, with certain amounts of funding to support, people will organize by themselves to work among themselves. This kind of success could be attributed to the high level of education and awareness of farmers and extensionists alike, and good economy of the country. Up to now, around 4,500 Landcare Groups have been formed across the country, involving approximately one-third of Australian population. Several countries including New Zealand, the Philippines, and South Africa have now started a similar movement with a good prospect.

6.1.7 How the Adoption Rate can be Improved?: In Soil Conservation Extension (Sombatpanit *et al.* 1997), Strategies needed for extending soil conservation to farmers successfully include (among other things):

- A holistic outlook of ‘land management’
- Farmers participation
- Use of appropriate technologies and applicable approaches
- Integrating of responsibility among government agencies and NGOs, and
- Wise use of subsidies and incentives

In fact, technologies for conserving soil are mostly simple and straightforward, especially to sufficiently educated people; but to apply them to the land, with farmers to be involved with, is not easy and there are examples of failure everywhere. Many past loan projects might appear nice and successful in the eyes of the local, though some evaluation results being kept in the office of donors or creditors might indicate a certain project to be as bad as a ‘total disaster’.

Since the publication appeared there has been much progress in several aspects.

6.1.7.1 A Holistic Outlook of ‘Land Management’: After the mid-1980s there have been a movement in recognizing ‘land husbandry’ as a discipline that would well cover soil conservation and many other branches of resource conservation in the manner that, when you husband your land well, soil will be automatically conserved. One major result from that was the establishment of the Association of Better Land Husbandry (ABLH) with headquarters in the UK.

The land husbandry concept still prevails and has become endorsed by the Workshop on Issues and Options in the Design of Soil and Water Conservation Projects (McDonald and Brown, 1999), which point out that land husbandry, along with crop husbandry and animal husbandry, will play their roles in creating sustainable rural livelihoods, which is considered a more realistic goal of 'development' than just to keep the soil in its place, the major purpose of soil conservation.

6.1.7.2 Farmers Participation: There are large number of literature in the field of 'participatory approaches'. This term has now become a buzzword, and such participatory principle is considered an imperative for resource management and conservation projects, which have other rural development aspects like health, education and infrastructure to involve with. In studying to more details, workers in this field have gone to the matters of assets which comprise five types of capital: *natural, social, human, physical and financial* (Pretty and Frank, 2000). With more interest in practicing participatory approaches, the future of adoption of soil conservation measures seems bright.

6.1.7.3 Use of Appropriate Technologies and Applicable Approaches: The World Overview of Conservation Approaches and Technologies (WOCAT) Project, with worldwide cooperating agencies and its secretariat in Berne, Switzerland, has been collating available and successful soil conservation technologies and approaches from several developing countries in Africa, Asia and Latin America (Giger *et al.* 1999). An 'approach' is simply defined as the ways to get soil conservation measure(s) implemented. Over 100 technologies and around 75 approaches have been digitally catalogued so far, and more are going to be added during these few more years. With results in the digital format, there will be available handbooks for technologies and approaches as well as WOCAT maps to be used as tools for implementing future soil conservation projects.

6.1.7.4 Integration of Responsibility among Government Agencies and NGOs: Several NGOs are strong and have wide area of operation. It has been observed that some NGOs have gained ground in certain discussion arena, especially concerning solving conflicts in resources use and management between government and rural people who are at the disadvantage status.

6.1.7.5 Wise Use of Subsidies and Incentives: Since 1996, the World Association of Soil and Water conservation (WASWC) has started the project to produce a book concerning the use of incentives in soil conservation projects. The Association can now present its product as the book under the title "Incentives in Soil conservation: From Theory to Practice" (Sanders *et al.,* 1999). The Association hopes that several case studies picked up from all over the world will be useful especially for participants who are working as project planners, implementers and evaluators.

Reij (1998) in his paper on "How to increase the adoption of improved land management practices by farmers", he cites the need for project implementers to find 'triggering mechanisms'. This is similar to what Sombatpanit *et al.* (1993) called 'narrow path', which blocks a smooth running of project operation. When there is something to trigger (same as when a path is widened), an adoption will be achieved almost very fast. He exemplifies with three case studies.

(1) The use of donkey cart in Burkina Faso. The cart is expensive but liked very much by villagers to use. Some projects have used this point to test a theory by providing a

cart to a group of 4-5 farmers at a highly subsidized price (farmers pay only 10-15% of actual price). The farmers have in return to create certain soil conservation measures such as stone bunds, etc. If they fail to do so, the cart will return to the project, but if they practice as agreed, after some four years the cart will belong to them for good.

(2) Growing of grass on terrace risers and terrace lips: In upland areas of Java, Indonesia, large numbers of terraces have been constructed but erosion was still taking place, mostly from terrace risers and terrace lips. Farmers are reluctant to spend time and energy to grow grass on it. A project has therefore used a strategy by giving small credits to farmers to raise livestock in a stall-feeding manner, for which farmers have to have somewhere to collect grass. Then, the point has reached when farmers start to grow grass on the terrace risers and terrace lips as suggested by project officers.

(3) The case of West African improved planting pits: Ten farmers from Niger went to visit a farmer in Burkina Faso where the improved planting pits (zai) were practiced. Upon returning home they started to do the same thing. It went off like a wild fire; 4 ha of land were treated in 1998 with what they had seen; the figure swelled to 70 in 1990, 400-500 in 1991, 1,000 in 1992 and around 6,000 in 1995.

The present author has his own experience about the triggering mechanism. Twenty-five years ago, when the Thai government launched an acid sulfate soils improvement program in the Central Plain. The Program would give limestone in the form of marl ($CaCO_3$) from the Government's pits without cost to farmers and the latter would bring it to lime their fields 100 km away. Having no experience in such kind of soil improvement, farmers were reluctant to accept it and the Program got stagnant. Then the Program put a strategy by offering to act as a middleman by hiring large trucks to haul the stuff from the pit, by which the farmers would share the cost in relation to the amount of marl each of them would like to obtain. The work went on very well and several hundred farmers could benefit from such program, which would otherwise not be acceptable if such kind of 'transport cost sharing' was not devised as a triggering mechanism. Now most farmers in acid sulfate soil areas of the Central Plain know this marl application technology very well and adopt it as a way of improving such soils when used for cultivation.

In the analysis of 'elements of success', Reij (1998) points out the need for the project or the agency to move from the target-oriented approach to process-oriented approach. The 'process' means the way people gradually change their behavior in certain aspects of life (such as resources use and management) and will one day cooperate in managing their common resources using improved methods, with an improved perception and attitude). Though the report in area or length of a soil conservation measure treated per year is easy to prepare by implementers and easy to understand by policy makers and auditors, the target-oriented work plan has so far not created sensible impacts towards 'sustainable rural livelihoods'. Such a concept is expected to gain ground quickly, and one day might be widely cited as the objective for rural development.

There is one thing that is a major cause for worrying. That is about the transparency and accountability matters prevailing in certain countries where soil conservation is very much needed. The basic cause of non-transparency, i.e. corruption, is considered a 'cancer' of society that obstructs all development programs not to succeed as planned. What is the use of appropriate conservation technologies and good farming systems, good soil and favorable climates if mechanisms related to its implementation are affected? In a corrupt society, actors who are the middlemen between technologies and land to apply them will not have a right attitude and a strong intention to get it done. This is an open question that might find a venue for discussion at the 12th ISCO.

6.1.8 Conclusions: Soil conservation is a kind of work which is not an end in itself, the measures need good understanding of people who create them in order to have proper maintenance and necessary follow up, so to reach the expected usefulness in sustainable land management. In so doing, a number of strategies are needed in order to gain the adoption from land users towards those soil conservation measures. In studying about farmers adoption It is necessary to distinguish whether an adoption is real or apparent; when agencies constructed everything for farmers without their involvement and farmers agree to having such deed done in their farms, that should not be called 'adoption' at all.

There are several methods that help in increasing farmers' adoption rate of soil conservation technologies. Apart from other conventional extension methods, finding proper triggering mechanisms seems to function well and hence the soil conservation measures created will stay, with a long lasting effect.

Since the adoption is quite essential in the matter of sustainability, both to the measures themselves and to the land and livelihoods as a whole, a thorough study of this essential item is suggested to be carried out, which will give a good example of human behavior towards innovations, so that new innovations to receive good adoption by land users will be created in the future.

For the time being, it is suggested that any kind of soil conservation measures that does not gain acceptance and adoption by farmers should not be used for promoting to the farmers at all. Too much of financial resources have already been wasted.

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6.2 The Use of Vetiver for Soil and Water Conservation

As a clonal plant, vetiver forms dense hedges when planted closely in rows, resulting in a living porous barrier which slows and spreads run off water and traps sediment. As water flow is slowed down, its erosive power is reduced and at the same time allows more time for water infiltrate to the soil, and any eroded material trapped by the hedges. An effective hedge will reduce soil erosion, conserve soil moisture and trap sediment in the run off water on site. Most vegetative hedges can achieve the same results as vetiver grass, but due to its extraordinary and unique morphological and physiological characteristics previously detailed vetiver has many advantages over other systems tested. This is evedent in the following sections:

6.2.1 Soil Erosion and Sediment Control on Sloping Lands: The use of vetiver for soil and sediment control can be exemplified in the following cases:

♦ A trial was set up on a sugar cane farm in the wet tropical cost of north Queensland in 1993 to determine the effectiveness of VHS on very steep land (15-20% slope) with a broken topography, typical of this region. Conventional narrow base banks as a means of erosion control are very difficult to layout and not widely acceptable to farmers, as these banks will hinder farm machinery operation and its safety, particularly during harvest time. Big sugarcane harvesters and their accompanying haul out trucks and tractors cannot negotiate the conventional bank layout, and for safety reason, they have to drive across these banks and damage them in the process. Therefore, very limited soil conservation works have been carried out resulting in often-severe erosion in the region; a new method has to be found to overcome this problem. The trial was conducted on two areas of the farm with great success over the last five years where soil erosion was greatly reduced, sediment was trapped on site and farmers can drive across the hedges during harvest time.

♦ In Fiji, the concept of using vetiver grass for soil and water conservation purposes instead of conventional structures was first developed in this country for the sugarcane growers approximately 50 years ago. The vetiver system is now widely used as a standard practice for soil and water conservation, particularly on small farms. As in other countries, VGT has proven to be very effective in soil erosion control, and when properly implemented the system has improved sugarcane yield up to 55%.

♦ In Queensland, soil conservation structures and land management techniques have been used to reduce water erosion on cropping and grazing lands. Engineering structures include diversion banks to divert runoff from upper non-arable land, contour banks (terraces), strategic row direction in low slopes and constructed waterways have been used.

♦ In Australia, VS was used as a replacement of contour banks in steep sugarcane lands on the wet tropical coast where the traditional method of soil conservation using contour banks (terraces) is not acceptable to farmers as the channels and banks can be dangerous for large machinery operations and vetiver hedges offer a solution to that problem.

♦ In tropical Queensland, vetiver provides shade for sheep in the summer in treeless pasture. Vetiver hedges has improved lambing percentage up to 30%.

♦ In India, on shallow gravelly Alfisol with 2.5% slope, vetiver hedge on contour reduced the run off by 76% and soil loss 97%, and increased mean soil moisture by 5 - 9% in the 0 - 45 cm depth. Increase sorghum, redgram and castor yields due to vetiver hedges ranged from 7.0 - 22.4%.

♦ In South Africa, **w**hile VS has been used to protect crops such as bean, banana, chilli etc, the two crops that benefited most from the VS are coffee and sugarcane. At Sarabica Coffee Estate, vetiver hedges have replaced contour banks as the standard soil conservation measure when planted between the rows of coffee plants. Hedges have reduced maintenance costs, facilitated traffic and provided mulch for weed control in addition to the soil and water conservation effects. At Vallonia Sugar Estate north of Durban, Maxime Robert has fully incorporated the VGT into the management of his farm in Natal. Vetiver has been used successfully for steep slope stabilization, farm road and stream bank stabilization, and contour terrace replacement. Recently he has extended his VGT into a macadamia orchard on steep lands.

♦ In Zimbabwe VGT is being used extensively in large sugar estate and similar to South Africa, VGT is instrumental in the stabilization of farm roads, erosion control in sugarcane fields and particularly in drainage ditches and irrigation channels.

6.2.2 Soil Erosion and Sediment Control on Floodplain: The use of vetiver for soil erosion and sediment control on floodplains are exemplified in the following cases:

♦ Vetiver System (VS) has been used as an alternative to strip cropping practice on the flood plain of Queensland. (Truong 2000). This practice relies on the stubble of previous crops for erosion control of fallow land and young crops. On this experimental site, vetiver hedges that were established at 90m interval provided a permanent protection against flooded water. Results over the last five years (including several major flood events) have shown that VS is very successful in reducing flood velocity and limiting soil movement, with very little erosion in fallow strips.

♦ Erosion by wave action can be eliminated by planting a row of vetiver on the edge of the high water mark. Being able to establish and thrive under waterlogged conditions, vetiver has proved to be very effective in reducing erosion caused by wave action on big farm dam walls.

6.2.3 Flood Erosion Control: The use of VS in flood ersoion control can be visualized in the following cases:

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

♦ Flood plain runoff and the impact of erosion on the flood plain is a big problem in Queensland where cultivation occurs. Strip cropping at right angles to the slope has been used to reduce the impact of erosion. The shift from high stubble crops such as wheat and sorghum to cotton has reduced the effectiveness of the strips. Vetiver grass planted right angle to the flood flow, i.e. parallel to the crop rows, has been used in these flood plain cropping areas as a vegetative water spreader and filter to reduce soil loss. The land is generally flat in the flood plain hence the vetiver strip should extend the full width of the flood plain to reduce the impact from diverting water flows in peak flood events.

♦ In Australia, VS has been used successfully on floodplain of the Darling Downs, Queensland, as an alternative to strip cropping practice which relies on the stubble of previous crops for erosion control of fallow land and young crops. Results over the last several years, including several major flood events have shown that VGT were very successful in reducing flood velocity and limiting soil movement, resulting in very little erosion in fallow strips and a young sorghum crop was completely protected from flood damage.

6.2.4 Slope Stabilization: On steep slopes, vetiver hedgehrows can stabilize the slopes as evident in the following cases:

♦ In forest plantation, vetiver has been used successfully to stabilize shoulders of driving tracks on very steep slopes as well as gullies developed following harvests.

♦ On the very steep slopes (40-50^o) in northern Thailand, where the slash-and-burn practice is widespread, vetiver hedges was used to built up terraces on which cash crops such as bean, corn, etc. or exotic fruit trees such as low-chill plum, peach, or apricot can be grown. These crops not only give higher-value product, they also cause much less erosion than root crops such as cassava or sweet potato.

♦ Gully erosion can be effectively stabilized by vetiver hedges. When planted on contour line above gully head, vetiver hedges will spread and slow down runoff water and stop the advancement of gully heads. This is well illustrated at a number of gullies in both cropping and grazing lands. Following the control of active erosion at the gully heads, gully floors are normally revegetated naturally with native species.

6.3 The Use of Vetiver for Soil and Water Conservation on Farmlands in Northern Thailand

The northern part of Thailand covers an area of about one third of the country (17 million ha), comprising 52% highlands area, 33% uplands, and 15% lowlands. Particularly, the upper northern part (8.58 million ha) has 72% of highlands, 16.7% of upland, and 11.3% of lowlands and water areas (Inthapan *et al.* 2000). Increase in the pressures of hill-tribe population and the land in the low-land agricultural areas, the forest encroachment was increased markedly in the highlands for slash-and-burn and shifting cultivation. Soils are degraded because erosion rate increases rapidly each year. The estimate soil loss was from 50-300 t/ha/yr (Inthapan *et al.* 1996). Economic loss, calculated from the value of N, P and K, was equivalent to about $ 95/year (DLD 1999). As a consequence of the traditional cropping system without soil and water conservation system and the proper crop management, soil fertility and crop yield were decreased. Consequently, farmers' life is impeded; it is also posting great threats to the environment and ecological balance. In particular, soil, water, and forest are being destroyed rapidly.

The following part summarizes the results on vetiver experiment of the Land Development Department conducted in the upper north of Thailand since 1990. These researches emphasize on the study of the use of vetiver to fight against soil erosion on sloping farmlands in the north of Thailand.

6.3.1 Row Number of Vetiver Hedgerows for Erosion Control: In a study of vetiver hedgerow on sloping lands for soil and water conservation, row numbers of vetiver hedge are related to the number of tillers - the more row numbers of vetiver hedge, the more vetiver tillers. Reducing row numbers of vetiver hedge can save the number of tillers. Therefore, a study of row numbers of vetiver hedgerow for soil and water conservation is very essential for the farmers. Inthapan *et al*. (1996) conducted the study on row number of vetiver, ecotype 'Sri Langka' on Tha Yang soil series (Soil Unit Group 48), characterized as sandy loam soil, shallow soil with gravelly in subsoil, and low soil fertility, and ease to erosion surface, on 20% slope located on 600 m.asl., having 1,374 mm of rainfall annually. The result indicated that single and double rows with 30 cm row spacing and 10 cm hill spacing provided non-significant difference in soil and water conservation, whereas they were different from farmers' practice with no vetiver hedge. Single row planting of vetiver hedgerow produced 0.95 t/ha of soil loss while double-row hedgerow gave only 0.71 t/ha of soil loss, or about 12.4% of farmers' practice with no vetiver hedge (Table 1).

Table 1. Effect of row number of vetiver hedge on soil loss (t/ha), Chiang Mai.

Treatments	Soil loss [t/ha]
1. Farmers' practice	5.70 a*
2. Single-row planting	0.95 b
3. Double-row planting	0.71 b

** Figures followed by different letters indicating significant difference at 95%.*
Source: Inthapan et al. (1996)

6.3.2 Plant Spacing and Hill Spacing for Erosion Control: Study of plant spacing and hill spacing can indicate how plant and hill spacing influenced soil and water conservation. Inthapan *et al*. (1996) studied the different plant and hill spacing on sloping lands. The result indicated that 10, 15, and 20 cm hill spacings were good, and not significantly different for soil and water conservation, whereas they differed from the farmers' practice with no vetiver hedge. Soil loss of trial with vetiver hedgerow was only 14.6% of trial with farmers' practice (Table 2). However, vetiver hedge with close hill spacing (10 cm) enhanced tiller growth and development to form dense row very fast, and was quite effective for soil and water conservation.

Table 2. Effect of hill spacing of vetiver hedge on soil loss (t/ha), Chiang Mai.

Treatments	Soil loss (t/ha)
1. Farmers' practice	5.70 a*
2. Hill spacing 10 cm.	0.87 b
3. Hill spacing 15 cm.	0.82 b
4. Hill spacing 20 cm.	0.80 b

** Figures followed by different letters indicating significant difference at 95%. . Source: Inthapan et al.(1996).*

6.3.3 Vertical Interval of Vetiver Hedgerow for Erosion Control: The effect of vetiver hedgerow at different vertical intervals on soil and water conservation was conducted by Inthapan *et al*.(1995). The results obtained during 1993-95 showed that different intervals were more or less the same, and not significantly different in soil erosion measured. An average soil loss was 3.27 t/ha, and only 59 and 31% of those farmers' practice and without vetiver hedgerow treatments, respectively (Table 3).

Table 3. Effect of vetiver hedgerow at different vertical interval on soil erosion in 1993-95, Chiang Mai.

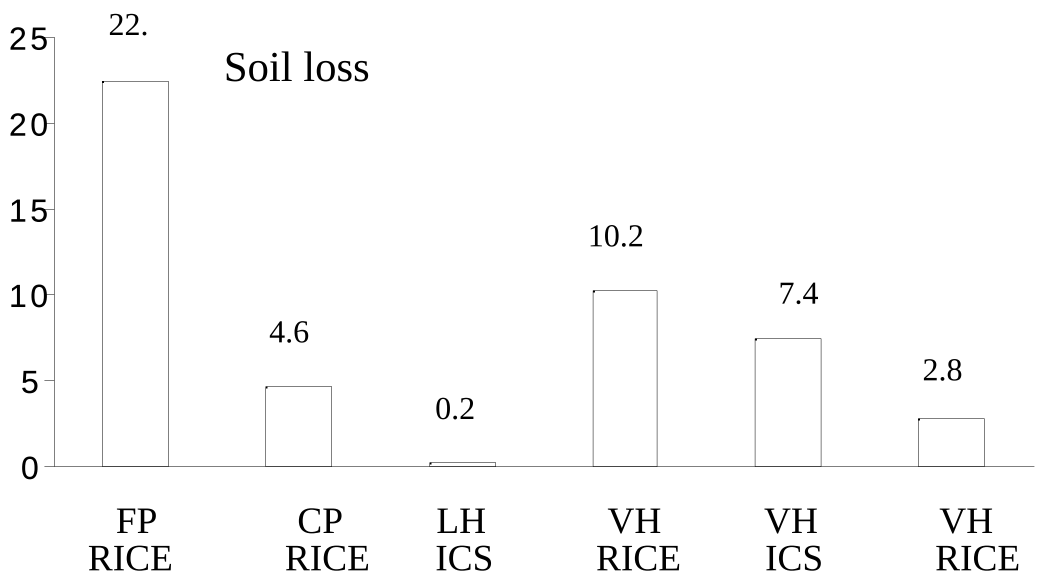
Treatments	Soil loss (t/ha)
1. Bare Soil	26.05 a*
2. Farmers' practice (corn/black bean)	5.49 b
3. counter planting (corn/black bean)	3.76 b
4. counter planting + vetiver (VI = 1 m)	3.08 b
5. counter planting + vetiver (VI = 2 m)	3.32 b
6. counter planting + vetiver (VI = 3 m)	3.41 b

VI = Vertical Interval
** Figures followed by different letters indicating significant difference at 95%*
Source: Inthapan et al. (1996).

6.3.4 Study of a Comparison of Vetiver Hedgerow with Other Grass or Leguminous Hedgerows: Peukrai *et al. (*1994) studied a comparison of vetiver ecotype 'Sri Lanka' hedgerow with leguminous hedgerow (leucaena and pigeonpea) at Pang Mapha district, Mae Hong Son province, on the slope complex soil (SC) located at 900 m.asl. with 20-40% slope and 1,261 mm of rain per annum. The vertical interval of vetiver hedgerows and leguminous hedgerows was 3.0 m. In 1992-93, a comparison of upland rice and integrated cropping system planting between the hedgerows showed that they were both good for soil and water conservation, with soil loss of both stripes at only 39 and 17% of that farmers' practice (Fig. 1).

According to this study, it was found that vetiver and leguminous hedgerows with integrated cropping system along the hedgerows reduced soil loss average, with a soil loss of about 3.8 t/ha, or only 18% of that upland rice monocrop in farmers' practice treatment.

In addition, Kanchanadul *et al.* (1998) studied 'Sri Lanka' vetiver hedge, comparing of natural grass strip and conservation cropping system at Ban Huai Chakan, Ping Kong district, Chiang Mai province, on Wang Hi soil series, with 25% slope and 600 m.asl. Their study indicated that all treatments were not significantly different in soil and water conservation, while they differed from that of farmers' practice with monocropping upland rice. Table 4 shows that the amount of soil loss and water runoff from those treatments were about 52 and 82% of that farmers' practice with upland rice, respectively. This is due to the fact that the hedgerow (vetiver and leguminous shrub) and natural grass strip can reduce soil and water run- off which enhance more water infiltration, providing soil moisture available for crop growth, particularly, in the dry period.



Remarks:

FP = Farmers' practice.
VH = Leguminous hedgerow
ICS = Integrated cropping system.
CP = Contour planting
LH = Leguminous hedgerow

Source: Peukrai et al. (1994).

Fig. 1. Amount of soil loss (t/ha) from different treatment at Mae Hong Son Province in 1992.

Table 4. Effect of conservation cropping system on soil loss (t/ha) and runoff (m^3/ha) at Chiang Mai site during 1993-95.

Treatments	Run-off (m^3/ha)	Soil loss (t/ha)
1. Upland rice	5,800	2.41 a*
2. Upland rice/peanut/vetiver hedge	4,819	1.27 b
3. Upland rice/peanut/natural grass strip	4,738	1.21 b
4. Upland rice/peanut/NFT [@]hedge	4,781	1.28 b

[@]NFT = leucaena + pigion pea. *Source: Kanchanadul et al.(1998).*
** The figure are followed by the different letters indicating on significant different at 95%.*

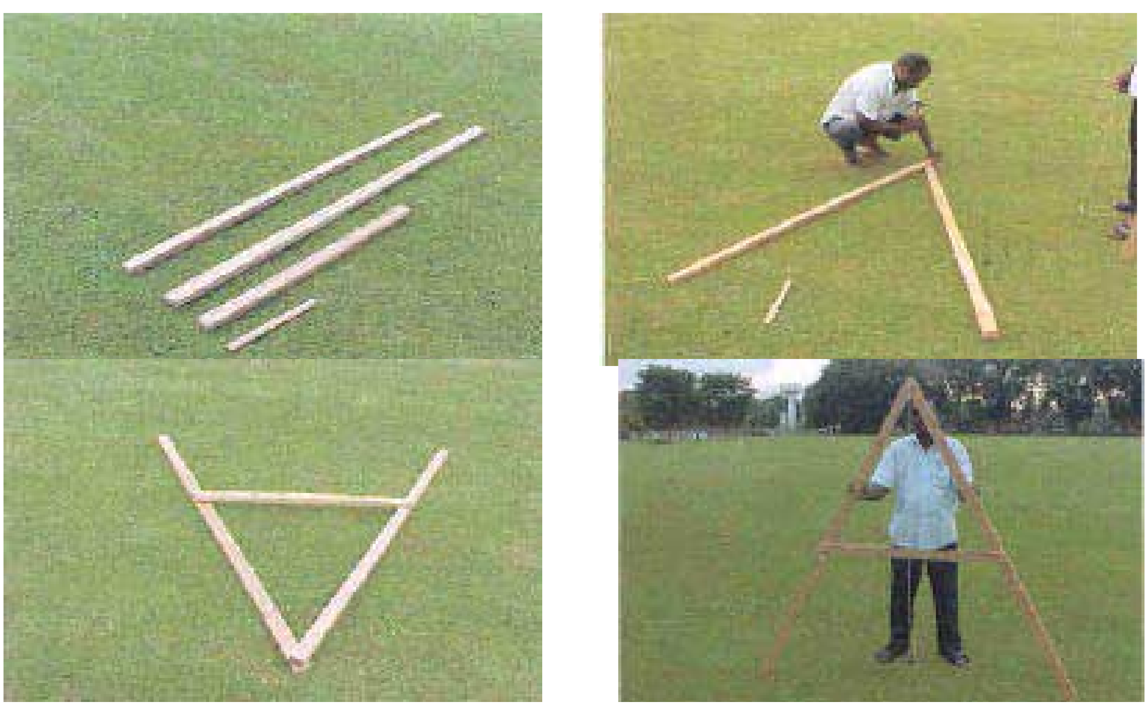
6.4 Techniques of Application of Vetiver Hedgrows on Sloping Farmlands

To apply the proper vetiver hedegrows on sloping farmland requires appropriate techniques. These are described below:

6.4.1 Making an A-Frame Instrument: The first instrument you need is an A-frame. This is a simple, yet effective tool, which looks like the letter A, thus its name. The A-frame is so simple that you can make your own, using materials generally found in your farm. To make an A-frame, three sturdy wooden or bamboo poles, an ordinary carpenter’s leveling instrument, and a string or a rope, are needed. Cut two pieces of wood, at least 1-2 m long to serve as the legs of the A-frame. Cut the third piece, at least _ m long, to serve as the crossbar of the frame. Tie together the upper ends of the longer poles. Let the lower ends of the legs stand on level ground. Spread the legs about 1 m apart to form a perfect angle. Brace horizontally the shorter pole to become a crossbar between the two legs. Tie the carpenter's leveling instrument on top of the crossbar.

Use the A-frame to layout the contour lines of the land. Soil erosion can be prevented by plowing and planting along the contour lines. The contour line is a level line from one end of the field to the other, and is found around the hill or mountain

A-frame instrument



6.4.2 Contour Line Layout: Cut tall grasses or remove any obstructions so that you can move easily and mark line. Two people will make the work much easier and faster. One will operate the A-frame while the other marks the location of the contour lines with stakes. Make a study of the area for which contour lines are to be determined. Begin marking contour lines near the highest point. Let the A-frame stand on the ground. Without moving the rear leg, lift the front leg. Then put the front leg down on the ground that is on the same level with the rear leg. The two legs of the A-frame are on the same level when the air space in the leveling instrument stops in the middle. When this happens, it means that you have found the contour line that is a level line between the two legs of the A-frame. Mark with a stake the spot where the rear leg stands. Move the A- frame forward by placing the rear leg on the spot when the front leg stood before. Adjust the front leg again until it levels of with the rear leg.

For every two to three meters of contour line you find, mark it with a stake. Follow this procedure until you reach the entire length of the contour line that is the other side of the mountain or hill. Try to locate as many contour lines as possible. The contour lines should be spaced from 8 to 10 m apart. Contour line layout by A-frame

6.4.3 Planting Vetiver Tillers along Contour Lines: Vetiver tillers are prepared in the nursery 45 days before planting in the field. Bare root tillers can be used for planting in the moist soil after few days of rainfall. Optimum planting duration is between mid-May to the end of July, when soil moisture is adequate.

6.4.4 Planting Short-term and Permanent Crops: You can plant short- and medium-term, income-producing crops between strips of permanent crops as a source of food and a regular income while waiting for the permanent crops to bear fruits. Suggested short and medium-term crops are pineapple, ginger, gabi, castor bean, cayote, peanut, mungbean, melon, sorghum, corn, upland rice, etc. To avoid shading, short plants are planted away from tall ones. All these crops plant along contour line parallel with vetiver hedgerows.

6.4.5 Practice Crop Rotation: A good way of rotating is to plant grains (corn, upland rice, sorghum, etc.), tubers (cayote, cassava, taro, etc.) and other crops (pineapple, castor bean, etc.) on strips where legumes (mungbean, bush sitao, peanut, cowpea, lablab bean, etc.) were planted previously and vice versa. This practice will help maintain the fertility and good condition of your soil. Other management practices in crop growing like mulching weeding and pest and insect control should be done regularly.

6.4.6 Fruit Trees and Vetiver Hedge: The land with existing orchards is considered a complete system which is already secure and sustainable. Therefore, similar to the fertile forests, cultivation of vetiver grass is neither necessary nor appropriate in such areas because the grass cannot grow as it normally does owing to weak exposure to sunlight. However, vetiver grass hedgerows can be established in the areas that face drought and erosion. If the perennial trees are not older than 3 years or are not close enough to one another, vetiver grass can be grown in rows parallel with the rows of fruit trees outside the shade, in a circle around the fruit trees at a radius of 1.5-2.0 m. on flat land, or in an inverted semi-circle on sloping land. By this way, vetiver leaves can also serve as mulch covering the base of the trees to help maintain soil moisture and prevent soil erosion.

Planting vetiver tillers along contour lines.

Short-term and permanent crops and vetiver hedgerows

Diversified cropping systems

A circle and a half-circle of vetiver hedge around fruit trees

6.5 Other Benefits of Vetiver Hedgerow

6.5.1 Soil Moisture Conservation: In Thailand, to conserve soil moisture in orchards, planting vetiver grass in semi circle of 2m radius down slope from the tree gave best results, this followed by semi circle of 4m radius and the planting of straight row 4m from the trees conserved the least moisture.

6.5.2 Watershed and Catchment Management: VS has been used extensively and successfully in India for catchment hydrology management.

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

In Thailand, methanol extracts of ground stem and root were found to be very effective in preventing the germination of a number of both monocotyledon and dicotyledon weed species. These results indicate the potential of vetiver extract as a natural pre-emergent herbicide.

6.5.4 Phytoremedial Applications*:* Phytoremediation (Greek: *phyton* = plant; Latin: *remediare* = remedy) is the use of plants and tress to clean up contaminated soils and water. It is an aesthetically pleasing, passive, solar energy driven cleanup technique. It can be used along with or, in some cases, in place of mechanical methods. This 'green-clean'technology is very popular in the U.S. nowadays, not only because it is environmentally friendly, but it also costs around one-tenth to one-third of conventional remediation technologies. It is expected that in the U.S. the use of phytoremediation techniques will increase more than 10 folds in the next few years. For the rest of the world, it is likely that this trend will also be followed. (Hengchaovanich 2000).

As mentioned in the earlier section, VS are used to remove contaminants. Most plants used in the western world are popular trees, some other grasses and wetland plants. Research over the last few years, in particular those conducted by Truong and Baker (1998), shows that vetiver is an ideal plant for such purpose. His findings showed that it is highly tolerant to toxicity of heavy metals such as Al, Mn, As, Cd, Cr, Ni, Pb, Hg, Se and Zn. It is capable of absorbing dissolved N, P, Hg, Cd and Pb in polluted water. Moreover, being a wetland plant itself, vetiver can also be used in a constructed wetland system.

In Thailand, it was reported that vetiver could decontaminate agrochemicals, especially pesticides and prevented them from accumulating in crops, polluting streams and other ecosystems (Pinthong *et al.* 1996). Some experiments were also carried out to determine the possibility of using vetiver grass to treat wastewater, and it was found that vetiver could uptake significant amount of N, P, K, Ca, Mg, Pb, Cd and Hg.(Sripen *et al*. 1996). Laboratory results also showed the ability of vetiver in absorbing heavy metals (Roongtanakiat *et al*.1999).

6.5.5 Trapping Agrochemicals and Nutrients: Vetiver systems has been shown to be very effective in trapping both fine and coarse sediments in runoff water from both agricultural and industrial lands (Meyer *et al*. 1995; Truong *et al.* 1996; Truong 1999). In addition, vetiver grass has a very high level of tolerance to extremely adverse conditions including heavy metal toxicity. Therefore VS, when appropriately applied can be a very effective and low cost means of reducing particle-bound nutrients and agrochemicals in runoff water from agricultural lands. The study of VS in trapping nutrients, herbicides and insecticides in runoff from two major agricultural industries in Australia - sugarcane and cotton. (Truong *et al*. 2000).

The results showed that vetiver hedges have proven to be an effective vegetative filter to reduce sediment bound pollutants such as endosulfan and phosphorus in cotton farm. Although pesticide and herbicide levels were not determined in the sugarcane trial, similar results to those from the cotton trial can be expected with these agrochemicals, as a very high proportion of P and Ca was trapped by the hedges. Further detailed studies to fully quantify the effectiveness of the grass through time are required, however.

In Thailand, vetiver has played an important role in the retention and decontamination of agrochemicals, especially pesticides, preventing them from contaminating and accumulating in the soils and crops. Research conducted in cabbage crops grown on steep slope (60%) in Thailand indicated that vetiver hedges had an important role in the process of captivity and decontamination of agrochemicals especially pesticides such as carbofuran, monocrotophos and anachlor, preventing them from contaminating and accumulating in the soils and crops.

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7. NON AGICULTURAL APPLICATIONS

7.1 Bioengineering

In many parts of the world, especially the tropical monsoon belt, rainy or monsoon season is a common yearly phenomena. Intense and heavy rainfall incidences with precipitation ranging from 1,000 to 4,500 mm per annum are normally anticipated, depending on geographical locations. Infrastructure projects in this region are therefore known to be fraught with rainfall-induced erosion, shallow mass movement and/or deep seated stability problems caused in the main by the removal of natural vegetation in the first instance. Of all these occurrences, construction activities especially contribute some 20 times the rate of other forms of erosion attributable to land use on the average. A separate survey in China showed that the non-agricultural practice caused 72.0 and 89.4% of total erosion area and soil loss respectively. As such it is important to solve the problems of erosion and/or stability arising from construction to achieve an overall reduction in the magnitude of the problems, which will be beneficial to the environment as well as to the local economy. Two ways are available to achieve this: either by way of conventional hard or 'harsh' civil engineering method or by way of 'green' or 'bioengineering' method.

Bioengineering, or strictly speaking soil bioengineering (in order not to be confused with similar term being used in medical or genetic sciences), is a relatively new sub-branch of civil engineering. It attempts to use live materials, mainly vegetation, on its own or in integration with civil engineering works to address the problems of erosion and slope stabilization. It was coined, as an inversion, after the German word, *ingenieurbiologie,* since this technique, although used over the centuries, evolved more systematicallly in the Germanic-speaking countries (Austria, Germany, Switzerland, etc) in the 1930's.

In late 1980's and the following decade, due to heightened awareness of environmental issues and availability of knowledge and parameters of plants that can aid as well lend credence to the design, bioengineering became more well known and accepted. This is evident from a more widespread use as well as a number of conferences or workshops being organized during those periods.

7.1.1 Erosion and Stability Problems Identified: Although erosion and stability problems are fairly distinct, common usage tends to overlap, as problems are intertwined. Erosion is the natural process whereby external agents such as winds or water remove soil particles. In the tropical monsoon belt this involves rainfall which is responsible for the removal of surficial layers of about 10~60 cm depth. Over time, rills and gullies deepen and these cause slopes to oversteepen, thus precipitating instability. Instability or deep-seated problems can arise on their own depending on slope geometry, inherent soil strength, ground water characteristics. These are basically geological/geotechnical problems that have to be addressed by proper studies and analyses.

With a variety of computer programs available, the evaluation of the stability of slopes to determine their 'factors of safety' against sliding or failures has now become less tedious or laborious. On the other hand, shallow-seated problems, which lie in the 60~250 cm depths, do not lend themselves for such accurate computation with available software. They present a chronic problem in the tropics with the attendant heavy rainfall and inherent highly erodible slope materials. However, it is believed this problem can be dealt with very effectively by bioengineering measures which will be described in subsequent sections.

7.1.2 Vegetation for Erosion Control and Slope Stabilization: Over the millennia, Nature has 'designed' vegetation as a means to blanket and stabilise the good earth. In the tropics this has evolved into rainforests comprising complex multi-strata canopy, from big trees, shrubs and leaf litters, covering the organic humus-rich top soils, that offer excellent overall protection. In the light of current awareness and conscientiousness of environmental issues, the preferred option to address the above problems would be to go back and seek solutions that Nature has already provided in the first instance. That is, to reinstate those areas ravaged by human beings by way of re-growing vegetation. The methods of sustainable revegetation have to be studied and applied where appropriate for the problems at hand as described below.

7.1.2.1 Control of Surface Movement by Grassing and/or Leguminous Cover Crops: The use of grasses and/or leguminous covers for surficial protection is common in civil engineering or infrastructure works. In fact, it is stipulated in most standard specifications. The methods popularly employed are by seeding (manual or hydro-seeding) and turfing/sodding.

Turfing is generally carried out using local grasses. Turfing is traditionally the best method as it gives instant coverage. However, due to various extraneous factors, such as heavy demand, lack of good nurseries, labour shortage, it is being overtaken by hydro-seeding on projects requiring mass production.

Hydro-seeding and turfing is successful in areas where the soil is not highly erodible (i.e. it has some cohesion) and it is not carried out in the midst of a heavy monsoon period. But its drawback is that it offers only surficial protection as shall be described in the next section.

7.1.2.2 Mitigation of Shallow-Seated Instabilities (Shallow Mass Movement) by Shrub and Tree Planting: Although grass can provide effective slope protection (when soil/climatic conditions are not extreme), its roots do not extend deep enough into the soil (generally in the order of 20~40 cm) to provide the grip and anchorage needed to prevent surficial slip in the event of heavy, prolonged rainstorm. The residual soils in the tropical region with little or no cohesion, once subject to fines (soil particles whose sizes are smaller than 74 microns) being washed out by rainwater will see the collapse of the soil structure and thus liquefaction or soil flow. On many highways one can often see random patches of stone pitching, gunite (shotcrete/cement spray) which are conventional rectification work carried out for the shallow-seated or shallow mass movement problems. It is not unusual to see a repeat of these repair works if the real root cause of the problems is not identified and solved accordingly.

Sometimes one would see the construction workers intuitively stake timbers poles/stakes into the ground after the slip occurs to help hold up the slipped slope temporarily. This is in lieu of trees or tree roots (to be very precise).

The advantages of trees and shrubs are to bind and reinforce the shallow portion of the soil surface by the root networks, to induce the soil water depletion (pore water dissipation) through evapo-transpiration as well as buttressing and soil aching action from embedded stems.

As seen in the temporary measure using timber poles and later after the establishment of trees: one major factor responsible for slope stability is the role of roots. Roots (or 'inclusions') impart apparent cohesion (c_r) in similar fashion to 'soil nailing' or 'soil doweling' in the reinforced soil principle, thus increasing the factor of safety of slopes permeated with roots *vis-à-vis* no-root scenario.

Interestingly, recent research at the Agricultural Research Service of the US Department of Agriculture (USDA) has discovered a unique fungi protein that may be primary glue (nicknamed 'super-glue' that holds soils together. The protein is named 'glomalin', for *Glomales*, the scientific name for the group of common root-dwelling fungin that secrete the protein through hair-like filament called hypha.

7.1.2.3 Erosion Control and Slope Stabilization by Vetiver Grass: Unheard of by most people up to the early 80's until being actively promoted in the agricultural sector by Mr. Richard Grimshaw, then of the World Bank; vetiver grass had actually been used a few centuries earlier in India. When Indians moved overseas, vetiver was brought along with them to new localities, thus explaining the presence of vetiver on various parts of the globe.

To assess the properties of vetiver for potential engineering usage, the author has conducted some experiments to do just that. Four trial embankments were constructed and planted with vetiver in August 1993 for the purpose of observing its field performance. Three months after planting, an exceptionally heavy monsoon hit the site, which caused numerous failures along major highways and hillside development projects. It was found that slopes planted with vetiver grass were not significantly affected although some slopes in the vicinity failed. In mid-April 1994, an excavation exercise was conducted to determine the rooting depth of vetiver. It was found that the massive root networks had reached a record depth of 3.6 m after 8 mos. of growth. Other conclusions drawn from these trial included: vetiver could grow rapidly to form a complete hedgerow which managed to trap wash-off soil material; from rooting depth monitoring exercise, it was evident that the roots managed to penetrate the harder stratum (with fragments of rocks). They not only grew vertically, but some seemed to incline themselves, following the side slope profile. From the limited trials carried out, results appeared encouraging and promising indicating the tremendous potential of vetiver for slope protection and stabilization work.

In response to a number of engineers' call for more parameters for a wide range of vegetation categories, so that they can plug them into elegant mathematical formulae in their designs, the author and his colleague decided to carry out some experiments to include vetiver among the list of vegetation with available parameters. One of the experiments involved tests on gain in shear strength in soils by the presence of vetiver roots versus identical soils which are root-free. By conducting large-scale direct shear tests at an embankment at varying depth levels, the increase in shear strength can be determined. It is also important to determine the root tensile strength properties in the process of evaluating a plant species as a component of slope stabilization. This is because when a plant root penetrates across a potential shear surface in a soil profile, the distortion of the shear zone directly resists shear while the normal component increases the confining pressure on the shear plane.

For the determination of root tensile strength, mature root specimens were sampled from 2-year-old vetiver plants grown on an embankment slope. The specimens were tested in fresh condition, limiting the time elapsed between the sampling and testing to two hours maximum. The un-branched and straight root samples about 15~20 cm long were connected vertically to a hanging balance via wooden clamp at an end while the other end was fixed to a holder that was pulled down manually until the root failed. At failure, the maximum load was monitored. The tensile strength of root is defined as the ultimate root tensile force divided by the cross-section area of the unstressed root (without bark, as it has weaker strength properties). It was found that the mean tensile strength of vetiver roots varies from 180 to 40 MPa for the range of root diameters 0.2~2.2 mm. The mean tensile strength is about 75 MPa at 0.7~0.8 mm root diameter which is the most common diameter class for vetiver roots. This is approximately equivalent to 1/6th(one-sixth) of the tensile strength of mild steel. Compared to many hardwood species, the average tensile strength of vetiver roots is very high. Even though greater tensile forces are required to break hardwood roots, their average root tensile strength values are lower than that of vetiver because their average root diameter is higher than the 0.7~0.8 mm average diameter of vetiver roots (Table 1).

Moreover, because of its dense and massive root system underground, it offers better shear strength increase per unit fibre concentration (i.e. 6 ~19 kPa per kg of root per m^3 of soil) compared to 3.2 ~3.7 kPa/kg per m^3 of soil for tree roots. With the above results, one can say that vetiver roots behave like ‘living’ soil nails or soil dowels that are now being widely used for steep slope stabilization processes. The difference is that there should not be any concern over long-term corrosion prospect of metallic nails to worry about. On the contrary, ‘living nails’ even improve with the passage of time.

While the dense underground root webs offer shear strength increase to soils resulting in slope stability enhancement, the upper parts of vetiver or the stiff stems act like a living barrier to trap silt in the erosion control process. Because of its rapid and vigorous growth rate, it can form a dense hedgerow if planted in that pattern in only 3~4 months and is capable of slowing down rainfall runoff, distribute it uniformly, filter it and trap eroded sediments at the hedge face.

Table 1. Tensile strength of roots of some plants

Botanical name	Common name	Tensile strength (MPa)
Salix spp.	willow	9-36*
Populus spp.	poplars	5-38*
Alnus spp.	alders	4-74*
Pseudotsuga spp.	Douglas fir	19-61*
Acer sacharinum	silver maple	15-30*
Tsuga heterophyllia	western hemlock	27*
Vaccinum spp.	huckleberry	16*
Hordeum vulgare	barley grass, forbs moss	15-31* 2-20* 2-7kPa*
Vetiveria zizanioides	vetiver	40-120 (aver. 75**)

** After Wu (1995)* *** After Hengchaovanich and Nilaweera (1998)*

Studies in Malaysia reported that compared with bare soil, vetiver was able to control runoff and eroded soil (soil loss) to 73 and 98% reduction, respectively. Under field simulated rain, studies in Venezuela suggested that votive could reduce soil loss and runoff substantially as compared to the control treatments using other vegetative barrier.

It is noteworthy to highlight the fact that the hedgerow adjusts itself in tandem with trapped silt on the upslope, thus ensuring that it will never get itself buried and die off.

As such, the remark of His Majesty the King of Thailand, made a few years ago that vetiver is a "living wall" is indeed very illustrative and enlightening from the bioengineering perspective. One can visualize that while the above-ground 'wall' caters for erosion control, the underground 'wall' (i.e. roots) simultaneously enhances slope stability.

7.1.3 Bioengineering Applications of Vetiver: The scope of applications are varied and many, it really leaves to the imagination what one wants to utilize vetiver, provided of course that the properties or attributes of vetiver are well understood. *To sum up, these can be categorized as follows:*

7.1.3.1 Slope Stabilization: This is where vetiver excels because of its long roots. As such, it should ideal for helping stabilizing cuttings and fills on highways, railways and dams. Highway bridge approaches are good locations to try vetiver bioengineering. Highly erodible and unstable slopes where shotcrete/gunite slopes are normally used can be substituted by vetiver aesthetically at lower costs.

7.1.3.2 Erosion and Gully Control: Because of its good roots and dense, stiff stems, vetiver can be used to reduce water velocity and trap sediments on highly erodible soils, gully locations to stabilize the spots in question. It can manage to grow well on very sandy soils. Vetiver planted near river or pond banks can trap the amount of silts that will flow in to make the water dirty and murky, plus the reduction in dredging maintenance costs.

7.1.3.3 Demarcation: Property boundaries or filled-up lands with or without structures can be stabilized with vetiver to keep their sitting structures intact. In tropical Australia, concrete dyke barriers at road shoulders are replaced with vetiver rows. This allows controlled low velocity flows down the roadway slope to support its revegetation. It also helps direct large flows to the outfall chutes.

7.1.3.4 Flow Diversion: Although vetiver will not be not be as good as concrete or hard barrier, but its green and relative effectiveness, cheap costs will be help divert and slow down areas where the sheet flows or flooding can harm the end-of-flow line objects or lands.

7.1.3.5 Transition Surficial Protection System: In many instances, especially river bank or river bed protection, gabion or mattresses have to be specified because of high velocity flow which vetiver alone cannot cope with. Moreover, the transition zone between the area protected by the 'hard' structures and the unprotected soil part is generally highly vulnerable. Other examples: strips between drain chutes, along the edge of concrete drainage channels, bridge or culvert wingwalls, etc.

7.1.3.6 Vetiver as a Pioneer Species for Revegetation Projects: It has been demonstrated in several countries that vetiver when planted on slopes produced favorable 'microclimate' that helps enhance the establishment of other larger trees that are intended for the project.

7.1.4 Tips in the Utilization of Vetiver for Bioengineering Purposes: To derive the maximum benefits in the utilization of vetiver, one must realize that vetiver, as a living plant, is being called upon to perform engineering functions. As such, it too should be considered in an 'engineering context', either on its own or to supplement civil engineering work in the bioengineering measures.

To start with, vetiver system must be used with a proper design, with the designer knowing the merits and the limitation of the system and to design his engineering works accordingly. Secondly, as 'an engineering material', it too must be subject to some specifications and enforceable control procedures before it can be used on the ground.

Since there are some cross-disciplinary works involved, it is suggested that engineers who feel they seriously need advice on agricultural techniques should seek the guidance or get the agriculturists involved in the process of securing good planting materials, correct planting techniques and maintenance procedure in order to ensure proper establishment and long-term sustainability.

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7.2 Phytoremediation

Phytoremediation (Greek: *phyton* = plant; Latin: *remedare* = remedy) is the use of plants and trees to clean up contaminated soils and water. It is an aesthetically pleasing, passive, solar energy-driven clean-up technique. It can be used along with or, in some cases, in lieu of mechanical, chemical or thermal methods. This 'green-clean' technology is very popular in the United States nowadays, not only because it is environmentally friendly, but because it costs around one-tenth to one-third of the conventional remediation technologies. It is expected that in the U.S. the use of phytoremediation techniques will increase more than ten-fold in the next few years. For the rest of the world it is likely that this trend will also be followed.

Phytoremediation takes advantage of plants' nutrient utilization processes to take in water and nutrients through roots, transpire water through leaves, and act as a transformation system to metabolize organic compounds, such as oil and pesticides. Or they may absorb and bioaccumulate toxic trace elements including the heavy metals, lead, cadmium, and selenium. In some cases, plants contain 1 000 times more metal than the soil in which they grow. Heavy metals are closely related to the elements plants use for growth.

Absorption of large amounts of nutrients by plants (and only a small amount of plant toxins that might be harmful to them,) is the key factor. Plants generally absorb large amounts of elements they need for growth and only small amounts of toxic elements that could harm them.

Phytoremediation is an *in-situ* approach, not reliant on the transport of contaminated material to other sites. Organic contaminants are, in many cases, completely destroyed (converted to CO_2 and H_2O) rather than simply immobilized or stored.

The establishment of vegetation on a site also reduces soil erosion by wind and water, which helps to prevent the spread of contaminants and reduces exposure of humans and animals.

Constructed wetlands are also considered one of the phytoremediation techiques. Constructed wetlands planted with reeds have been used to remove polluting substances from discharges from mine for quite sometime before the phytoremediation as we know it today comes into vogue. Presently a variety of other plants are being investigated for used in the wetland situation.

Phytoremediation applies well for very large sites with relatively low contents of organic nutrients or metal at shallow depths and will take relatively longer time for treatment. For very high pollution levels, conventional or other methods may have to be resorted to but at a much greater cost.

7.2.1 Plants used in Phytoremediation: Plants intended for phytoremediation purposes should meet the following criteria:

- depth of root zone,
- growth rates and yield,
- potential to evapotranspirate groundwater,
- degradative enzymes production, and
- propensity to accumulate and ability to tolerate contaminants.

Being a relatively new discipline, the list of plants that can be used for phytoremediation is still limited but now this list keeps expanding as more investigations are carried out.

Among the plants which have been tried and tested for various situation are:

- poplar trees (used in the absorption of pesticides)
- Indian mustard grass(accumulates selenium, sulfur, lead, chromium, cadmium, nickel zinc and copper
- tomato (absorbs lead, zinc and cadmium)
- bamboo(accumulates silica in its stalk and utilise it as crude protein in its leave)
- sunflower(absorbs radioactive materials such as uranium, cesium and strontium-made famous in the cleanup of post Chernobyl nuclear reactor disaster)
- duckweed (for explosive waste)
- willow(for hydrocarbon)
- fescue, ryegrass, bermuda grass (for petroleum products)
- water hyacinth (uptakes lead, copper, iron and mercury).

7.2.2 Vetiver as a Phytoremediation Plant: An obscure plant until introduced and promoted actively by the World Bank through the relentless efforts by Richard Grimshaw then serving with the Bank during the late 1980's, vetiver initial usage was mainly focused in the agricultural sector. As it later became better known, the scope of its applications has been explored and greatly expanded after its unique characteristics have been determined. Vetiver lends itself ideally to engineering and environmental protection functions, hence touted as 'miracle grass', wonder grass, super grass or multi-purpose grass etc. Among its many unique characteristics are:

- It possesses seeds that are sterile, thus is non-invasive and will turn to weeds
- It grows upright and, with its stiff stems, is able to form a dense hedge within 3~4 months, resulting in the reduction of rainfall runoff velocity, and formation of an effective sediment filter. The hedgerow can adjust itself in tandem with trapped silt by forming new tillers from nodes on the culm of higher branches. It also possesses substantial biomass.
- It has a vigorous, massive and strong root system that penetrate vertically to 2~3 m depth in a year, depending on soil types. The strength of the roots has been determined to be about 75 Mpa or $^1/6$ th of mild steel.
- Tolerance to extreme climatic variation such as prolonged drought, flood, submergence, and extreme temperatures from –15 to 55ºC.
- Tolerance to a wide range of soil acidity and alkalinity (pH from 3.0 to 10.5).
- High level of tolerance to high levels of soil salinity, sodicity and magnesium.
- Highly tolerant to Al, Mn, As, Cd, Cr, Ni, Cu, Pb, Hg, Se and Zn in the soils.
- Highly efficient in absorbing dissolved N, P, Hg, Cd and Pb in polluted water.
- High level of tolerance to herbicides and pesticides.
- Although extremely versatile and hardy as above, it is intolerant to shade.

When one examines the above attributes vis-à-vis the criteria of a phytoremediation plant as cited earlier one would see that it is a promising candidate for phytoremediation purpose.

Researches in Australia over the last six years confirms the following quantitative figures on levels of tolerance by vetiver.

Table 1. Levels of tolerance of vetiver

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

Tests have been conducted to find out the manner of distribution of the heavy metals in the roots and shoots as tabulated in Table 2 below:

The significance of this finding is that As, Cd, Cr, and Hg move up very little to the shoots, while some 1/7 to 1/3 of Cu, Pb, Ni and Se are translocated to the shoots. For Zn it is evenly distributed (40%) between shoots and roots.

Table 2. Average distribution of heavy metals in vetiver shoots and roots

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

This means that vetiver planted at contaminated sites, the shoots can be safely grazed by animals or harvested for use as mulch or handicrafts compared with the thresholds set by the environmental agencies and tolerance of the animals concerned. (see Table 3 below):

Table 3. Threshold levels for potential soil contaminants

Substance	Thresholds ($mg\ kg^{-1}$)		CHEM† unit
	Environment*	Health*	
Inorganic			
Antimony	20		
Arsenic	20	100	30
Barium			400
Cadmium	3	20	3
Cobalt			50
Chromium $^{6+}$			25
Total Cr	50		250
Copper	60		100
Lead	300	300	200
Molybdenum			10
Manganese	500		
Mercury	1		2
Nickel	60		100
Selenium			20
Sulfate	2000		
Tin	50		50
Zinc	200		500
***Organics*, etc.**			
CN (free,total)			25
CN (complex,total)			250

Mono aromatic hydrocarbons			7
Poly armatic hydrocarbons		20	20
Phenols			5
PCB's			1
Gasoline (C_5-C_{10})			100
Kerosine (C_{10}-C_{16})			100
Oil (C_{17} _)			1000
Dieldrin	0.2		
Benzo (a) pyrine		1	1

**Australian and Newzealand Environment and Conservation Council/National Health and Medical Research Council*
†Chemical Hazards and Emergency Management (CHEM) unit

7.2.3 Application of Vetiver in Phytoremediation: Two approaches are being made to make use of vetiver in phytoremediation, namely: (i) Reclamation of Deteriorated Soils, and (ii) Rehabilitation of Contaminated Soils and Water. The former includes all naturally occurring deteriorated soils such as saline soil, acid sulfate soil, skeletal soil, sodic soil, sandy soil, magrove soil, shallow soil, and steep slope land. The latter include all man-made contaminated soils and water such as garbage landfills, mine tailings, industrial watse dumping areas, effluent disposal from aseptic tanks, effluent from piggeries, cattle and poultry farms, purification of polluted water, algal growth in the river and reserovoir. Each approach will be treated separately in the sections below:

7.2.4 Vetiver in wetland applications: The Latin name of vetiver is *Vetiveria zizanioides.* '*zizanioides*' means along river banks, which connotes its riverine origin and water affinity making it a suitable wetland plant.

As mentioned earlier, reed (*Phragmites* spp.) beds have always been used successfully in a wetland system for quite sometime such as the removal of pollutants from discharges from abandoned mines in Wales, United Kingdom.

However, it was reported that reeds could not tolerate certain chemicals such as Atrazine and Diuron from discharges of sugarcane farms in Australia while vetiver was not affected.

7.3 Reclamation of Deteriorated Soils

Deteriorated soils are soils which possess poor physical and chemical properties as the result of natural phenomena. Such soils are unproductive, giving poor yields to crops grown on them even with proper agricultural practice such as providing fertilizer, irrigation and pest control. They are normally referred to as problem soils, including: (1) saline soil, (2) acid sulfate soil, (3) sandy soil, (4) soil with hard pan, (5) vertisols soil, (6) peat soil, and (7) skeletal soil.

In addition to these naturally-caused deteriorated soils, crop yields are also low if fertility and moisture are not adequate. Improper land management also contribute to poor yield as the result of degradation of soil properties, especially in the decline of organic matter.

7.3.1 Major Deteriorated Factors: The major sources of land and soil deterioration are the low fertility and poor potential fertility, affecting most highland soils and the strongly leached soils on the slightly higher terrain. These soils are all acid, with limited base saturation, and tend to have low cation exchange capacity (CEC). Thus not only are natural levels of most nutrients low but the high acidity and poor CEC mean that amendments using fertilizers are difficult and require care. The other widespread soil limitations are shallow depth, lateritic gravel, the fertility problem and the liability to loss of applied nutrients during the wet season, especially on steep slopes. In addition they reduce the total water-holding capacity of the soil profile, limit rooting depth, and increase the erosion hazard and impact.

There are also a number of more specific soil constraints such as salinity and alkalinity, acid sulfate soils, coarse-textured sandy soils, result in very poor physical and chemical characteristics. Among the important deteriorated soils in Thailand are the followings:

(1) Saline soil
(2) Sodic soil
(3) Acid sulfate soil
(4) Soil with hard pan
(5) Lateritic soil

7.3.2 The Use of Vetiver to Reclaim Deteriorated Soils: Due to population pressure and the need for land for agricultural activities, deteriorated soils are being reclaimed through the use of vetiver, which is found to be the most effective and low cost. Vetiver is known as a pioneer plant by agronomists. It is a species with extremely strong reverse resistance, including saline and alkaline, damp, drought, infertility and heat. These are described below:

7.3.2.1 Saline Soil: Saline soils are soils which contain excessive levels of soluble salts for the growth of most conventional crops.

The Phikun Thong Royal Development Study Centre in Narathiwat, southern Thailand has planted vetiver to stop brackish water. The grass grows well and effectively holds the soil. This usage leads to the extension of vetiver to schools and farmer housing.

The study of the effects of salt tolerant on vetiver growth has also been conducted in Chanthaburi and Chachoengsao provinces. The results indicated that at salinity levels between 0-10 mmhos, all ecotypes under trial can survive. As the salinity level increases, the grasses begin to die. When the salinity level reaches about 20 mmhos, only salt tolerant ecotypes can survive (sea water has a salinity of 40-50 mmhos). The ecotypes found to be salt tolerant are from 'Nakhon Phanom', 'Kanchanaburi', 'Udon Thani', 'Ratchaburi', and 'Prachuap Khiri Khan'; and all are *V. nemoralis*.

Lowering water table is the most effective means of reducing dry land salinity. With its salt tolerant ability and deep rooting characteristics, vetiver has been successfully used to control soil erosion and at the same time lower the saline water level in south eastern and western Australia.

7.3.2.2 Sodic Soil: Sodic soils are soils that contain excessive levels of exchangeable sodium (relative to the total salt concentration in the infiltrating water) for crop production. Contrary to saline soil, sodic soils may have much reduced permeabilities and poorer titlth. This comes about because of certain physical-chemical reactions associated, in larger part, with the colloidal fraction of soils that are primarily manifested in the slaking of aggregates and the swelling and dispersion of clay minerals.

Since 1965, the National Botanical Research Institute, Lucknow, UP, was a pioneer in using vetiver for ameliofration of sodic soils. However, it is only recently, after 40 years, that vetiver has again been opted for large-scale trials under the World Bank Program in the state. High concentration of salts in the root zone of soil limit the productivity of 950 million ha of otherwise productive land around the world. In India alone, there are 8.1 million ha of sodic land where productivity is limited. Behl and Singh (1998) were able to grow vetiver successfully in the soils with high levels of exchanageable sodium in the root zone with high pH (9 to 10.6) throughout the profile, poor water intake, occasional anaerobic stress due to water logging, poor availability of phosphorus that limits the growth, and low fertility.

7.3.2.3 Acid Sulfate Soil: Acid sulfate soils (ASS) are soils that occur on the low-lying coastal areas with brackish sediments. Their natural drainage is poor or very poor, and if they have not been artificially drained, the water table lies close to or at the surface, and sometimes throughout the year. ASS constitutes a major component of arable lands in many tropical countries in Africa and Asia such a Thailand and Vietnam where rice is the main food crop. These soils are highly erodible and difficult to stabilize. Eroded sediment and leachate from ASS are extremely acidic. The leachate from ASS has led to disease anad death of fish in several coastal zones of eastern Australia.

Vetiver has been successfully used to stabilize and reclaim a highly erodible ASS on coastal plain in tropical Australia, where actual soil pH is around 3.5 and oxidized pH is as low as 2.8.

As there is vast area of ASS in Thailand, there has been a great effort in reclaiming and improving such soil by using vetiver (Muensangk 2000) who did the experiment on the use of vetiver to reclaim ASS on Bang Nam Prieo soil series (P-Iia, Typic Tropaquepts) under greenhouse condition. He concluded that the 'Sri Lanka' ecotype exhibited the highest plant height and produced the highest number of tillers/hill. There was no statistical difference on plant height from using every rate of 15-15-15 fertilizer. He was of opinion that the vetiver system reclaimed ASS by retaining the runoff as a means of moisture conservation, gaining 60% of the rainfall to run off vetiver system's moisture conservation. He concluded that "This is the best way of recharging ground water".

7.3.2.4 Soil with Hard Pan: Planting of vetiver in compact hard pan and poor soil at Huai Sai Royal Development Study Centre, Phetchaburi Province to study the development of the roots system revealed that vetiver can penetrate hard pan layer of soil. This is verified by digging a vertical soil porfile and using water from a hose to wash off soil particles to exhibit the amount of roots in both the topsoil and hard-panned layers. It can be concluded that vetiver roots could break through the hard-panned layer as numerous roots were found in the hard-panned layer. A breakthrough indeed.

7.3.2.5 Lateritic Soils**:** The Huai Hong Khrai Royal Development Study Center has carried out experiment on vetiver planted in lateritic soil to test the growth and survival rates of 14 ecotypes. The results suggested all 14 ecotypes under study can grow moderately well and are able to survive through the dry season.

References for Section 7.3:

Muensangk, S. 2000. The use of vetiver grass for reclamation and improvement of acid sulfate soils in Thailand. I. Pre-experimental study. *In:* Preceedings ICV-2, 18-22 Jan. 2000, Phetchaburi, Thailanad, pp. 288-293.

7.4 Rehabilitation of Contaminated Soils and Water

One of the causes of environmental degradation is pollution due to the presence of pollutants in soils and water. The extent of the pollution in both the developing and developed countries is quite significant owing mainly to uncontrolled discharge of pollutants from various sources, including chemical by-products, heavy metal and other industrial wastes, pesticides, and fertilizer residues, domestic garbage and landfill leachate, etc. into the environment. Such environmental degradation has been a major concern for the public and private environmental agencies worldwide. Various control measures have been attempted, but their high cost is a major drawback, especially in developing countries. Thus there is clearly a need to seek certain low-cost technology, such as phytoremediation, to deal with the ever-increasing levels of pollution.

7.4.1 Rehabilitation of Contaminated Soils:

7.4.1.1 Treatment of Mining Spoils: In many countries of the world with mining activities, proper treatment of mining wastes to contain the degree of toxicity and to improve the environment at and surrounding the sites have received much attention due to enforcement of environmental regulations. However, the use of vegetation in the recent past was not too successful due to the very hostile soil and ambient temperature conditions of those sites until the breakthrough in vetiver applications. In South Africa, vetiver managed to rehabilitate the tailings of several diamond, gold and platinum mines where other plants initially could not grow due to very high temperature(40~50ºC).

In Australia, vetiver has been successful in rehabilitating tailings of coal, bentonite and gold mines. In China, it has been experimented on a lead mine and being used on a copper mine.

7.4.1.2 Treatment of Landfills or Garbage Dumps: Landfills or garbage dumps contain varying degree of toxic materials. Experimental trials using vetiver have been carried out for an old landfill site in Australia and an urban garbage dump in Guangzhou, China.

In the Australian trial, it was discovered that vetiver has been able to revegetate an old landfill side slope which was eroded and bare due to inability of grasses and native species to establish there because of the toxicity present in the landfill.

Phytoremediation by vetiver succeeded in extracting the heavy metal contents and created favorable microclimate that induces subsequent colonization of other species. Vetiver planted at the toe of the landfill also sucked up the leachate which otherwise flowed toward a nearby stream course, posing considerable health risk.

In China, experiments showed that vetiver managed to survive, even thrived in the garbage dump. It was even claimed that bad odor has been greatly reduced in the process!

In Thailand, a trial was carried out at a major landfill in Kamphaeng Saen, 90 km north-west of Bangkok, where 5,000 t of garbage are being dumped daily. Planting was carried out in July 1999 during the rainy season. After four months, it was observed that the plants were able to survive fairly well, despite the leachate and toxicity normally associated with such a dump site. Field and parallel laboratory experiments are conducted at Chulalongkorn and Kasetsart Universities and still ongoing. Table 1 shows some preliminary results to date.

Table 1. Preliminary results from Kamphaeng Saen landfill site

Unit: ppm

Item	**Period**	**Heavy metals**				
	(month)	**Ni**	**Cr**	**Cu**	**Pb**	**Zn**
Soils	0	16.1	32.4	16.6	16.14	62
	3	33	50	34.1	44.7	102
Vetiver grass	0	5.3	1.4	0.92	0.85	9.4
	3	6.7	2.6	9.9	4	54

PARAMETER

Item	**pH**	**BOD+**	**COD+**	**Cl+**	**TKN+**	**TP+**	**Ni**	**Cr**	**Cu**	**Pb**	**Zn**
Leachate	9.2	6,607	13,160	1,541	3,266	18.5	0.422	1.38	0.245	0.151	2.9

(+ Unit: mg/l) ** Tested at the Pollution Control Department (PCD) Laboratory*

7.4.1.3 Removal of Agrochemicals and Pesticides: In Thailand, research conducted on cabbage crops grown on steep slopes indicated that vetiver hedges had an important role in the process of captivity and decontamination of agrochemicals and pesticides preventing them from contaminating and accumulating in crops.

7.4.2 Rehabilitation of Contaminated Water:

7.4.2.1 Water Purification: Vetiver was tried in China for the removal of P and N. It was found that after three weeks, virtually all P was sucked up, while 74% of N was removed. Experiments conducted in Thailand on wastwater indicated that vetiver had the ability to uptake heavy metals and accumulated in the shoots and roots. Such experiments indicated the possibility of vetiver as a biological wastewater treatment.

7.4.2.2 Remediation of Eutrophic Water: River and lake water subjected to pollution by N and P, especially P which is the key element responsible for water eutrophication exhibiting as bluegreen algal growth in rivers and lakes. With intensive farming adjacent these water bodies, the quantities of N and P are bound to increase. From experiments in China, it was found that vetiver can be grown along the shore or banks to first filter off the chemicals and then grown hydroponically in water along banks. The N and P were removed efficiently and the water became more transparent after treatment.

7.4.2.3 Vetiver in Wetland Applications: The Latin name of vetiver is *Vetiveria zizanioides.* '*zizanioides*' means along river banks, which connotes its riverine origin and water affinity making it a suitable wetland plant.

As mentioned earlier, reed (*Phragmites* spp.) beds have always been used successfully in a wetland system for quite sometime such as the removal of pollutants from discharges from abandoned mines in Wales, United Kingdom.

However, it was reported that reeds could not tolerate certain chemicals such as Atrzine and Diuron from discharges of sugarcane farms in Australia while vetiver was not affected. Assuch, in some situation, vetiver may be able to perform better, depending on trial and experiments.

7.4.2.4 Vetiver for the Removal of Effluents: In the same manner of pollutant removal as mentioned in the foregoing sections, vetiver can be used for trapping P, N and other nutrients in effluent discharges. In China, it was reported on the successful use of vetiver in a piggery. In Australia, a summer camp with several lodges had planted vetiver to intercept the effluent that seeped out from a septic tank with good success.

7.4.2.5 Conclusion: As mentioned above, vetiver possesses unique characteristics that lend itself as an ideal plant for phytoremediation purposes. However, the use of vetiver in phytoremediation work is still not widespread, being pioneered in mostly limited in South Africa and Australia. Even there, many instances are test sections and some are laboratory experiments only. It is hoped that once it is better known and more people start trying it, more information will come to light that will convince people to apply it as in the case of bioengineering.

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7.5 Disaster Prevention, Mitigation or Rehabilitation

7.5.1 What are Disasters?: "A disaster can be defined as any unforeseen or sudden situation that the affected community is unable to cope with, or an event when natural hazards interact with existing conditions so that they disrupt the ability of a community to feed and care for their families. The natural hazards become disasters when the disruptions exceed the adjustment capacity of the community" (Shelton 2000).

7.5.2 What are the Causes of Disasters?: The primary causes of natural disasters are storms and torrential rains which often result in landslides, mudslides, flood, destruction of construction sites, buildings, orchards, etc., and even death of people.

7.5.3 Recent Disasters:

7.5.3.1 Torrential Rains in Papua New Guinea: During the first few weeks of December 1999, there was a period of heavy and sustained rainfall resulting in many landslides that destroyed areas of forest and village gardens, blocked roads and damaged houses. The only road linking two thirds of the approximately two million people population of the PNG highlands with the rest of the country and the seaports, was cut and no essential supplies were able to get through until the road was cleared after about a week. This particular incidence was not a serious disaster, unlike the one which occurred in 1970 (see below), but it nevertheless caused hardship to many people (Shelton 2000).

The real natural disaster caused by very heavy and sustained rain occurred in Simbu Province in PNG in 1970. A torrent of water, rocks and debris that inundated on the people caused twelve deaths in the village. The only warning they had, and that was not much more than a minute, was the roar caused by the wall of water, estimated to be 10 m high, bearing down on them. During such a period of sustained torrential rain, rock and mudslides occurred in areas of virgin bush in the mountains above the village but remote from any other settlements. Some of these landslides blocked the river, formed an unstable dam and water was backed up behind it (Shelton 2000).

7.5.3.2 Hurricane Mitch in the Caribbean: "On 24 October 1998, Atlantic Tropical Storm Mitch was upgraded to a hurricane that developed into one of the strongest and most damaging storms to ever hit the Caribbean and Central America. At its height on 26 and 27 October, the hurricane had sustained winds of 290+ kph and dumped heavy rains over Central America. Although the winds diminished as Hurricane Mitch traveled inland over Honduras on 30 October, the storm continued to produce torrential rains, reaching rates of more than 100 mm per hour. Catastrophic floods and landslides occurred throughout the region. When it was over, some 9,200 people had died; almost 270,000 homes were lost; 21,325 miles of roads and 335 bridges were destroyed. Immediately after the storm, some 2 million Central Americans were pushed out of their homes. Agricultural losses were staggering. Mitch's impacts on watersheds, human lives, and the economies of the affected countries will be felt for at least some 8 to 10 years…assuming that another storm of such magnitude does not return." (Smyle 2000).

7.5.3.3 Cyclones in Madagascar: Madagascar was hit twice by severe cyclones in February and March 2000. Almost 80% of the 162 km rail line of the Fianarantsoa to East Coast (FCE) Railway has been covered by land slides. These included 280 landslides and washouts, and the services had to stop for two months -- a severe blow to the livelihood of the people and the economy along the rail corridor (Hengchaovanich 2000).

7.5.3.4 Landslides at Doi Tung: In the rainy season of 1996, heavy rainfall caused landslides and collapse of roadside and backslopes, including those with cement-sprayed metal netting walls. Landslides, which was the combined results of road construction, followed by heavy and sustained rains, caused damages on houses and public buildings (Charanasri 2000).

7.5.3.5 Shift Sand Dunes in SE China: In Jiangsi province in southeastern China, an area of 17,600 hm^2 of Poyang Lake Basin has been desertified in various degrees. In Nanchang city, the capital of Jiangsi province, 2,017 km^2 of land are covered with shift sand dunes as the result of southernly winds. Such shifting sand dunes move northward with a speed of 5m/yr. During a period of 30 years, i.e., from 1950 to 1980, eight villages of Guangshang and Fushan Townships in Nanchang County and Houtian Township in Xinjian County were destroyed and covered by shift sands, causing the loss of 660 hm^2 of farmlands and damage of a series of water supply facilities due to sedimentation (Cheng *et al.* 2000). Although its action is much slower than that of storm or torrential rains, it can be considered as a form of natural disaster.

7.5.4 Prevention of Disaters: For practical purpose, it is not possible to prevent any disasters, including landslides, mudslides, floods, or any other destruction caused by storms and heavy sustained rain on steep slopes, forested or not, particularly if the profile is already saturated and if it overlays rock or some other sort of impervious layer.

7.5.5 Mitigation of Disasters and Other Measures after the Disasters: As it is not possible to prevent disaster from happening, the best we could do is to mitigate them or putting measures to reduce damages caused by these disasters in the future. Among those found to be most practical is the use of the vetiver system. These will be discussed on a case by case basis of the recent disasters mentioned earlier.

7.5.5.1 The Case of Papua New Guinea Torrential Rains: Vetiver system provides a partial long-term solution to soil degradation, fits in with traditional technologies farmers are familiar with, can be controlled and managed by farmers (because it is low cost), and is proven to work under such conditions. It fits in well with attempts to make life easier and more sustainable for the at-risk rural population in disaster prone areas.

It is of great interest to note that once landslides have occurred, the land that has moved and accumulates at the base of the slope is very prone to move again. In Papua New Guinea, many farmers like to plant gardens in such a soil, as it is much deeper than normal, is easily dug, is not as steep at the original, and is usually reasonably well drained. Having lived with nature all their lives, farmers normally plant trees into this loose soil in an attempt to stabilize it. Shelton (2000) suggested that if vetiver hedgerows could be planted on the contour, it would fix the soil and achieve the same purpose faster. He also noted that the area where the landslide originated usually has very little soil left, is steeper than previously, and is unproductive to grow crops. Planting contour vetiver hedgerows can lead to its reclamation over many years as the hedges may prevent the loss of any more soil, allow the accumulation of organic matter and encourage the establishment of trees which will eventually stabilize it.

7.5.5.2 The Case of the Caribbean Hurricane: Immediately after Hurricane Mitch in the Caribbean in October 1998, international experts in disaster mitigation and vulnerability reduction rushed to Central America to assist in diagnosing what had happened and what needed to be done. The majority of their recommendations consisted of things which natural resource and civil engineering professionals have been recommending on a daily basis as being “good practice”, many being things for which the vetiver system is very well-suited (Smyle 2000).

7.5.5.3 The Case of Doi Tung Landslides: When the rainy season ended, land leveling to create terraces of vetiver hedgerows and hydro-seeding were implemented to stabilize newly formed gullies. Reinforcement of friable loose soil utilizing cement beams arrangement in squares to support the wet soil weights, and other engineering methods have been in practice whenever and wherever needed at critical sites. In all cases, vetiver hedgerows have been fertilized, selectively weeded, and pruned for 1-2 years, and then the local plant species have been allowed to naturalize among vetiver grass, compete and finally dominate the site. By this time, vetiver was no longer needed (Charanasri 2000).

7.5.5.4 The Case of Madagascar Cyclones: The central cause of the landslide and damages were the adverse effect of the rainfall wrought by the cyclones, the lack of protective mechanism to cope with the exceptional rainfall event, the population and economic pressures that led to ongoing slash-and-burn agricultural practice on the hill slopes flanking the railway tracks, thus precipitating in erosion and instability problems (Hengchaovanich 2000).

Since the damages were casued by rainfall and/or water, recommendations were given on measures to divert/mitigate urgently, in the first instance, potential harmful water forces. Thereafter, the affected slopes would be treated and strengthened through vetiver grass planting, coupled with some other appropriate engineering solutions.

7.5.5.5 The Case of Shift Sand Dunes in SE China: Vetiver was introduced to Fushan Township of Nanchang City in March 1998 to stabilize the sand dunes. It was planted in hedgerows along the contour lines. Although the sands lacked of plant nutrients, 91% of the planted vetiver survived and grew well. Besides, vetiver promoted other plants to grow. Soon, the sandy dune was finally fixed with vegetation. The successful experience is valuable not only to Poyang Lake area but also to other river banks and coastal region which covers a large area in Southeast China (Cheng *et al.* 2000).

7.5.6 Discussion: It seems that recent disasters have been far more deadly than it used to happen. The reason for such devastating act of nature is because of the destruction of forests and wetlands that act as "buffer" systems diminishing the surface runoff, and because flooding was aggravated by a lack of adequate watershed management. People die, are injured, or lose their homes in natural disasters, because they continue to build and live in unsafe structures and in vulnerable locations. Another reason stems from social vulnerability and poverty. Poor people do not have access to arable and safe land. They have to live and farm on marginalized areas, such as floodplains and steep slopes, maximizing their exposure to the next disaster.

“VS can play a key role in disaster mitigation and vulnerability reduction. The purpose and role of VS in disaster mitigation and vulnerability reduction is to protect and conserve, not nature, but our interventions within nature and our attempts to manage nature for our own ends. VS is not and cannot be a substitute for appropriate siting of infrastructure, for avoiding encroachment into flood plains and other vulnerable areas, for halting watershed and soil degradation, in short, for overall good natural resource management and land stewardship, for common sense, and for quality designs and construction” (Smyle 2000).

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8. UTILIZATION OF VETIVER

8.1 Handicraft Production

The main objective of planting vetiver is to make use of the plant in soil and water conservation, especially in slope areas. There are several other related uses of the vetiver plant such as on the farmlands, in agricultural systems, on the edges of the ponds, etc. However, planting for conservation purpose focuses on its benefits in terms of conservation which cannot be valued in terms of cash for the growers. Therefore some farmers are reluctant to accept its potential benefits.

In most Asian countries, vetiver has traditionally been utilized in many ways. The leaves, for example, have been utilized to make roof thatch, compost and mulch, etc. Its fragrant roots have traditionally been utilized to extract essential oil used as a fixative for high-priced perfumes; they have also been utilized in traditional medicines. Due to the presence of certain pesticidal compounds, its roots have been placed in the closet to repel insects. In Thailand as well as in some other countries, many new ideas have recently been added to utilize vetiver, for example, as a medium for mushroom growing, as green fuel, and as raw material for wood and concrete panels, etc. The utilization of the leaves plays a complementary role in growing vetiver for soil and water conservation purposes since the leaves are normally cut off at regular intervals to stimulate its growth. Such cut leaves can be utilized in making handicrafts as a supplementary occupation to earn extra income. The present paper will describe how to utilize vetiver leaves as raw material for making handicrafts.

8.1.1 Preparatory Steps for the Utilization of Vetiver Leaves in Handicraft Making: In making handicraft products from vetiver leaves, three preparatory steps have to be followed. These are:

8.1.1.1 Pre-harvest Operation: Vetiver leaves to be utilized for handicraft making should be at least three months old, irrespective of the age of the plant. They can come from a single hedgerow, or multiple hedgerows, or a field of vetiver planted for any other purposes, including the multiplication plots that are not used for transplanting. Normally, vetiver does not need any special care like watering, weeding, pesticide spraying, or fertilizer application. However, if such treatments are nominally provided, the leaves will be more luxuriant in growth with no sign of damage from pest attacks, and thus yield better-quality products.

8.1.1.2 Harvesting of Vetiver Leaves: Sickles or knives are used to harvest vetiver leaves. Cutting should be made at the distance of 15-20 cm above ground level. Cutting lower than this (e.g. 5-10 cm) will affect subsequent growth of the plant although the yield of leaves is higher. In normal situation, harvesting can be done every two to three months during the rainy season, depending on the growth of the plant. It is important to cut the leaves off before the onset of dry season to avoid fire damage during the prolonged drought period and to activate the plant to resume growth at the onset of the next rainy season. Cutting will also stimulate tillering.

The cut leaves should be spread thinly in the field to allow water to evaporate, at least for a few hours, before they are transported to the processing area. If the fresh leaves are transported immediately after harvesting, extra weight of water will add to the cost of transportation, although this may be small if the amount harvested is not large.

8.1.1.3 Post-harvest Treatment of Vetiver Leaves: There are many methods used by different agencies in Thailand in preparing harvested leaves, especially in drying; some simply spread the leaves on the floor to dry in the sun, while others use the oven to dry. The followings are steps in processing the harvested leaves developed by the Department of Industrial Promotion:

- (i) Boil the leaves for 3 minutes and hang them to allow water to drip dry overnight.
- (ii) Spread the leaves thinly on the floor to dry in the sun for 3 days.
- (iii) Fumigate the dried leaves in the cabinet overnight with sulfur to prevent molding.
- (iv) Select the leaves that are long, wide, and healthy; then use a needle to rip off sharp spines along the edge of the lower surface of the leaves.
- (v) Immerse the selected leaves in the water; then wrap them with newspaper or cloth to make them soft. Such treatment makes them easy to work with, and will not break while interlacing or weaving.
- (vi) Repeat Step (iii) to make sure that mold will not attack them.
- (vii) Dye the treated leaves, either with natural dyes (such as bark, leaf, fruit, etc.), or chemical dyes to make the products colorful and attractive.

8.1.2 The Making of Handicrafts from Vetiver Leaves: Similar to other natural materials commonly used in handicrafts, vetiver leaves contain high amount of fiber, thus are ideal for wicker works. They can be utilized directly to make wicker works, or interlaced into 'basic units' of different shapes and forms before setting up to form any particular wicker works, or using looms to weave into mat. Other materials like rattan, wire, rod, wood, etc. may be used to support the forms.

8.1.2.1 Direct Utilization of Vetiver Leaves: Most wicker works can be made directly from prepared vetiver leaves without having to be made into 'basic unit' (see detail below). These include a wide range of products from handy accessories, containers, decorating materials, home appliances, and miscellaneous objects.

8.1.2.2 Production of Basic Units: Two types of basic units of wicker works can be made from vetiver leaves. These include: (i) *braids*, and (ii) *interlaces.*

(1) Braids: Braids are formed by twisting three or more threads of natural fibers such as vetiver leaves. Various patterns of braids have been developed by Thai people.

(2) Interlaced Patterns: Thai people have developed various interlaced patterns whose Thai names reflect their similarity with certain natural objects or phenomena such as flowers, seeds, animals, appliances, running water, etc. They are shown in front and back covers.

8.1.3 Types of Handicrafts Made from Vetiver Leaves: Most handicrafts made from vetiver leaves are wicker works, made directly by interlacing the prepared vetiver leaves into a particular form of products, or made from braids or interlaced patterns without having to set up, like the place mat, pillow, etc. Some are, however, made by assembling braids or interlaced patterns to form an object by sewing or sticking with glue.

The Department of Industrial Promotion (DIP) has provided basic training in producing handicrafts to a number of women's groups under the supervision of various agencies such as the Department of Cooperative Promotion, the Department of Agricultural Extension, the Land Development Department, the Department of Public Welfare, the Doi Tung Development Project.

Handicraft products made from vetiver leaves can be grouped under following categories:

8.1.3.1 Handy Accessories: These are the most common group of wicker works made from vetiver leaves since the demand is quite high. These include bags, hats, belts and brooches.

8.1.3.2 Containers: This type of wicker works is used to put certain objects into it. They include:

- *Basketry:* Many forms, shapes, and sizes of baskets are produced, such as fruit baskets, winnowing baskets, utility baskets, wine baskets, and flat baskets or trays.
- *Pottery:* Such as pot-plant cases, wine-bottle case, etc.
- *Other Objects:* Tissue-paper boxes, utility boxes, etc.

8.1.3.3 Decorating Materials: Home decoration items, like wall clocks, picture frames, lamp-shades, dollies, animal figures, flowers, etc.

8.1.3.4 Home Appliances: These products are similar to home decoration objects but they are used also as appliances such as chairs, stools, room partitions, tables, etc. Mats and similar objects are also produced by weaving.

8.1.3.5 Miscellaneous: Such as folders, diary covers, file covers, etc.

8.1.4 Socio-Economic Considerations:

8.1.4.1 Benefits of Making Handicraft from Vetiver Leaves: The following benefits are envisaged from utilizing vetiver leaves to make handicrafts:

- Earn extra income from sale of products.
- Encourage farmers to plant more vetiver and obtain indirect benefits of planting vetiver such as reducing soil erosion and enriching soil nutrients and moisture.
- Encourage farmers to cut the leaves of vetiver at regular interval, thus inducing growth of the vetiver plants and reducing the danger of fire.
- Encourage the establishment of housewife groups (or other related groups) to make productive use of their time, thereby helping the well-being of the members and encouraging their unity.

8.1.4.2 Marketing of Vetiver Handicrafts: Although at present vetiver handicrafts are not established products in the market in Thailand, yet they are quite well known to the public due to their publicity through mass media. The only problem is their availability in the markets. The following places are selling vetiver handicrafts:

- Narayana Phand Co. Ltd., a private undertaking of the Ministry of Industry which is well known as the country's largest Thai Handicraft Center whose main objective is to promote cottage industries which generate supplementary income to the villagers, has acted as 'Vetiver Grass Product Distributor and Design Developer'.
- Several cooperatives under the Department of Cooperative Promotion are selling vetiver products made by the members. Some of the well-known ones are:
  - Chiang Kham Women and Youth Settlement Cooperatives, Phayao.
  - Occupational Training Center, Mae Sai District, Chiang Rai.
- Doi Tung Development Project, Doi Tung, Mae Fa Luang District, Chiang Rai.

8.1.5 Bleaching: Naturally, fiber derived from plants, whether the stems or leaves, have their original colors, which are yellow or brownish yellow. However, to meet the demands of the market, the fiber materials for weaving have to go through dyeing process by first bleaching to have a white color, and then dyeing to make colorful finished products.

Bleaching Solutions

Chemical Substance - Ratio	2 Methods
· Bleach the fiber with H_2O_2 at room temperature. - H_2O_2 : Water = 1:20 - 1:30. - Use H_2O_2: 20-50 cc/liter	· Soak the fiber in water for 10-12 hrs before bleaching. · Clean the fiber with water.
· Bleaching the fiber with H_2O_2 at high temperature (about 70-80^oC) - H_2O_2 : Water = 1:20 - 1:30. - Use H_2O_2: 10 - 15 cc/liter and no more than 20 cc/liter.	· Boil the water at about 80^oC Add H_2O_2 and stir thoroughly. · Add the fiber and leave for 30-60 min. · Take the fiber out and clean thoroughly.
· Bleaching the fiber with chlorine. - H_2O_2 : Water = 1:20 - 1:30 - Use chlorine powder: 8 - 10 g per liter.	· Dissolve chlorine into prepared water. Divide the water into four colors. Wait until the chlorine is sedimented, then use the clear water. Repeat the step until all of the water are dissolve with chlorine. Soak fiber in the chlorine water for 30 min. and clean it with water. Then put the fiber in water which contains acetic acid 5 - 10%.

8.1.6 Color Mixture for Dyeing: In order to have various colors of the dye, they have to be mixed to obtain desired color. The following table provides necessary information on mixing the color for dying:

Dye color	Color composition	Resulting color
Purple	Pink + Dark Blue *Steps* - Use pink color as the main color. - Gently add dark blue color and stop when it turns to purple. If one wants bluish purple, then continue adding blue color and it will give the color of reddish purple or bluish purple	Redish purple Bluish purple
Crim-son	Golden yellow + Pink *Steps* - Use pink color as the main color. - Gently add golden yellow until the color turns to crimson	
Grey	Dark Blue + Purple + Black *Steps* - Use moderate quantity of dark blue color. - Add a little of the purple color. - And finally add a little of the black color.	Light grey
	Dark Blue + Black *Steps* - Maintain dark blue as the main color and add moderate amount.	Dark grey

	- Add a little amount of the black color to make it bluish grey.	
	Dark Blue + Purple *Steps* - Maintain dark blue as the main color and add moderate amount. - Add a little amount of purple to make redish grey color.	Reddish grey
Green	Golden Yellow + Blue *Steps* - Use golden yellow as main color. - Gently add dark blue until it changes to dark green.	Dark green
	Light Yellow + Blue *Steps* - Use light yellow as main color. - Add dark green to give a green leaf color.	Leafy green
	Orange + Blue *Steps* - Use orange as main color. - Gently add dark blue to make brownish green.	Khaki color
Orange	Light yellow + Pinkish Red Golden yellow + Crimson *Steps* - Use yellow as main color and pour in first. - Then add crimson or pinkish red to make orange color	Orange
Brown	Yellow + Purple + Dark Blue *Steps* - Use yellow as main color. - Add purple to make it brown. - Add dark blue to make it dark brown.	Dark brown
	Golden Yellow + Bright Red + Dark Green *Steps* - Use yellow as main color. - Add bright red to make orange color. - Add little green to make brown color.	Golden brown
	Orange + Dark Blue *Steps* - Use orange as main color. - Gently add dark blue to make brown color.	Brown

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8.1.7 Processes of Dyeing: These processes are explained below:

Proportions	**Methods**
· Dye water: 1 portion of fiber per 30 portions of water · Dye color: depends on the preference for dye color concentration · 2 - 4 tablespoons of acetic acid	· Soak the fiber for at least 6 hours before dyeing. · Boil dye water at high heat or boiling slowly. · Put the dye color and stir thoroughly. · Put the fiber into the boiling dye water and constantly turning it over for 5 minutes. Then remove the fiber out of the water. · Add acetic acid and stir. · Place the fiber back in and continue boiling the fiber for 5-10 minutes. Keep turning it over. · Take the fiber out and clean with water.

8.1.8 Natural Dyes: These are dyes present in certain plants. They can be extracted and used to dye vetiver leaves. Among the most effective and easy to find are turmuric rhizome, butterfly pea flower, teak leaf, and red cabbage.

The extraction method to make 4 liters of dye solution is as follows: Obtain 50-100 g (dry weight) of plant material, boil in 4 liter of water until boiling. Remove from fire and leave it for 1 hr. Filter, express excess water and wash with hot water to obtain remaining dye in order to make 4 liter of dye solution.

Dying Process:

1. Soak prepared dry leaves in hot water (be sure to press the leaves in the water)
2. Place on low-flame fire, at 60-80^{o}C for 1 hr.
3. Repeat steps 1 and 2 every day for 3-5 days in order for the leaves to absorb more dye.
4. Add 5 g of allum into dye solution. Boil until the allum dissolves. Continue soaking for 1 day
5. Remove the leaves from the dye solution. Wash off extra dye. Dry in the shade.

Note: In order to make the leaves soft and not remain too brittle, add 1 table spoonful each of olive oil and hair conditioner dissolved in 3 liter of water. Soak the leaves for 3-5 minutes before weaving.

8.2 Agricultural Input and Other Related Products

The main purpose of growing vetiver is to conserve soil and water, particularly for steep slope areas. In spite of the effort, however, some farmers are still reluctant to accept its valuable attributes because the cultivation of vetiver in agricultural areas in order to conserve soil and water does not produce tangible benefits in terms of income. Actually, vetiver leaves and roots can be used for other purposes, especially its leaves, which usually have to be cut down to the ground periodically to induce tillering and root growth as well as to avoid fire during the dry season, can be used of in various ways, particularly to produce agricultural input products which would provide the farmers with an extra income.

Although essential oil also can be extracted from vetiver root, and there seems to be a high demand for such oil in perfumery business, but in order to have the oil, digging its roots is required. Such a practice is against the principle of soil conservation and of course, of VS in general. Thus, this course will not touch on essential oil extraction or other uses of the roots (e.g. as herbal medicine and vetiver blind) as it is rather dangerous to encourage such a practice.

8.2.1 Mushroom Culturing: Vetiver leaves contain chemical compounds such as cellulose, hemicellulose, lignin and crude protein as well as various minerals which can be used as substrate for mushroom culturing. The Thai Department of Agriculture has conducted an experiment by cutting leaves and culms of vetiver into small pieces, 1-1.5” in size, and soaked them in water before allowing them to ferment for 3-4 days. Then they were packed in a bag and sterilized, using the same procedure as in mushroom spawn preparation. The content was then inoculated with different kinds of mushroom spawns. Pleurotus spp. (e.g. oyster mushroom, abalone mushroom, shiitake mushroom, etc.) are able to produce mycelium and form fruiting bodies to become the mushroom.

8.2.2 Compost: Vetiver culms and leaves, which are cut to accelerate tillering can be used to make compost similar to other crop residues. In the process of making compost, vetiver culms and leaves completely decompose within 60-120 days. Then, it will become soft, friable, and dark brown to black in color. The analysis showed that compost made from one ton of vetiver leaves is equivalent to 43 kg of ammonium sulfate. Vetiver compost tends to gain more major nutrients such as nitrogen, phosphorus, potassium, calcium and magnesium on an average of 0.86, 0.29, 1.12, 0.55 and 0.41% respectively, with a pH of 7.0 In addition, vetiver compost provides humic acid which enhances soil fertility.

8.2.3 Mulching: Vetiver leaves are excellent material for mulching. Similar to other mulching material, vetiver leaves provides shade to the plot, thereby decreasing the temperature and at the same time conserve moisture of the plot and keep weeds under control. Vetiver mulch can be applied to vegetable plots, at the base of fruit trees, and field crop plots.

8.2.4 Animal fodder and feed stuff: Many small farmers and agencies that support small farmers reject vetiver because they think that it is useless as a forage. This is in fact not true. If vetiver hedges are cut regularly, the forage value of the leaves is comparable to other grasses, and in drought years the only grass that provides any feed value at all is vetiver. In India vast plains of *Vetiveria nigratana* are burnt each spring to produce an early bite for Fulani livestock.

The Thai Department of Livestock undertook a study on the nutritive value of vetiver as animal feedstuff. The trials were conducted on ten ecotypes of vetiver with the result that Kamphaeng Phet 2 gave better nutritive value than other ecotypes in terms of quantity of crude protein, digestible dry matter, and minerals. Vetiver cut at four-week interval is optimal in terms of output and nutritive value. The study on the toxic content in the ten ecotypes revealed that vetiver has insignificant level of nitrate and hence is not harmful to animals. Furthermore, nitrate and hydrocyanic acids are not found in vetiver.

The study also looked into the nutritive values of vetiver ensilaged with various ingredients in terms of palatability, pH level, dry matter percentage, lactic acid, muteric acid, dietary value and digestibility of dry matter. It was found that vetiver silage fested in treatments with 10% molass, 15% cassava, and 0.5% urea, plus 10% molass, all have acceptable quality.

The study revealed that young vetiver leaves can be ground to feed fish and livestock feed but mature leaves cannot be used for such purposes because their nutritive value is lower than other grasses, and because of the high roughness and silica content.

The analysis also indicated that vetiver has the content of crude protein lower than that of other grasses used for animal feed.

In comparison with dried straw, vetiver has a lower dry matter percentage but higher content of crude protein and digestible fiber. Meanwhile the analysis of nutritive value of silage indicated that vetiver-based silage has higher animal nutritive value than straw-based silage, and dry straw and signal grass. The analysis of major nutrients in vetiver leaves and culms showed that they have a lower phosphorus but higher potassium content when compared to sweet corn and baby corn leaves and stems.

8.2.5 Thatching: Thai people as well as other rural people in Asia have long utilized vetiver culms and leaves for roof thatching in the same way as nipa palm leaves prior to the use of cogon grass (*Imperata cylindrica*) which can be easily found. Vetiver grass that will be used for making roof should be grown in a healthy condition and should be at least one year old. The leaves should turn from green to yellow, but they should not be completely dry. The leaves are normally harvested between January and February by cutting the grass at about 10 cm above ground. Then comb off short or broken leaves, leave to sundry, and bundle into "kone" comprising about 30 handful bunches which can produce about 5 to 7 thatches.

To make each individual thatch, a piece of bamboo is used as a central column to hold the grass together. At each binding, 5-6 vetiver culms with about 12-16 leaves are folded, with one third of the broader end being on the shorter side, and the other end on the longer side, and then fastened tight to the central column with bamboo strips or other materials. Binding is done until the thatch is completed.

A thatch of vetiver grass is about 120-170 cm long, consisting of 150 bunches of culms and leaves. This is equivalent to about 750-900 vetiver tillers per thatch. The laying of the thatch starts from the lower level of the roof and continues up to the top of the structure, with the shorter end of the thatch being on the underside.

Vetiver grass has a better quality for roof thatching than cogon grass because the culms and leaves of vetiver are coated with wax, have a unique scent which repels insects. The durability of a vetiver thatch depends on the neatness of thatch making. The thatches with more or denser vetiver grass will be more durable. The manner in which the thatches are laid on the roof also matters. For example, on a steep roof like that of a traditional Thai house, vetiver thatches can be more durable than on a flatter-roofed structure.

8.2.6 Green Fuel: Broken vetiver culms and leaves that cannot be utilized for other purposes can be mixed with water hyacinth, as a mixer, in a proportion of 3:2. Then compress the mixture into shafts with a cylinder-shaped fuel squeezer, 1.7 cm in diameter. Fuel shafts can burn easily and produce little smoke, but yield high temperature. For example, it takes 5 minutes to boil 1 liter of water, and the fuel still keeps on burning for up to 28 minutes.

8.3 The Alternative Roles of Vetiver Utilization

Vetiver is now successfully applied for soil and water conservation, both inside and outside farm lands all over the country. Low cost investment and simple technology would encourage more and more widespread customers in the near future. Natural resources and environmental impact area also maneuverable by vetiver hedge systems.

8.3.1 The Royal Project Foundation's Visions: The Royal Project Foundation's visions are focussed on the alternative roles:

8.3.1.1. Study on hydraulic characteristics of the vetiver hedge systems: The objective of such study is to obtain engineering evidence and limitation when vetiver is applied.

The water discharge through the vetiver hedge system model varied with the flow rate. Velocity increases after passing the rows. Run-off on the slope land model was also observed. Downstream cut and upstream fill occurred. It seems that there is more cut than fill. The results significantly suggests the necessity of models in the workshop along with the tests in the field.

8.3.1.2 Soil bioengineering applications: Vetiver grass for soil bioengineering applications is recognized as a tool for erosion control on slope land. Although engineering measure can be effective solution to encounter the disastrous problem, stabilization can be achieved, but nature's rehabilitation or reclamation could not be performed.

Vetiver hedge system for biotechnology harmonizes with the structure will overcome the unpleasant situations. Vetiver system itself possesses some limitations. Rill and sheet erosion can be easily managed by the vetiver system. Concentrated flow or gully erosion needs channel improvement and some structures. Wind erosion can be better protected when vetiver enhances the growth rate of the trees as well as that eroded by wave action can be eliminated when planted with the right vetiver cultivars or ecotypes.

Land slide requires more engineering work. Decreasing slope cooperates among trees, vegetation cover from volunteer species, by the time vetiver conducts the pioneer species on the first hand.

8.3.1.3. Research and Development Technology for the Vetiver as Generating Income Crops: Not only do we learn the state of the main problems, but also fruits the self-reliance economic all the grass laid down to the farmers. Value-added vetiver is painted art as dorm keyword. Vertical integration by compiling all the outstanding results from each procedures as follows:

- Variety, activist and ecotype are selected for cottage industry specifications.
- Extension to farmers by contract farming system.
- Post-harvest management for quality control verifies the cottage industry requirement, such as vertiver fiber and pulp standardization.
- Lab-scale research for product development for pulping paper process
- Development for herbal medicine, cosmetics and botanical pesticides
- Industrial art and decorative design products
- Essential oil and related products
- Construction material
- POZZOLAN
- Vetiver clay bundle for grain soil
- Energy saving concrete panels

8.3.2 Vetiver: Crop of Maintenance

- Pilot project model
- Farm production demonstration
- Project cottage industry plant test for:
  - Decorative products
  - Pulping paper and related products
  - Grain size demonstration units

8.3.3 Marketing:

- Marketing promotion.
- Consumer attitude.
- Sales planning and strategy.

8.3.4 Vision: Better understanding related to the function of vetiver hedge system. Products would provide a lot of benefit to be maintained in the near future for the environments and natural resources.

9. VETIVER SYSTEM TECHNOLOGY TRANSFER IN THAILAND

9.1 Department of Land Development

Department of Land Development (DLD) is an agency under Ministry of Agriculture and Cooperatives. Its headquarters is located in Bangkok with field operation conducted at 12 regional offices. There are 64 Land Development Stations located throughout the country, with 198 Land Development Units at the district and village levels. Since 1993, DLD has established a policy to promote and extend the use of the VS to the farmers.

In the year 2000, the activities conducted by DLD can be summarized as follows:

9.1.1 Budget Allocation: DLD received a total budget of Baht 269.9 million for multiplication of vetiver tillers for soil and water conservation (SWC) purpose. They are to be used for the followings:

- For SWC operated by DLD, 320 million tillers.
- For distribution to various governmental organizations and farmers, 70 million tillers.
- Multiplication is to be done at 20 main multiplication stations distributed throughout Thailand. Total cost per tiller in polybag, kept in the nursery for 45 days, and operated through contract farmers, is Baht 1.65 (including planting material, transportation, planting, and replanting).
- Training of 8,228 farmers.

9.1.2 Production of Recommended Ecotype for Each Region:

- *Northern Part:* Sri Lanka, Nakhon Sawan, Kamphaeng Phet-1, Phra Ratchathan, Monto, India (Khoukloa)
- *Northeastern Part:* Roi Et, Songkhla-3, Phra Ratchathan, Monto, India (Khoukloa)
- *Central Plain and the Easter Part:* Prachuap Khiri Khan, Ratchaburi, Kamphaeng Phet-1, Kamphaeng Phet-2, Surat Thani, Songkhla-3, Phra Ratchathan, Monto, India (Khoukloa)
- *Southern Part:* Songkhla-3, Surat Thani, Phra Ratchathan, Monto, India (Khoukloa)

9.1.3 Training: Each year, DLD offers training courses on vetiver system for the government officers and farmers. For example, in 1999, 150 head villagers, 19,240 farmer leaders, 260 government officers, and many NGOs attended the training course which included such tropics as back ground information of vetiver, introduction to VG, how to multiply vetiver, VG for SWC and other purposes, field operation, field trip, group discussion and presentation, and evaluation.

9.1.4 Distribution of Planting Materials: Vetiver tillers are distributed to various governmental and non-governmental organizations as well as the farmers who would like to use the vetiver for SWC purpose. The amount of tillers distributed varies from 5,000-20,000 tillers per each agency or farmer.

9.1.5 Activities in 2001: For the fiscal year 2001, DLD receives a total budget of Baht 285.9 million for vetiver multiplication. This budget will be used for following activities:

- For soil and water conservation, 330 million tillers.
- For distribution to various governmental organizations and farmers, 70 million tillers.

A total of 9,737 farmers are to be trained.

9.2 Department of Agricultural Extension*

9.2.1 Introduction: Department of Agricultural Extension (DOAE), in collaboration with the Department of Agriculture, Kasetsart University, and Centro Intercional de Agricultura Tropical (CIAT), launched a project on "Cassava System Adjustment to Reduce Soil Erosion in Thailand" since 1994. The objective of the project is to enhance the development and adoption by farmers of improved cassava cropping systems and cultural practices that will retain soil productivity and reduce erosion while sustaining a reasonable farm income. The implementation engaged farmer participatory research method. The implemented areas were in Nakhon Ratchsima and Sa Kaeo provinces during 1994-98; Kalasin and Chacheongsao provinces during 1997-98.

9.2.2 The Procedure: The project's procedure included the preparation of field staff, preparation of project sites, farmers' meeting and training, demonstration plots on erosion control method, farm trials on farmers' fields, harvesting field day and meeting, pilot demonstration plots, and scale-up production field.

9.2.3 The Results:

9.2.3.1 Selecting Soil Erosion Methods by Farmers: The farmers visited the demonstration plots at the research center. There were 24 treatments of soil erosion control. They were asked to give score for each method. The farmers selected some methods that may be useful in their own fields and under their own condition. In general, they selected the methods that gave higher cassava yield, provided yield and income from intercrops, and were more effective in soil erosion control.

9.2.3.2 Farmers' Trials in the Farmers' Fields:

(1) Nakhon Ratchasima province: The farmers chose seven methods of soil erosion control to do farm trials in the first year. In the second year, five out of seven methods were re-selected to repeat the trials to confirm the results. They selected only two methods from the second year trial which were vetiver grass barriers alternated with chewing sugarcane barriers and pumpkin intercrop to conduct the pilot demonstration plots in 1 Rai (6.25 Rai = 1 ha) in the village. Finally, the farmers chose only vetiver grass barriers method to extend to the production fields at community level. The planting of vetiver grass barriers has now increased to 2000 Rai.

(2) Sa Kaeo province: The farmers chose eight methods for the first year trial and re-selected five methods for the second-year trial. In the third year, the farmers chose only vetiver grass barriers method to conduct the pilot demonstration plot. They finally extended to 300 Rai in the production fields.

There were two new provinces starting the project in later stage of Phase I. The farmers in Kalasin province were conducting 'Year Two Farm Trial', while those in Chacheongsao province were under 'Year One Farm Trial'.

9.2.4 Conclusion: By the end of Phase I (1994-98), the participated farmers recognized the importance and the need for soil conservation in cassava fields. The farmers in the two pilot provinces, Nakhon Ratchasima and Sa Kaeo, adopted vetiver grass barriers method. The farmers in Nakhon Ratchasima gathered in group to grow vetiver grass for soil conservation purpose for about 2000 Rai. They were given instruction on the method of making contour lines and in multiplying vetiver tillers. Similarly, farmers in Sa Kaeo province formed group to grow vetiver grass as contour strips on hilly casava production areas for about 300 Rai.

The method of participatory research involved farmers participation and decision making for every step of implementation from entering the project to the end, while allowing the farmers to select the methods to be trialed by the farmers themselves. This has encouraged them to learn and to find opportunity and potential for problems solving for themselves and their communities.

· *Extracted from a report "The Project for Cassava Production System Adjustment to Reduce Soil Erosion in Thailand" by Wilawan Vongkasem. Somnuak Hemvijit, Kaival Klakhaeng, Anuchit Tongglum, Sompong Katong, Danai Suparhan and R. Howeler, Department of Agricultural Extension.*

9.3 Department of Highways*

9.3.1 Introduction: Department of Highways (DOH) has paid concentrated interest on the important role of soil and water conservation to reduce environment impact, not only in the highway construction projects, but also in the existing highway erosion control projects. Since 1993, DOH has established the policy for its Maintenance and Construction Units to make use of vetiver on the highway slopes for erosion control in not less than 113 highways. In this regard, over 6.5 million tillers have been planted. The application of vetiver for erosion control on the highway slopes is not only simple and employs low cost technology, but also gives higher efficiency, and reduces the environmental impact due to its natural application.

Vetiver can effectively reduce or control soil erosion on the slopes if planted in rows across the slope. The row spacing should be 1 m, and clump spacing should be 10-15 cm. The process of soil erosion protection occurs both in the surface and the subsurface soils. This phenomena happened in such a way that when the vetiver clumps grow closed laterally, they act like a living wall which stands against and slows down run off, while the eroded soil is deposited behind the vegetative barrier. The tillers grow up through it and start building up natural terraces, and adjust themselves to rise above these natural terraces, which act like a living wall as long as the vetiver hedgerows are alive. If the soil condition is good, their root system penetrates deeply to about 3 m and expands radially to about 0.5 m. The root system acts as an underground curtain which tightens the soil particles like reinforced earth to protect erosion.

9.3.2 Target Area for Vetiver Grass Planting: *On the highway cut slopes (technically known as 'backslopes') and high embankment slopes ('sideslopes') which are on the mountainous areas, there is a strong tendency of soil erosion, particularly in the northern, southern, north-eastern parts of the country, where soils are sandy or silty, deriving from granite or sandstone. All these areas are the target areas of vetiver planting of DOH for erosion control and soil conservation.*

Typical method of vetiver planting on highway slopes can be classified in two categories depending on the condition or the seriousness of the erosion on the highway slopes. They are:

9.3.2.1 On highway slopes where erosion is not severe: Tillers are planted in row at the spacing of 1-2 m and in clump at the spacing of not more then 10-15 cm.

9.3.2.2 On highway slopes where erosion is severe: Tillers are planted in row at the spacing of not more that 50 cm between rows and not more than 5-8 cm between tillers.

9.3.3 Design of Vetiver Grass Planting Applied for Highway Slopes: Application of the vetiver system in highway erosion control can be accomplished by many approaches. DOH has designed the Standard Drawing [SP-204 1994; and SP-206 (Revision) 1999 "Vetiver Planting for Highway Slope Protection"]. The purpose of the design is to direct and help the Maintenance and Construction Units to use vetiver for erosion control correctly and perfectly throughout the country. The main designs are as follows:

- Vetiver planting on cut slope (back slope) and on fill slope (side slope) protection
- Vetiver planting for bridges slope protection
- Vetiver planting for highway ditch-lining protection.
- Vetiver planting on shoulder slope
- Vetiver planting together with the other slope-protection works to provide more efficiency and stability, such as planting on the back of gabion wall, masony wall, and also in concrete square grid slope-protection system.

** Extracted from a report on "The Role of Vetiver grass in Erosion Control and Slope Stabilization Along the Highways of Thailand" by Surapol Sanguankaeo, Chawalit Sukhawan, and Ekawit Veerapunth, Department of Highways.*

9.3.4 Discussion: *The typical method of vetiver planting generally for the slope protection is to plant tillers with the spacing of 5-15 cm between tillers and 50-200 cm between rows, depending on the condition of the erosion. For the serious case, a narrower spacing should be applied.*

The main reason of narrow spacing for the highway slope protection is because the highway slopes are steeper than the other natural slopes or farming slopes. In such a condition, the faster runoff can easily wash off the soil and the sheet erosion occurs rapidly. Finally, rill or gully develops that affects the highway slope stability. The narrow spacing of the vetiver hedgerows can overcome such problems, particularly at the time of vetiver planting during the rainy season.

The design notes provide more details about the construction methods. For example, how to select proper vetiver ecotypes, how to prepare the slope, method of planting, duration of planting, fertilizer application, etc. The notes also give the maintenance practice of the vetiver hedgerows.

Polybagged tillers kept in the nursery is recommended for planting in the field, and the suitable period for planting is at the beginning of the rainy season.

DOH has applied design for the erosion control of highways in many projects, not only in construction projects, but also in maintenance projects. Success has been achieved, especially on the maintenance projects for sideslope erosion control, or sideslope rehabilitation projects as the result of the collapse of the sideslopes. Vetiver planting on the highway sideslopes can be efficiently applied and mostly successful, unlike the design applications on backslopes that encountered the difficulty of vetiver planting because of the unsuitability of the soil or the slope condition. As a consequence, the results for some projects were perfectly successful.

The application for highway ditch to provent the damages of concrete or mortar-ditch lining due to the runoff from back slope, or to reduce the flow along highway earth ditch (called ditch check) was also quite successful.

The application of the combination with the other slope protection works, for example, on the back of gabion wall, masony wall, etc., has also been made in a pilot project of shore protection along the sea road in southern part of Thailand, the preliminary result of which is very encouraging.

9.4 Department of Public Welfare (DPW)

9.4.1 Introduction: The highland populations in Thailand, consisting of the ethnic minority groups such as Karen, Hmong, Yao, Araka, Lahu, Lisu, Lua, H'tin and Khamu, and local Thai, are about 99,000. The dominant group is the Karen with 354,574 people. Most of them live in the remote mountainous areas. Their belief, religion, language and culture are different from the Thai people. Normally the practice shifting cultivation, part of which was to grow opium poppy which crates the problems of soil erosion, as well as several other including the production of illegal narcartic drug. The amount of soil erosion is estimated at about 7.2-50.4 t/rai/yr (TA-HASD 1991). The ill effect of soil erosion on the highland is further aggravated by sedimentation of the river, soil infertility and low productivity that lead to low income. As a consequence, they have to seek for new areas to start forest clearing again, a typical shifting cultivation which results in watershed encroachment. All these activities affect the ecological systems and provoke sudden lowland flooding.

His Majesty the King was the first person who realized the hardship of the hilltribe people and had initiated the Royal Project in the 1960's, one activity of which involved the planting of vetiver hedgerows along the contour of the sloping areas. Slowly, the hilltribe people change their cultivation practice and settle down in their villages with no more shifting cultivation. With several other support from the Royal Project like the introduction of alternate crops to replace opium poppy such as temperate fruit trees, vegetables, flowers, etc., their well-beings have been improved tremendously.

The Hilltribe Welfare Division (HWD) of the Department of Public Welfare (DPW) has been charged with the function of promoting conservative agricultural activities in the hilltribe communities since 15 years ago. Such activities include the growing of paddy, field crops in contour conservation strips with alternate rows of grass and legumes, fruit tree plantation such as longan, lychee, mango; animal raising and off farm activities are also promoted to integrate their farming systems. Staff of HWD were located in the provinces, zones, and key villages to implement social welfare and development activities in responsible areas having no line agencies. Our field staff are the ones who contact the Land Development provincial offices for soil and water conservation activities as w ell as the line agencies for other activities.

9.4.2 The Evolution of Conservation Strips: The 'conservation strips' have been experimented at the Highland Agricultural and Social Development Project (HASDP) since 1987. HASDP has introduced crops such as Ruzi grass, Setaria grass and legume to be grown in strips by using land use option in participatory extension process (PEP). These crops have been incorporated into the hilltribe's rotational cropping practice which rotate their farmland from one area to another and the fallow period is 2-4 years. The Ruzi grass is left in their fallow and then it became aggressive weed on the farmland. With the introduction of vetiver into the highland, it was used to replace Ruzi grass and finally has solved the problem of Ruzi grass turning into weed. PWD has advised the hilltribe to pant vetiver strips in annual (upland rice, maize, cabbage) and perennial (lychee, longan, tamarin) crop production. PWD provided planting materials as well as technical support.

9.4.3 The Implementation Areas: The areas implemented by PWD cover the northern provinces of Chiang Mai, Chiang Rai, Mae Hong Son, Lampang, Phayao, Tak, Phrae, Phitsanulok, Phetchabun, Khamphaeng Phet, and Uttaradit, and also a western province of Kanchanaburi. In total, these occupy the area of 1,357 ha.

9.4.4 Vetiver Extension Methodology: PEP is used to set up development plan for hilltribe village. Not only village profile data and problem census data, but also government policies are considered in order to set up option and plant for village development with the villagers. The field staff will be partners with the villagers in every step in vetiver extension. These steps include planning, implementation, evaluation and monitoring. The staff will facilitate the planting of vetiver that is done by the villagers themselves. Problems will be discussed with the villagers in order to find out the new option for next year implementation and planning. During the monitoring and evaluation periods, the villagers and staff will evaluate the existing results, problems and solutions for next year. Such solutions will be used as reference data for net year planning.

9.4.5 Adoption Approach: PWD uses problem census to find out solution and set up plan for village development. In mountainous areas, the main problem is low productivity of the farmland originally caused by planting crops along steep slope with no conservation measure. A solution was found by the villagers themselves to use vetiver strips in annual and perennial crop planting on sloping areas.

The new hilltribes who have no experience in vetiver strip planting will follow an adopted process of PWD. Such process has three stages, namely:

- *First Stage – Demonstration Stage:* Vetiver strip is demonstrated in small plot by field staff. Planting material is provided by PWD and the Department of Land Development (DLD). The objective of this stage is to demonstrate the benefit of vetiver and arouse the villagers' interest.
- *Second Stage – Improvement Stage:* In this stage, farmers are encouraged to try vetiver strips by themselves. DPW and DLD will support all input and technical advice, but plot management is done by the villagers. The objective of this stage is to allow them to test how good they can manage vetiver strips and to see the benefit of vetiver strip by themselves.
- *Third Stage – Expansion:* The villagers accept the new method and adopt it on the larger scale by propagating tillers from their own plot or their neighbors. Then farmers will adopt the recommendation and expand to the areas to their own farmlands in their villages. At this stage, experienced villagers, who faced the problem of Ruzi and Setaria grass aggression, have replaced them by vetiver strips
.

9.4.6 Results of Vetiver Extention on the Highlands: HWD has started vetiver extension as soil conservation strips on the highlands since 1992. Mae Hong Son Hilltribe Welfare and Center (MHS-HWDC) was the first center that promoted vetiver strips with 30 hilltribe farmer families and cover the area of about 27 ha.

In 1993, Chiang Mai, Chiang Rai, Mae Hong Son, Lampang, Nan, Phitsanulok and Phetchabun HWDCs promoted vetiver strip planting in their responsible areas and the total areas covered was about 112 ha. The participated farmers lack knowledge on vetiver planting. Thus PWD requested training budget from the Office of the Royal Development Projects Board (ORDPB).

In 1994, PWD expanded vetiver planted areas to 13 provinces, covering a total area of 157 ha, and ORDPB has supported farmer training program with a grant of Baht 52,470.

The total area in vetiver promotion of PWD during 1992-2000 in 482 villages (3,403 families) is 1,357 ha or 25.1% of the responsible villages of HWD. The upper northern provinces such as Chiang Mai, Chiang Rai and Mae Hong Son have the vetiver strips covered areas of 326, 144, 385 ha, respectively. The lower northern provinces have less vetiver strips than the upper northern provinces because these provinces have less mountainous areas. Thus vetiver promotion as soil and water conservation strips depend on topographic suitability. The most important factor for vetiver promotion is farmer participation in finding problem, planning, implementation and evaluation.

9.4.7 Conclusion:

- An effective approach is participatory planning process (PPP) that emphasize on people participating in finding problems, implementation, and evaluation, and cooperation with the DLD. This approach relates to community needs, and problem solving about environmental deterioration by using vetiver as conservation strips.
- Adoption approach should be used in the new vetiver planting.
- In an upper northern region such as in Chiang Rai province where vetiver has been planted in 666 ha, the hilltribes have had experience in planting vetiver strips in the Thai-Australia Highland Agricultural and Social Development Project since 1987. Thus they had adopted vetiver more than the other highland areas which have less hilltribe population and slope land.
- Most mountainous areas need to have soil and water conservation measure. Thus the agencies concerned should concentrate their efforts in these areas.

9.4.8 Limitation of Vetiver Extension:

- Hilltribe farmers have low level of education. Most are illiterate and live in remote areas.
- Some staff do not have knowledge on vetiver because they have no background in agriculture.
- Staff and budget for introducing vetiver to new areas is insufficient.
- Hilltribe people use herbicide (paraquat) on their farmland, thus affecting the vetver strips.
- Hilltribe people use 4-wheel tractor for their land preparation and, in many instances, destroy vetiver strips.
- Hilltribe people live in remote area having poor road condition which makes it difficult to transport vetiver planting materials

9.4.9 Suggestions:

- Farmer training should also include on-the-job training
- Adequate budget for staff and hilltribe training on vetiver extension should be provided.
- Cooperation with DLD and the agencies concerned should be emphasized.
- Propagation plots in remote areas should be established.
- Tambon Administration Organization should be aroused to promote and provide budget for vetiver promotion.

References for Section 9.4

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9.5 Border Patrol Police Bureau

9.5.1 Introduction: The Border Patrol Police (BPP) Bureau was established in 1951 by Police General Phao Sriyanond, acting as the first Commissioner. The initial purpose of setting up the BPP was to control and protect peace along the border of Thailand.

The BPP is characterized by its ability to perform three tasks, viz. fight like a brigade, in charge of criminal prevention, and control (just like ordinary police force). In addition, they can perform the task of civil servants, especially in the field of community development. These characteristics have been developed since the early period, and maintained up to the present time. The present tasks are as follows:

- Border protection and peace-keeping
- Prevention and control of insurgency
- Crime prevention and control
- Assistance and development services
- Community and mass relations

In assistance and development service, BPP has set up BPP schools for the children who live along the border and remote areas as the ordinary educational service cannot perform its function in those areas. Such schools as taught by the BPP officers. At present there are 176 BPP schools spread throughout the remote areas of the Kingdom.

9.5.2 BPP's Vetiver Program: On 19 February 1992, at Bhuping Palace in Chiang Mai, His Majesty the King gave his initiative about the vetiver grass and advised BPP to plant it in their bases and surrounding areas as a mean of preventing soil erosion and maintaining the topsoil and soil moisture. BPP has proceeded in vetiver planting until now.

9.5.3 Objectives:

- To assent His Majesty's initiative on soil and water conservation and improving the deteriorated environment.
- To propagate and conduct planting demonstration of vetiver in eroding and deteriorated areas.
- To promote and recommend the use and utilization of vetiver to the farmers.

9.5.4 Target*:*

- Demonstration Areas: Target areas for initial planting demonstration cover 562 villages including:
  - Surrounding villages in 176 BPP Schools in at least two areas each, a total of 352 areas.
  - Surrounding villages in 64 perform-bases of at least three areas each, a total of 192 areas.
- BPP aimed to propagate 1.5 million tillers for use in the followings:
  - To be grown in 352 areas surrounding the BPP schools, 2752 each, a total of 97000 tillers.
  - 2,800 tillers for each village surrounding the BPP perform-bases, a total of 530,000 tillers.

9.5.5 Activities:

- BPP initiates experiments on vetiver propagation and growing in eroding areas and to persuade the farmers to make use of vetiver for soil and water conservation, water treatment, and environmental protection.
- The following steps are taken:

  Preparation:
  - Assigning study areas that have erosion and deterioration problems
  - Requesting for selected vetiver ecotypes from the Department of Land Development
  - Organizing seminars and training program to promote understanding and the use of vetiver

  Propagation:
  - Studying and selecting vetiver ecotypes and cultivars suitable for each area
  - Propagating vetiver tillers to reach the target set

  Expansion:
  - To farmers and other people in eroding and deteriorated areas
  - Planting and demonstrating in BPP schools and perform-bases

  Maintenance and Evaluation:
  - Maintain high survival rate and study impacts on the environment
  - Follow up the progress of works, consul and evaluate assigned reports.

9.5.6 Growing Vetiver in BPP Schools: Vetiver is grown on step terraces, in hillside ditches and bunds, on sloping land, around fruit trees (in half-circle facing uphill to trap sediment and debris. The total number of vetiver so far planted is around 24 million. The activities in BPP schools are mainly to restore vetiver planting and to organize seminar and training program. Some BPP schools are unable to grow vetiver because the areas have saline water and hardpan soil.

Problems:
- Lack of water and drought
- Lack of healthy vetiver tillers
- Livestock invasion
- Fire

9.5.7 Growing Vetiver in the Communities:

- Providing vetiver tillers to the communities
- Planting vetiver around the ponds, sloping land and around fruit trees

  Problems:

- Communities lack concern on the significance of vetiver
- Communities did not comprehend
- People misunderstood that vetiver is a weed
- Lack of water and healthy tillers
- People thought that vetiver diffuses their growing areas.

9.5.8 Studying and Promoting Procedures: BPP has solved the above problems as follows:

- Emphasize studying of target areas to be the most efficient. People accept and know how to use vetiver in soil and water conservation and in improving the environment.
- Maintain vetiver to have the highest rate of survival and make utmost use of them.

9.5.9 Experimentation and Demonstration: The following pragmatic practices are given:

- ♦ Growing for preventing damaged topsoil, soil erosion on step terraces and sloping land.
- ♦ Preventing contamination of water source by planting vetiver in contour along the slope. Vetiver root systems form an underground barrier that prevents soil water and toxic substances from flowing down below.
- ♦ Conserving soil moisture by planting vetiver parallel with row of fruit tree and in half-circle around fruit trees.

9.5.10 Campaign on Vetiver Growing: The following campaigns have been made:

- ♦ Promote and recommend the use of vetiver to the farmers
- ♦ Extend knowledge by organizing seminar and training
- ♦ Take care of the vetiver plant.

9.6 Office of the Royal Development Project Board

9.6.1 Introduction: The deteriorated condition of the soil is mostly due to erosion of soil surface caused by rainfall and heavy runoff sweeping over the soil surface. This washes away the fertile topsoil. Sometimes this leads to the problem of soil collapse which damage agricultural land, resulting in the decreasing productivity of the areas which had previously yielded high agricultural produce, despite receiving adequate rainwater. However due to heavy runoff, the torrential water flow wipe away the soil surface which is rich in organic contents.

Realizing the state of the problems and their origins as well as the potential of vetiver grass in preventing soil erosion and preserving soil moisture, His Majesty the King granted an initiative to conduct an experimentation and utilization of vetiver grass for soil and water conservation. This is because the method of utilizing vetiver involves simple technology which the farmers can implement by themselves with a little expense.

His Majesty granted the first initiative regarding cultivation of vetiver grass on June 22, 1991. According to the initiative, experimentation on vetiver cultivation to prevent soil erosion should be undertaken at the Royal Development Study Centers (RDSC) as well as other suitable areas widely and accordingly with the topography of the areas, especially the Huai Sai RDSC and the Khao Hin Sorn RDSC. Therefore, all RDSCs together with concerned agencies cooperated to study and plant vetiver grass according to His Majesty's initiative. The experimentation and cultivation of vetiver are the issues that His Majesty the King is fully concerned about. This can be seen from the fact that His Majesty always keeps abreast of the outcomes of the implementation and periodically grants additional initiatives which presently total 24 occasions. These initiatives make vetiver utilization in Thailand widespread.

His Majesty the King granted initiatives to construct six RDSCs in the different regions of the country. The Centers' aim is to conduct study, experiment and research in order to formulate guidelines and methods of development in many aspects, which conforms to the specific topographical and social conditions of each region. The successful results are then being demonstrated in the form of a "Living Natural Museum". Therefore, each center serves as a model of the integrated development that farmers and interested people can study and attend training to further apply as guidelines for making a living.

9.6.2 Existing RDSCs: There are at present six RDSC's located in different parts of the country. In terms of the research works that each of the Centers has implemented, they are found to be unique and different from one another. Each Center emphasizes their study in different aspects consistent with the geographical conditions of the Centers' area. These Centers are:

9.6.2.1 Huai Sai RDSC: The interesting research works include:

- Vetiver cultivation in hardpan soil by studying the root growth of vetiver planted on the fragments of hard soil compressed in a box as well as studying the cultivation of vetiver together with fruit trees in stone boxes containing hard soil.
- Vetiver cultivation in the integrated farming system by cultivating vetiver across the slope and utilizing its leaves as soil cover materials.
- Vetiver cultivation in a circle around the fruit trees, vegetables, and floral and ornamental trees, as well as utilization of vetiver leaves as materials for covering the base of the trees.
- Utilization of vetiver leaves as mushroom propagating material.
- Vetiver cultivation along the gullies and around the ponds in order to prevent soil erosion.

9.6.2.2 Khao Hin Sorn RDSC: Study and research on many issues include:

- Testing of vetiver growth when cultivated in flooded condition
- Comparative study of the effectiveness of vetiver and embankment which affects soil erosion. This is to compare between cultivation of vetiver in about two or three rows across the slope in cassava plantation and establishment of embankments across the slope. The purpose is to study soil and water loss rate as well as the rate of cassava production.
- Testing of shelter resistance of vetiver
- Study of vetiver utilization to prevent the spread of cogon (*Imperata cylindrica)*
- Vetiver cultivation in many patterns in the Centre's area as well as in the farmers' plots such as in pomelo plot, in tamarind plot, in inverted-v shape across gullies, in a circle and in a semi-circle around the base of the trees

9.6.2.3 Kung Krabaen Bay RDSC: Conduct the followings:

- Testing of vetiver growth in critical conditions by testing the cultivation of vetiver with bamboo and cultivation of vetiver in laterite soil
- Vetiver cultivation for rehabilitation of deep gullies
- Vetiver cultivation in gullies to slow down the runoff and prevent soil erosion
- Vetiver cultivation to replace the establishment of embankments

9.6.2.4 Huai Hong Khrai RDSC: The interesting studies of the Centre encompass:

- Vetiver cultivation to conserve road shoulders on the slope areas
- Study of vetiver growth on laterite soil
- Vetiver cultivation to trap silt along the slope of the area
- Vetiver cultivation on road shoulders of cut-soil slope
- Vetiver cultivation on embankments in the temperate grains planting experimental *plot*

9.6.2.5 Pikun Thong RDSC: Conduct the followings:

- Vetiver cultivation on embankments which block acidic water
- Vetiver cultivation in para rubber field
- Study of soil management to cultivate vetiver in swamp peat areas

9.6.2.6 Phuphan RDSC:

- Vetiver cultivation to form a barrier and increase soil moisture in the slope areas of field crops experimental plots. The slope of the field crops experimental plots in the Centre lead to planting problems because of its gradient which allows the runoff to erode the areas. The experimentation of cultivating vetiver across the channels of water flow found that the problem mentioned reduced within 2-3 years because the slope can adjust its gradient until it is finally levelled.
- Vetiver cultivation to prevent soil collapse and soil erosion on hillside in the peripheral areas of the Centre. The hillside areas are eroded downwards by runoff. The experimentation of vetiver cultivation across the water flow can reduce the velocity of the water flow as well as trap silt by 10-20%
- Study of the root system of vetiver
- Vetiver cultivation to prevent soil collapse and soil erosion, to increase moisture as well as to trap silt along 65 check dams. After experimenting the cultivation of vetiver, it is found that within 1-2 years, vetiver can prevent soil erosion and trap silt by 20-30%

9.6.3 Activities of RDSCs: All of the six Royal Development Study Centres are, therefore, important places where the study, experimentation and cultivation of vetiver grass are being implemented. Each Centre undertakes similar activities as follows:

9.6.3.1 Gathering and comparative study of vetiver ecotypes: This involves gathering specimen of the vetiver ecotypes specimen from many areas in order to study the growth characteristics and determine the suitable ecotypes to serve the utilization purposes of each area.

9.6.3.2 Vetiver Propagation: Propagation of vetiver ecotypes has been done using many methods such as in bags, in strip blocks, and in farm plots. This enables the production of a big amount of vetiver saplings for distributing to the requested agencies and farmers as well as for growing in the Centres' areas to support the study, research and experimentation of its further application in different aspects.

9.6.3.3 Training for Transferring of Knowledge: There are demonstrations of different methods of vetiver plantation within the Centres such as around the fruit trees, in the integrated farming plot and along the pond edges, for interested people to study as well as attend training.

From what I have presented, we can conclude that the six RDSCs have implemented many activities to fulfill His Majesty's initiatives on vetiver utilization for the benefits of soil and water conservation. The results of the study, research and experimentation are applied for many uses. Moreover, training programs are organized and demonstration plots of various methods of vetiver cultivation are established for interested people to study and adopt in carrying out their agricultural occupation. It is obvious that at present vetiver is utilized in many ways, having an impact on the Thai environment and consequently on the world's environment.

9.7 Department of Industrial Promotion

9.7.1 Introduction: The Department of Industrial Promotion (DIP) is an organization under the Ministry of Industry. It is charged with the duty of promoting industrial enterprises, including cottage industry. DIP has supported the Royal Development Projects Board in promoting the vetiver, particularly in handicraft making.

9.7.2 Activities Conducted by DIP Related to Vetiver:

9.7.1 Research and Development: Research on pre-harvest, harvesting and post-harvest have been undertaken on various aspects such as the optimum length of leaves, the treatment of leaves prior to bleaching, the optimum height of cutting, the best solutions for bleaching, dying, etc.

9.7.2 Promotional Activities: DIP has tried to promote the utilization of vetiver leaves to make handicrafts through various cooperatives which are under the supervision of DIP.

9.7.3 Training: DIP organized several training courses on handicraft making from vetiver leaves for various groups such as the housewife groups, cooperatives members, as well as for other groups under the supervision of other government agencies such as the Department of Land Development, Department of Agricultural Extension, the Royal Development Study Centers, the Border Patrol Police Bureau, the Office of the Accelerated Rural Development, etc.

9.7.4 Contests: A number of contests have been held with the aim to promote the utilization of vetiver handicrafts. Two such contests were held, namely:

♦ *The 1995 Contest:* During the Commemoration of the 50th Anniversary (Golden Jubilee) Celebrations of His Majesty the King of Thailand's Accession to the Throne, DIP organized the first 'Vetiver Handicraft Contest' on 23 August 1995. The awards were given to two categories of products, namely, (i) bags, and (ii) other objects.

♦ *The 1999 Contest:* In order to celebrate the auspicious occasion of His Majesty the King's Sixth Cycle (72th) Birthday Anniversary (5 December 1999), the second DIP

Competition was held. The items submitted included decorating objects such as lamp shades, picture frames, blinds; and home appliances such as baskets, trays, shelves, etc.

9.7.5. Exhibitions: Two exhibitions were organized by DIP, namely:

♦ *The 1996 Exhibitions*: After the 1995 Contest mentioned earlier, 179 items submitted for the contest were displayed at the Exhibition Hall of ICV-1 in Chiang Rai. A brochure describing the award winning products was produced for distribution. The second exhibition of the same products (150 items) was organized during 28-31 August 1996 at the Siam Grand Hall in Bangkok. In both exhibitions, some products were also available for sale.

♦ *The 1999 Exhibition*: After the 1999 Contest described earlier, all 125 items submitted for contest were displayed at the Third National Seminar on Vetiver held at Kasetsart University in Bangkok, 15-18 January 1999. Later on, all 304 products submitted for DIP Contests in 1995 and 1999 were re-displayed at the Queen Sirikit Botanic Garden in Chiang Mai for Her Majesty's viewing during the Royal visit on 2 February 1999. After the observation, Her Majesty disseminated these products to the Bang Sai Handicraft Vocational Center in Ayutthaya province to serve as models of vetiver products, and at the same time, to illustrate to the diplomats as well as the Royal guests, the utilization of vetiver leaves in handicraft making.

9.7.6 Publications: With funds available from the Office of the Royal Development Projects Board, DIP published a number of publications for promoting the utilization of vetiver leaves for handicraft making, e.g. 'Vetiver Handicrafts in Thailand' (PRVN Technical Bulletin No. 1999/1), and a Thai language version with more detail explanation and illustration, issued in 2000.

9.8 Doi Tung Development Project

9.8.1 Introduction: Greatly concerned about the soil conservation crisis caused by the road construction operation which took place during 1989 to 1991, Her Royal Highness the Late Princess Mother, who decided to re-forest the denuded mountainous areas of Doi Tung, asked for advice and assistance from His Majesty the King. His Majesty suggested the possibility of establishing vetiver hedgerows on the back slopes and side slopes of the mountain roads. He also introduced HRH to some literature published by the World Bank, describing the special ability of well-planned vetiver hedgerows to serve as biological retaining walls that could both protect against erosion and maintain soil moisture. After careful consideration, HRH decided to introduce vetiver to Doi Tung Development Project (DTDP) for the purpose of exploring the possibility of using it to minimize soil erosion and retain soil moisture. The first 10,000 tillers of Surat Thani ecotype *(Vetiveria zizanioides)* were introduced in February 1992. Later, an ecotype of *V. nemoralis* from Phimai was also introduced, followed by numerous others..

9.8.2 Activities Related to Vetiver at DTDP: The following activities were conducted:

♦ Production of quality planting materials through the use of bare-root tillers, tillers grown in polybags, and tissue-cultured plantlets. The latter was found to be ideal for planting out in the field. This was because their roots begin the regeneration process almost immediately after field planting while those of other planting materials did not begin regeneration process until a full 2-4 weeks after filed planting, and this delay period extends even longer during the dry season. For this reason, all vetiver planting at DTDP has been done using tissue-cultured plantlets, the explants of which were derived from young inflorescence. This operation produced 20 million plantlets in 1993, 25 million plantlets in 1994, 29 million plantlets in 1995, and 60 million plantslets in 1996. Because of such a magnitude of plantlets produced, it was quoted as the largest vetiver project in the world. DTDP is at present the largest source of vetiver plantlets provided to various government and private agencies, both within the country and abroad.

♦ The establishment of vetiver ecotype collection plots. Surat Thani ecotype was found to be the most suitable to be grown on the highland with large variation of temperatures from 10 to 40°C, and can adapt to a wide range of soil and moisture conditions. Two other ecotypes, also of *V. zizanioides*, namely Ratchaburi and Sri Lanka, and another one, Phimai, from *V. nemoralis*, were found to be promising.

♦ The establishment and management of quality vetiver hedgerows, wherever they were planted. Unfortunately, since their job has been terminated when other vegetation took over, they are no longer visible at most sites.

♦ The use of vetiver cut-leaves as mulch for fruit tree plantings. Their leaves are durable and not readily rotten. This property has made it an ideal material for roof thatching or other construction material.

♦ The exploration of other possible applications of vetiver leaves such as handicraft making, both by hand and by simple weaving machines, the making of biodegradable pots from ground dry leaves and culms, etc.

♦ Researches on vetiver were conducted in collaboration with the Department of Agriculture in determining vetiver root distribution patterns and the ability of vetiver roots to absorb nitrates and pesticide residues leaching through the soil. Thus, a strategic establishment of vetiver rows may be a very effective means of preventing unwanted substances from seeping into precious water sources.

♦ The growing of vetiver as a nursing plant in the 4000-rai reforestation project was undertaken, as has been magnificently demonstrated during the study tour of ICV-1 in 1996.

♦ The use of vetiver to stabilize back slopes and side slopes of newly cut roads. In certain critical areas where landslides occurred, vetiver has been used to rehabilitate the areas such that disaster from such collapses was mitigated. In this way, several buildings were saved.

9.9 The Concept of Vetiver Extension and Promotion

9.9.1 Introduction: Agricultural development visualizes production as a source of income and the most important work for the countries which depend on agriculture with the majority of the people engaged in farming. Agricultural practices have been developed since the demand of food increasing with the increase of world population.

Agricultural development means changing for better production by the use of new varieties and/or new systems with appropriate use of resources. Farmers will learn how to produce maximum yield for better income and better quality of life. Agricultural development should include the following elements:

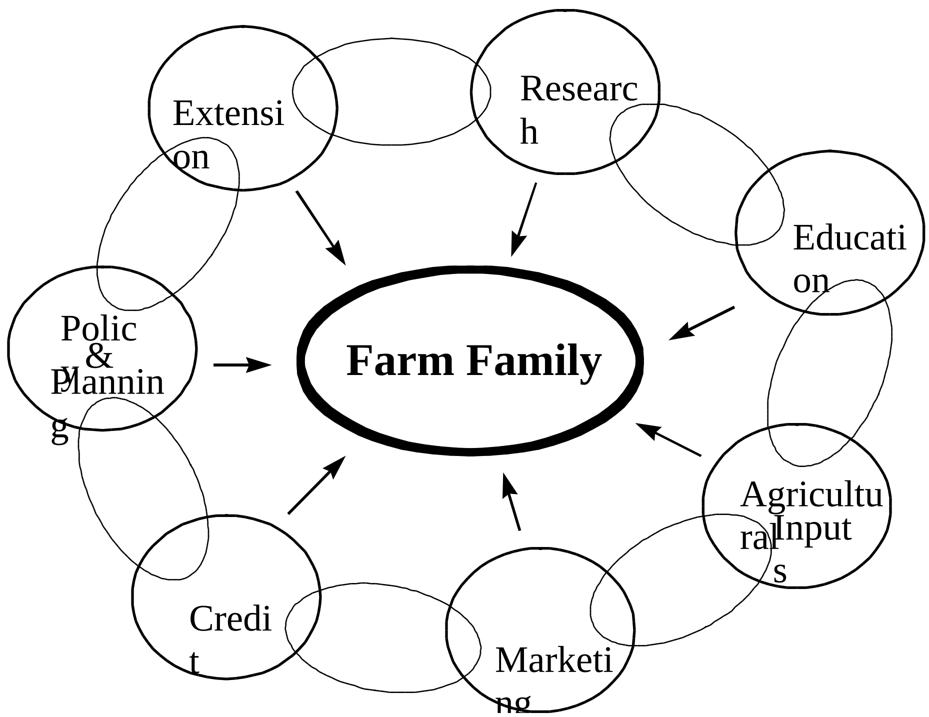
9.9.1.1 Research: Research is one of the important elements of the development. Research for new technology in agriculture will enable the farmers to grow better crops with better production technology, and obtain better income.

9.9.1.2 Agricultural Input: Whenever farmers grow some crops, the input supplies such as seed, fertilizer, water, pesticide and management will maximize the output.

9.9.1.3 Infrastructure: Infrastructures assist agricultural development. These include market place, feeder roads, communication, retail outlets of input, and credit and loan. In order to have better development, all of these infrastructures have to be available and promoted.

9.9.1.4 Farmer Incentives and Agricultural Price: These elements have played an important role that makes farmers interest and practice. What they expect are good price and good income. Farmer's incentives come from the attention and good care of the extension officials. Close relation and close advice will make farmers happy and satisfied.

9.9.1.5 Land Development: At this moment, land and soil on highland for development have serious problems because of the changing in soil fertility and increasing use of the land that causes land degradation.



Source: *Swanson, B.E. 1984. Agricultural Extension, Reference Manual FAO. p.22.*

Fig. 1. Linkages supporting the farm family

9.9.1.6 Agricultural Extension Education: Agricultural development could not exist without the knowledge of the farmer development. Agricultural extension education is the most important element of the whole development process because the farmers learn from these elements and practice in appropriate way with their basic or indigenous knowledge that makes better agricultural development. The success of agricultural development does not aim only to maximize production, but it must improve the quality of life of the farmers. Quality of life is different from one country to another, and from one culture to another as well. The common understanding on this issue is how the people in the rural area can live with food security, healthy and in better environment. Farm family becomes the focus of the development; so family has to be in the good community. Fig. 1 shows farm family which is linked to the elements that support each other.

Agricultural development on the highland is no exception. These elements of development need to be prepared and carried out in order to make agricultural development most successful and sustainable.

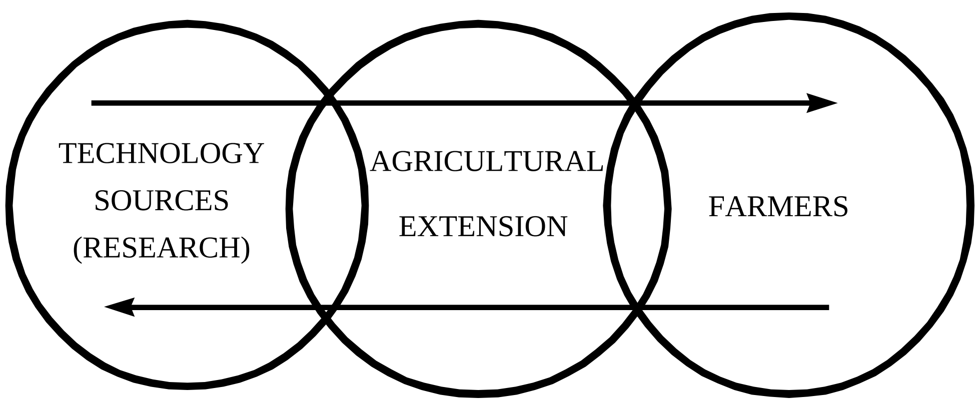
9.9.2 Agricultural Extension Education: Agricultural extension is one of the essential and most important elements in agricultural development. Agricultural extension education is the process that can change the behavior of the farmers to know, to learn, and to adopt new technologies or innovations for their agricultural practices. The process of the learning is mostly done in the informal way in which the farmers can learn by doing. Agricultural extension consists of three processes, viz.:

9.9.2.1 Education Process: The objective of agricultural extension is to change the behavior of the farmers to adopt the innovation. Then, the behavior can change when the learning process is taking place. But education in this process is mostly done by the pattern of informal education because it is easy for the farmers to learn without any limitations, and especially through the method of 'leaning by doing'.

9.9.2.2 Continuous Process: The development of the knowledge for the farmers must be turning around and changing due to the change of the technologies and methodologies of new agricultural practices. Farmers have to learn from one situation to another, and keep on learning. Then, the development will change from time to time, and from the better to the best.

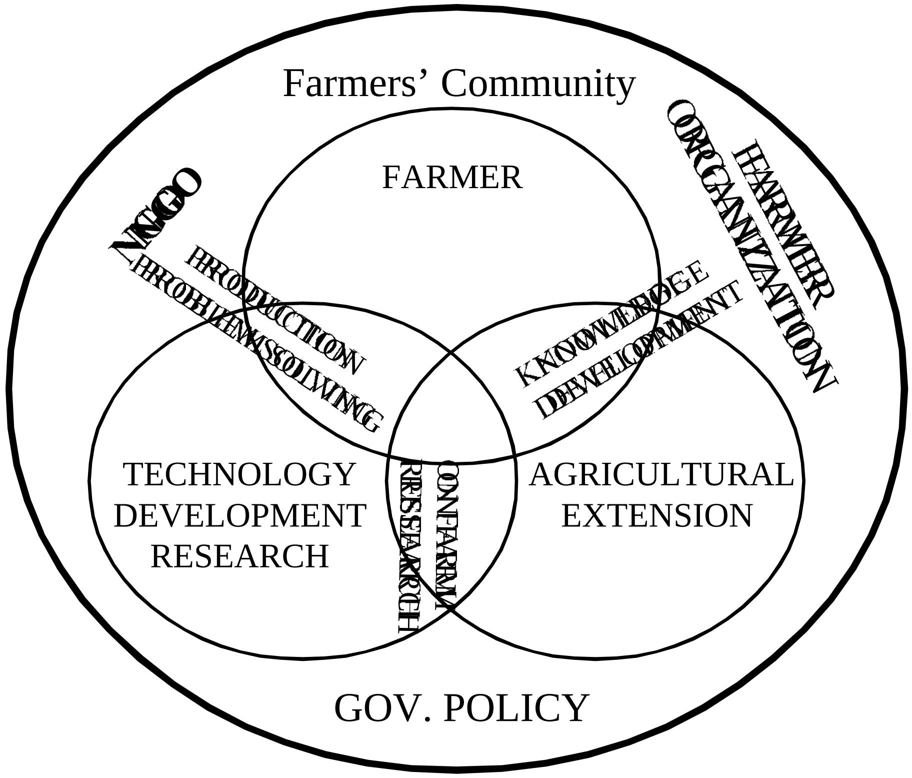
9.9.2.3 Democratic Process: Farmers will accept the innovation and use it with their own consideration and decision. They are happy to adopt the new technologies or new system. Whenever they consider that it is appropriate to the own capability and with their own satisfaction. Participating in the living process of the farmers is considered as high as the farmers can. Then the technologies or the methods that they adopt will be more sustained.

Agricultural extension education is the bridge that links between the knowledge from the research output to the farmer practices.



Source: *Angkasith (1995). Supervision in Agricultural Extension, p.28.*

Fig. 2. Extension linkages from research to farmer: System that exists and mostly used in the underdeveloped countries.



Source: *Angkasith 1995. Supervision in Agricultural Extension, p.28.*

Fig. 3. Research, extension and farmer linkage development system

Figs. 2 and 3 show the changes of extension process, and the development of the extension process in which research, extension and farmer have to work closely under the support of the community, government and non-government organizations. This will make the process more effective.

9.9.3 Scope of Agricultural Extension Responsibility: Agricultural extension education has specific mandate in which extension workers have to perform and be responsible. These include:

9.9.3.1 Agricultural Production: The main responsibility of agricultural extension education is to increase production that can make better income for the farmers and to maintain good natural resources.

9.9.3.2 Marketing Distribution and Utilization of Farm Products: Agricultural production can be subsistence, semi-commercial and full-commercial. Marketing system and production price of whatever crops the farmers are growing have to be carefully considered. Farm products have to utilized in terms of value added and agro-industrial purpose.

9.9.3.3 Conservation and Development of Natural Resources: At present, natural resources seems to be the most important element to all people who are involved in agricultural development. During the past three decades, the world had enough resources to support agricultural practice. Now it has less, and the use of natural resources becomes inappropriate. This causes soil degradation, shortage of water, and especially pollution (through the use of chemicals to increase production). Extension workers have to take serious consideration and have to advice and provide strong recommendation to the farmers to practice agriculture in the proper way.

9.9.3.4 Management on Farm and House: Agricultural production becomes economical oriented. Farmers have to learn how to keep their farms and houses in better condition. Farmers have to manage investment and make a profit that can bring better income.

9.9.3.5 Family Living and Farmer Quality of Life: The ultimate goal of the people is to have good quality of life and family living condition. Farm family is a goal for the farmers; they have to have better income, be in good health, with good education, enjoy safety of life,and live in good environment. Extension workers have to teach the farmers on how arrived at these conditions.

9.9.3.6 Youth Development: The future of agricultural development is in the hand of young people (young farmer). Extension work has to plan for the future of agricultural development. Young farmers who will take an important job for the future have to be prepared; they have to be informed, trained, and educated in the new agricultural system so that their farming can be sustained.

9.9.3.7 Leadership Development: Extension needs leadership for the future of agricultural development. Extension workers and farmers should have a vision for development in the future which will lead to the success of these wishes.

9.9.3.8 Community Improvement and Resources Development: Farm family is the base of the community; thus its improvement and resource development must be in the proper way.

9.9.3.9 Public Affairs: Extension work always involves in public affairs, especially the community where farmers live. Farm families have to support the public affairs such as cultural activities and public development.

9.9.4 Principle of Agricultural Extension Education: Generally speaking, every work has to have the principles which will be the foundation for activities of the job. Agricultural extension education, also have principles, viz:

9.9.4.1 Educational Service: Agricultural extension is an educational service. Extension education develops the knowledge of the farmers in agricultural practices by using technologies for better production. Farmers have to learn from the real situation and by doing.

9.9.4.2 Based on Farmer's Situation: Extension education has to educate the farmers from what they are, and how they operate the farm. In introducing new method, new technologies or new system, these must be adjusted to the farmer's situation, step by step. They should be merged with the farmer's condition as much as they can.

9.9.4.3 Based on Agricultural Research Support: Extension is the work that introduces the new technologies or new system of crop production. So, research in agriculture must be the source of technologies that can make change to increase crop production. Research is also one of the most essential and important component for agricultural development.

9.9.4.4 People Participation: Extension is the learning and practicing process. It needs the cooperation among the people involved. Farmers have to be a part of the process;

so do the extension workers and others. So, extension will be more effective if the people involved with full participation.

9.9.4.5 Democratic Process: Extension will be more effective if the farmers are willing to join the program and make their own judgment and decision.

9.9.4.6 Based on Farmer's Interests and Needs: Extension work will be successful if it is based on the problem and needs of the farmers. Farmers have their own interests and needs. Extension should response to these interests and needs.

9.9.4.7 Set Planning and Project: Extension work is the process that takes many elements and time. Then, planning and project set up according to the purpose and target for the successful are necessary. Extension needs to be planned for the better operation, monitoring and evaluation.

9.9.4.8 Use of Local Academic Resources: Local wisdom, local knowledge and indigenous knowledge are a must that extension worker has to take into account. Because local wisdom or academic resources will make new technologies appropriate to what farmers have. Farmers will be happier when their local wisdom has been accepted and used.

9.9.4.9 Develop and Use Local Leaders: Local leaders are one of the most important components for extension work. They will be the channel that extension process has to carry out. Farmer leaders can assist the extension work and they should be developed for more efficient operation. Thailand has used the system of selection of the leaders. The one who is capable will work closely with extension workers and farmers. Contract farmer (COF) is the leader in development programs that exit in Thailand.

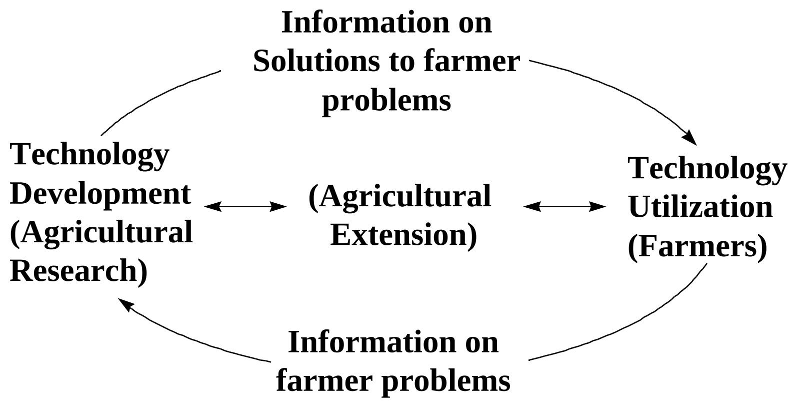
9.9.4.10 Work With, Not Work For: Success of agricultural extension is to make the farmers learn how to practice by themselves. Ultimate goal of extension is that the farmers are self-reliance. They have to be on their own. Extension work provides only advice and suggestion for their own consideration and decision.

9.9.4.11 Based on Bottom Up Process: Extension should start from what farmers have and what they are; so problem and needs should start from farmers up to the policy and implement level for the better service. Extension work should depend on the farmer's situation and adoption as the policy of the top.

9.9.4.12 Use Subject Matter Specialist (SMS): Extension needs specialty in specific problem and specific technologies. SMS can solve the problem of the farm at the right spot; thus technology has to come from specialist.

9.9.4.13 National Policy: Extension work is the process that makes farmer produce better production and better income. But national policy is one of the most important element which the farmers have to follow to get fully support. Therefore, extension workers have to inform the farmers about the national policy and give a strong support to the farmer. In this way, the farmers will be more successful.

9.9.5 Agricultural Extension Approach and Methodology: Agricultural extension process is the vehicle that transfers the information to the farmers. Technologies have to be developed and be available to the farmer for production development. How can farmers receive these technologies? There are many forms that extension work can approach the farmers for transferring the knowledge through different methods and strategies. Fig. 4 shows the concept of technology development, transfer of information, and utilization (Swanson 1984).



Source: Swanson, E.B. 1984 Agricultural Extension Reference Manual P.89

Fig. 4. Simple concept of technology development

Agricultural extension approach has been developed in many forms. Normally there will be nine common forms of approach (Swanson 1984). They are:

9.9.5.1 Conventional Agricultural Extension Approved: This approach has clarified as the ordinary work in the third-world countries where they work on a day-to-day basis, and it must go along with the national system. The objective is to increase national agricultural production, farm income, and quality of life of the rural population. Organization for this extension is mostly from the central government under the Ministry of Agriculture.

9.9.5.2 Training and Visit (T&V) System: This system is the development system of approach to improve the effectiveness which is encouraged and supported by the World Bank to be used in the third-world countries. Objectives are the same as conventional approach by increasing agricultural production at the individual farm level.

The objectives of the T&V system as a reform movement of conventional agricultural extension organizations should also be described. Some of the more important problems the T&V system attempts to be solved are:

(a) to improve the organization of extension by introducing a single, direct line of technical support and administrative control,

(b) to change the multi-purpose role of many extension workers to a clearly defined, single-purpose role involving only education and communication activities,

(c) to improve coverage by limiting the number of farm families or households one extension worker is expected to visit,

(d) to improve mobility by providing appropriate transport so each worker can regularly visit his or her contact farmers,

(e) to improve each extension worker's technical skills and knowledge about improved agricultural technology be providing regular in-service training sessions,

(f) to improve extension's ties with agricultural research through the addition of more subject-matter specialists, who are expected to maintain regular contact with their research counterparts and to ensure a continuing flow of information that transmits technology to farmers and farmer problems back to research personnel,

(g) to improve the status of extension personnel by giving them a relatively clear-cut extension job with reasonable expectations that they can successfully carry it out; this will increase their level of respect in the community and begin to build their self-confidence, and

(h) to reduce the duplication of services that occurs when extension is fragmented among different ministries (for example, agriculture, livestock or forestry) or is added to new area or commodity development schemes in a country or province that already has a general agricultural extension system.

Organization and scope of T&V system is based on the total number of farm families or household. In the case of Thailand, the ratio of responsibility of each extension worker to farmers is 1 : 800 or 1 : 1,000.

9.9.5.3 Agricultural Extension Organized by Universities: This approach was founded in the United States. The program is carried out by federal, state and local government as well as by land-grant colleges and universities in each state, the so-called Cooperation Extension. The university will be responsible for the work with the staff from the colleges and extension centers through the experiment stations located around the state.

In addition to the above three forms of extension approaches, there are also other approaches that should be employed as an alternative approach as well (Axinn 1988). They are:

9.9.5.4 The Commodity Specialized Approach: The assumption here is that the way to increase productivity and production of a particular commodity is to group all functions relating to it under one administration, including extension along with research, input supply, output marketing, and often prices. Extension program planing is controlled by a commodity organization, and implementation is through field staff of the organization. Resources tend to be provided by the commodity organization, for which agricultural extension is considered a sound investment. While it may use many of the same methods and techniques as the approach mentioned above, the measure of success is usually the total production of the particular crop.

9.9.5.5 The Agricultural Extension Participatory Approach: Here the assumption is that farming people have much wisdom regarding production of food from their land, but their levels of living could be improved by learning more of what is known outside. It further assumes that effective extension cannot be achieved without the active participation of the farmers themselves as well as of research and related service; that there is a reinforcing effect in group learning and group action; and that extension efficiency is gained by focusing on important points based on expressed needs of farmers and by reaching more small farmers through their groups/organizations instead of through individualized approaches. The purpose is to increase production and consumption and enhance the quality of life of the rural people. Program planing is controlled locally. If such groups as farmers' associations do not exist, the extension staff should assist to form them. Priorities vary greatly from place to place and from time to time within the country. Field personnel tend to be local, lower cost, with training and background appropriate to local needs. Resources required tend to be less than with other approaches, and a high proportion may be provided locally. Implementation is through group meetings, demonstration, individual and group level, and also local sharing of appropriate technologies. Success is measured through the number of farmers actively participating and benefiting as well as continuity of local extension organization.

9.9.5.6 The Project Approach: This approach assumes that rapid agricultural and rural development is necessary and that the large government bureaucracy in the regular Ministry of Agriculture. Extension service is not likely to have a significant impact upon either agricultural production or rural people within an appropriate time frame, and that better results can be achieved by taking a project approach in a particular location, during a specified time period, with large infusions of outside resources. The purpose is often to demonstrate what can be done in a few years. Central government controls program planning, often with considerable input from international development agency. Implementation typically includes project allowances for field staff, housing rather than regular governments programs, and foreign advisors for local staff. Short-run change is the measure of success.

9.9.5.7 The Farming Systems Development Approach: The assumption with this approach is that technology which fits the needs of farmers, particularly small farmers, is not available, and needs to be generated locally. The purpose is to provide extension personnel (and through them farm people), with research results tailored to meet the needs and interests of local farming system conditions. Program plans evolve slowly during the process, and may be different for each agro-climatic farm eco-system type since they include a holistic approach to the plants, the animals, and the people in a particular location. Field personnel tend to be highly specialized, relatively expensive, and from outside the area being served. Implementation is through a partnership of research and extension personnel with each other and with local farmer, taking a "systems approach" to the farm, and sometimes involving several different scientific farmers' fields and homes. The measure of success is the extent to which farm people adopt the technologies development by program and continue to use them over time.

9.9.5.8 The Cost-Sharing Approach: The assumption here is that the program is more likely to fit local situations and personnel are more likely to serve local people's interests if part of the cost of agricultural extension is paid locally. It also assumes that farm people are too poor to pay the whole cost, so central and regional governments typically provide most of it. Helping farm people learn those things they need to know for self-improvement and increased productivity is the purpose. Control of program planning is shared by the various levels paying the costs, but must be responsive to local interests in order to maintain 'cooperative' financial arrangements. Field personnel tend to be recruited locally, cost less, and remain in one location for long periods of time. Because of the nature of this approach, resources required from central governments tend to be less. Success is measured by farm people's willingness and ability to provide some share of the cost, individually or through their local government units.

9.9.5.9 The Educational Institution Approach: In this approach, the assumption is that faculties or colleges of agriculture have technical knowledge which is relevant and useful to farm people. The purpose is to help those people learn about scientific agriculture. Program planning tends to be controlled by those who determine the curriculum of the education institution. Implementation is through non-formal instruction in groups, with individuals, and with other methods and techniques, sometimes conducted by a college or university with agricultural extension personnel of another agency as the main audience. While considerable resources are required, since they are shared between the classroom program of the educational institution and agricultural extension, the approach can be attendance and the extent of participation by farm people in the school's agricultural extension activities.

9.9.6 Methods of Extension: Farmers will learn to use the technologies for their cultivation practices and develop the production. How they learn and how to teach and train seem to be concerned to extension worker. The success of the transfer of knowledge to the farmers are the methods and techniques that make the farmers learn efficiently and effectively. There are depend on how the extension worker will consider to use the appropriate methods for the teaching. Some conditions have to taken into account.

- For farmers, or receivers, or learners who will be the part of the end transferring of the knowledge, there have to have some conditions concerned with farmers such as age, character, culture, education, tradition, and environment. Farmers in some part of the world are easy to learn but in some part, they are not. They are different from one society to another. The extension workers have to consider this factor as well.
- Extension workers, or trainers, or teachers, who will be responsible to transfer the knowledge to the farmers, have to understand the farmers and how to transfer the knowledge. They have to have knowledge of transferring and know how to work and train the farmers. Also, they have to have the techniques and experience to deal with the farmers and know the role as the trainer.
- Technology or knowledge that will be transferred to the farmers have to be considered on what to transfer. Extension workers have to consider appropriate knowledge to the farmers which should not be lower or higher level to the farmers. Knowledge has to be based on the need and usefulness to the farmers and must be appropriate for adapt to the local wisdom or indigenous knowledge of the farmers as well.
- Environmental conditions, include time and place to be transferred, and the knowledge which depends on the farmer situation, should be under the circumstance that suits the farmers and extension workers.

The above four factors will make more effective transfer of knowledge to the farmers with the appropriate methods. Extension methods which mostly followed what FAO has recommended are:

- *Individual Method:* This method will transfer the knowledge to the farmers one by one, or face to face. There are many techniques that are used, including farmers and home visit, office calls, letters, telephone calls, and informal discussion. This method is effective as each farmer will learn directly of specific knowledge from the extension workers. Mostly farmers have low education level and it takes more time to teach them.
- *Group Method:* This method involves the extension worker transfer the knowledge to the group of the farmers who will learn from each other as well. These include group meetings, demonstrations of both method and result, field study tour or field trip, and field day. This group method will be more effective if the farmers are homogeneous group, i.e having the same culture, level of education, and language. Farmers must have middle to high level of education, and less time to teach than the individual method.
- *Mass Method:* This method is the way that knowledge will be transferred to the mass media which include radio broadcasting, television, newspaper, poster and exhibition. This method will be the process that transfers knowledge to the large number of farmers who can learn by them- selves. So, the farmers have to have the high level of education, and will be effective in terms of less time, but disadvantage in terms of the knowledge received.

9.9.7 Vetiver Extension and Promotion: *From the agricultural extension and training (education) programs that are the processes on how to make the farmers or clientels to accept and adopt the technology for production development. Agricultural extension process is an important process that all concerned people have to be aware of because the adoption process is the result of the efficient transfer process. Many times, farmers drop the technology and do not adopt it; that makes the extension program fails.*

Technologies and transfer process must be considered seriously. Because technologies that will be transferred have to give the benefit and the development or the change to the farmers.

9.9.8 The Dissemination of the Vetiver System: Vetiver system is the technology that is useful to the farmers in term of:

- ♦ Soil fertility and water conservation
- ♦ Soil protection
- ♦ Soil capability development
- ♦ Support the moisture to crops.

So, vetiver has the utility that is not direct to agricultural production, unlike other crops grown by the farmers who still want to grow them, and ignore to pay the interest on vetiver. That makes its extension and promotion the most difficult.

But, it is a challenge for the extension workers to make it works through promotion campaign. Extension and promotion of vetiver must be done through the systems that included:

- ♦ Knowledge about vetiver technology.
- ♦ Long-term benefit to the farmers.
- ♦ Ultimate goal of the vetiver growing has to be clarified.
- ♦ Benefit of by-products has also to be clearly identified.

Thus extension workers and researchers have to prepare vetiver extension program carefully in order for the farmers to have more understanding and will accept and adopt this technology.

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10. THE SUMMING UP

10.1 The Miracle

10.1.1 The Miracle Grass: The lecturer hinself never believes in miracles. He may be borne to be a scientist. From his early years of childhood, he always argued with his mother (who, like most Thai people of her age, believed in superstitious and miraculous issues) that there is no such thing as miracle. When the first International Conference on Vetiver was organized under the theme, “Vetiver: A Miracle Grass”, he was not so happy with the theme, but how could he argue? Yet, at the end of ICV-1, he was *half-convinced* that the word “miracle” may be appropriate to use, especially if we want to advise the farmers to grow vetiver for soil and water conservation (as many of them still believe in such thing as miracle). At the same time, we must try to prove that vetiver itself is a wonderful plant. Other than using it as a single hedgerow for soil and water conservation, which we all agree that it works, what other characteristics lend support to it to be called a ‘miracle’. The lecturer is not going to give the tainees a long list of those characteristics like ecological, physiological, genetics, which have already been discussed at length earlier, but only a few most fascinating ones:

♦ Drought resistance, because it has deep root system, and unique tough shoot structure which resists the force of running water, and at the same time, does not allow much water to evaporate from the plant.

♦ Living nail of its roots which enable it to penetrate deep down the soil of hard texture, thereby breaking it, making it friable and porous enough for air and water to pass through.

♦ Living wall and barrier of both the above ground portion which acts as a sieve, trapping all organic matters to be deposited right there in front of the hedgerow, thus increasing organic matter and humidity, slowing down the fast runoff, and allowing it more time to infiltrate down the soil layer, while the underground portion with thick mass of fibrous roots acting as underground wall absorbing all nutrients, agrochemicals, toxic substances, and only allowing clean and clear excess water to pass through slowly. It works well on flat land, on gentle slopes, as well as steep slopes, and on diverse types of soils.

♦ Its most amazing feature is probably its tolerance to a wide range of environmental stresses, from acid soil to alkaline soil, from very dry place to the wet one, even heavy metals and agrochemicals used as pesticides; from pollutants of domestic and farm wastes to toxic industrial wastes!

♦ Yet, unlike other grasses or legumes popularly used as cover crops, vetiver is not fertilizer- and moisture-demanding. It can thrive even in pure sand with little soil moisture, yet, once firmly established, it helps to make the environment suitable for other plants to grow. We now know that it is a C-4 plant with close association with useful microorganisms that help it to fix atmospheric nitrogen and dissolve insoluble soil phosphorus, both of which are important elements for its growth. It is a humble grass, easy to grow and requires no maintenance once it is established. It is a poor man’s crop. The lecturer recalls what Noel Vietmyer of the U.S. Academy of Science once said, “It’s so worthless that even billions of specimens will not make any millionaires”. That was in 1996 when we had ICV-1. Now, only four years later, the demand for it is great that many people earn a good income from selling the tillers or plantlets, for planting, and their leaves and culms to make handicrafts and other products.

♦ The lecturer once called it *"Glory to the Land"* in his first book that he wrote for His Majesty in 1992, because, like His Majesty whose presence in His Kingdom is "Glory to the Land", vetiver's presence in God's Kingdom, by virtue of its unique property in being suitable to be used as living hedge, which is resistant to fire, drought, diseases and pests, which can grow on most soils in a wide range of climatic conditions, and which can improve the moisture content of the soil profile without competing with crops, truly deserves the same name of its developer, as *"glory to the land"* as well.

♦ When Thailand announced the Amazing Thailand Years during 1998-99, the lecturer wrote a series of booklets for the Horticultural Research Institute of the Department of Agriculture on "Amazing Thai Fruits", plus another one which he was so proud of, that is, *"Amazing Thai Vetiver"* for the Office of the Royal Development Projects Board. By that time, he was convinced that it is *almost* a miracle plant.

♦ While reading through all the manuscripts submitted to ICV-2 early this year as the Editor of the Preceedings of ICV-2, and listening to the many panels and papers, observing poster papers and demonstrations, the lecturer was *finally convinced* that vetiver is truly a miracle plant.

♦ It is now the lecturer's turn to convince the traineees that vetiver is a miracle plant. The trtainees have witnessed with their own eyes during the past ten days what vetiver can do and cannot do. They were all captivating, and the trainees should by now be a convert. The lecturer's humble request to all the traineees is that the latter would return to their home countries and try their best to captivate their people that *vetiver is truly a miracle plant*.

10.1.2 From Obscurity to Popularity within a Single Decade: When Mr. Richard Grimshaw and his colleagues at the Agricultural Division of the World Bank set up the Vetiver Information Network in 1989 with the publication of a book, "Vetiver: A Hedge Against Soil Erosion", few people paid attention to the vetiver grass. By the blessing of God, Mr. Grimshaw presented the book to His Majesty the King through Dr. Sumet Tantivejkul, then the Secretary-General of the Office of the Royal Development Projects Board. Reading through it and after careful consideration, His Majesty adopted the idea of using vetiver for soil and water conservation and introduced a simple technology to the hilltribes in the first place. This vetiver grass technology has been found effective with little or no expense, and requires minimum care once its growth has been established. Another historic event took place on 29 June 1991 when His Majesty gave a Royal command and introduced vetiver as an object for trial at the various Royal Development Study Centers. Throughout the year, His Majesty delivered ten more commands for his subjects to do experiments on vetiver. At the same time, His Majesty gave $10,000 to the Vetiver Information Network to be used to promote research on vetiver which will lead to the dissemination of useful and practical in formation on vetiver. Before presenting his contribution to Mr. Richaard Grimshaw of the Vetiver Information Network, who had been given an audience to discuss the vetiver program in Thailand, His Majesty expressed his belief that vetiver could well be the answer to stabilizing Thailand's fast eroding lands while reducing excess runoff and the problems that this runoff causes.

Vetiver research and development was booming when Thailand was honored to organize the First International Conference on Vetiver (ICV-1) in Chiang Rai in 1996, followed by the ICV-2 in Phetchaburi in 2000 (see details later), with about 400 participants in each, and from 41 and 31 countries, respectively, from all five continents attending.

Vetiver has emerged from being a crop of obscurity to a crop of popularity in just a decade in spite of the fact that it was once called a grass, a useless plant, and not even considered as a crop. Amazing, isn't it? This could not happen at all without the cooperation and dedication of a number of people, organizations, both in the government and the private sectors, who have helped in various ways to make it so well known to both agricultural and non-agricultural sectors alike. It is now the lecturer's pleasant duty to put in record here of all their great contributions.

10.2 The Cooperation

10.2.1 The Vetiver Networks: One of the comments the lecturer received from Mr. Richrard Grimshaw, a pioneer in vetiver research and development at the World Bank and the Coordinator of the Vetiver Information Network, about the contents of this Training Course, that is "Participants should be made aware of the importance of networking". Being the Executive Secretary of quite a number of FAO's networks, like Asian soybean, food legumes and coarse grains, medicinal and aromatic plants, oil palm, sericulture, etc., the lecturer fully agreed with his suggestion. Through networking, we receive up-to-date information about vetiver at no cost; we exchange our ideas and experiences with each other, we receive grant for our research projects or to attend meetings, study tours, training courses, on-the job training, etc. Above all, networking keeps us close together as if we were family members.

When Mr. Richard Grimshaw set up the "Vetiver Information Network" in the late 1980's, his idea was just to release information to research workers who were interested in vetiver. No plan to set up other networks. As time went by, and a lot of people were interested in its publications, and at the same time he has retired from the World Bank, thus could not draw resources to run the Network, yet he continued the network under a new name, "The Vetiver Network (TVN)", and run it as an independent autonomous body with funding support from donors who were a number of government and private sectors. The first network was a regional one for Latin America, set up in October 1995, followed by the second one soon after ICV-1 in January 1996, that is the Pacific Rim Vetiver Network. A few more regional as well as many national networks were soon establsihed under the umbrella of TVN.

The following paragraphs give a list of all existing vetiver networks: *(See details of the networks, acronyms and contacts in Annex 3)*

10.2.1.1 Global Level: Vetiver System is a low-cost technology to solve big problems of soil and water conservation. However, before such a system can be transferred, there is a need of funds for research and development as well as for transfer the derived technology. The Vetiver Network (TVN) has been established as a non-profit organization to support the use and utilization of vetiver for soil and water conservation. It is the first and the only global vetiver network that started the whole activities on vetiver since the latter part of the '80. During the first few years of its existence, it received full support from the World Bank. However, such support has been terminated and it now depends on grants from various governmental and non-governmental agencies. It provides technical as well as financial supports to other networks around the world and also helped in the organization of meetings on vetiver at the international as well as national levels.

10.2.1.2 Regional Level: At present there are five regional networks, whose details are give below in order of their establishment, namely:

- *Latin American Vetiver Network (LAVN):* Established in October 1995 to disseminate and assist with the exchange of information in Spanish regarding the use of vetiver grass within the region, LAVN has been successful in its goal of dissemination. The Secretariat Office is located in San Jose, Costa Rica. At present there are 20 member countries namely Mixico, Guatemala, El Salvador, Honduras, Nicaragua, Costa Rica, Panama, Colombia, Venezuela, Boliviaa, Ecuador, Peru, Brazil, Chile, Argentina, Uruguay, Paraguay, Cuba, Dominican Republic, and Puerto Rico. Major activities include the publication of a newsletter (the *Boletin Vetiver),* provided material to the Vetiver Network Homepage, videos, technical information on specific topics; assembled a directory of the most active VS users and network members, provided small grant for initiaition of vetiver nursery, etc. (Miller 2000)

- *Pacific Rim Vetiver Network (PRVN):* Established in April 1996, with the Secretariat Office at the Office of the Royal Development Projects Board in Bangkok, Thailand. At present, there are 20 member countries namely Australia, Brunei, Cambodia, China, Cook Islands, Fiji, Indonesia, Japan, Lao PDR, Malaysia, New Caledonia, New Zealand, Papua New Guinea, Philippines, Samoa, Taiwan, Thailand, Tonga, Vanuatu, and Vietnam. The main activities include the publication of a quarterly newsletter, *Vetiverim,* now Number 14 (October 2000), the publication of occasional technical bulletins (six have been produced up to now), established a HomePage, production of CD ROMs on various subjects, and provided consultants at the request of other countries (two teams have been released, one to Myanmar to solve the problem of erosion in the watershed areas in Shan State, and the other to Madagascar to rehabiliate the railroad track damaged by two cyclones in early 2000), as well as providing planting materials to neighboring countries such as Laos, Vietnam and Myanmar (Chomchalow 2000).
- *South African Vetiver Network (SAVN):* Established in November 1996 with the Secretariat Office at the Institute of Natural Resources, Scottsville, South Africa, SAVN’s targets are in four specific areas, viz. (i) provincial and regional government department/parastatals, (ii) local champions, (iii) mass circulation publications, and (iv) NGOs. Activities included the publication of newsletter and support of two research projcts, one to determine if any existing cultivars perform better than other in the cooler high altitude environments, and the other to determine more precisely the impact vetiver has when used in landfill rehabilitation.
- *Europe and Mediterranean Vetiver Network (EMVN):* Established in November 1998, for a period EMVN operated its own HomePage which was little more than a mirror of the TVN Website. After one year this was discontinued in favor of a section within the centralized TVN Website. EMVN produced its first newsletter in April 1999. The fourth one just came out in Novemebr 2000. The Secretariat Office is located in Lagos, Algarve, Portugal. The members include Portugal, Spain, Italy, Albania, and a few other countries which have potential such as Greece, Syria, Turkey, Morocco, and the Canaries (Pease 2000).
- *West African Vetiver Network (WAVN):* The Secretariat Office is located in Accra, Ghana. However, due to poor health of the Coordinator, Mr. Linus Folly, this regional network is now inactive and no information has ever been received.

10.2.1.3 Sub-Regional Level: There are two sub-regional networks in South America, namely:

- Andean Vetiver Network (ADVN): With the Secretariat Office in Chili, its members include Peru, Argentina, Paraguay, Uruguay and Venezuela
- El Salvador/Nicaragua (SNVN): With the Secretariat Office in El Salvador, its members include El Salvador and Nicaragua.

10.2.1.4 Country Level: At present, there are 19 national vetiver networks; six in Asia, four in Africa, nine in Latin America, viz.:

(1) Asia:

- China Vetiver Network (CVN)
- Indian Vetiver Network (INVN)
- Indonesian Vetiver Network (IDVN)
- Philippine Vetiver Network (VETINETPHIL)
- Thailand Vetiver Network (THVN)
- Vietnam Vetiver Network (VNVN)

(2) Africa:

- Cameroon (CMVN)
- Amhara State Vetiver Network (ASVN) in Ethiopia
- Madagascar Vetiver Network (MGVN)
- Tanzania Vetiver Network (TAVEN)

(3) Latin America:

- Brazil Vetiver Network (RBV)
- Chile Vetiver Network (CLVN)
- Colombia Vetiver Network (C-VN)
- Costa Rica Vetiver Network (CRVN)
- Ecuador Vetiver Network (EQVN)
- Mexico Vetiver Network (MEXVN)
- Panama Vetiver Network (P-VN)
- Peru Vetiver Network (P-VN)
- Venezuela Vetive Network (VEVN).

10.2.1.5 City Level: In a large country, e.g. China, there may be a need to set up city vetiver network. One has already been established, i.e. Fuzhou Vetiver Network (FZVN), in Fujian province, southern China.

Note: There is still inconsistency in the use of acronyms of some vetiver networks. This was because there was no rule or guideline before their establishment. The problem arises when two national networks would like to use the same acronym, e.g. China and Cameroon, both want to use CVN. To avoid further confusion and chaos, the lecturer has discussed with Joan Miller of TVN and came to the decision to use a four-letter-code for all levels of the vetiver networks, the last two are VN for Vetiver Network, while the first two are for country code, based on e-mail country code, e.g. India = IN, Indonesia = ID, China = CN, Cameroon = CM. There should be no problem with the region or sub-regions as there are not many of them and they are quite distinct. The problem still remains, however, with the old networks having different acronym systems; some use a three-letter-code while the other more than four. We have to allow them (those networks whose acronyms are underlined in the above paragraphs) to continue using the ones they used before although we have requested them to voluntarily change to the newly adopted system, to make the system consistent. For the new networks, please use the new system and register it with the lecturer who will act as the Registrar for TVN in this regard.

In countries which use languages other than English as their national languages (in fact many do, like Brazil Vetiver Network - RBV), the suggestion is to use English translation of the network and use the acronym derived from English name, rather than the one derived from the national language. They may, however, use the national language and acronym derived from it if used within the country.

10.2.2 The International Conferences on Vetiver (ICV)

10.2.2.1 ICV-1: The First International Conference on Vetiver (ICV-1) was held in Chiang Rai, Thailand, 4-8 February 1996. It was organized by the Royal Development Projects Board, in cooperation with the Chaipattana and the Mae Fah Luang Founadations, with support from the World Bank and the FAO Regional Office for Asia and the Pacific, to commemorate the 50th Anniversary (Golden Jubilee) of His Majesty the King of Thailand's Accession to the Throne. It was attended by 400 participants, 100 of which were foreigners from 41 countries. The theme of ICV-1 was "Vetiver: A Miracle Grass". In addition to the presentations of plenary, contributed and poster papers, discussions, exhibition and study tour, a constitution for ICV was drafted and, although not yet endorsed by the Meeting, was implemented through the involvement of an Interim Committee (IC) which was quite useful in selecting Thailand as an alternate host for ICV-2 in place of South Africa, the proposed host which could not make it.

10.2.2.2 ICV-2: The Second International Conference on Vetiver (ICV-2) was held in Cha-am, Phetchaburi, Thailand, 18-22 January 2000. It was also organized by the Royal Development Projects Board, with support from the Chaipattana Foundation, to commemorate the Sixth Cycle (72nd) Birthday Anniversary of His Majesty the King of Thailand. It was attended by 400 participants, 100 of which were foreigners (almost the same figure as that of ICV-1) but from 31 countries. The theme of ICV-1 was "Vetiver and the Environment". The nature of the Conference was exactly like that of ICV-1, but in a much larger scale, especially the exhibition which was arranged in a specially constructed pavilions whose roof was made of vetiver leaves. For the first time, the 482-page Preceedings, containing manuscripts of all papers presented were published prior to the conference. Everyday, an ICV-2 Daily News was also published.

10.2.2.3 ICV-3: The Third International Conference on Vetiver (ICV-2), as proposed and agreed upon during ICV-2, will be held in Guangzhou, Guangdong province, China, 18-22 October 2004. It will be organized by the Chinese Academy of Science.

10.2.3 Other International Workshops: A few international workshops were recently organized. These were:

10.2.3.1 The First International Vetiver Workshop: The First International Workshop was held at the Rubber Research Institute of Malaysia (RRIM) in Kuala Lumpur, Malaysia, 13-16 April 1992. It was organized by P.K. Yoon on behalf of RRIM and was attended by 87 participants from nine countries.

10.2.3.2. The International Vetiver Workshop: This workshop was originally planned as the First China Vetiver Workshop, which was held in Fuzhou, Fujian province, China, 21-26 October 1997. It was organized by the China Vetiver Network and was attended by 100 participants, seven of whom were from foreign countries. Because of the presence of international participants, the Organizer later called it the International Vetiver Workshop which included two plenary sessions, a mid-workshop tour, a three-day post-workshop field survey, a poster session and an exhibit of publications and sample of handicrafts made from vetiver. There were 28 papers presented at the Workshop.

10.2.3.3 The International Ground and Water Bioengineering for Erosion Control and Slope Stabilization Workshop: The Workshop was held in Manila, Philippines, 19-21 April 1999. It was concentrated on bioengineering technology that utilizes vegetative-structural solutions to prevent erosion and stabilizes site disturbed by infrastructures and transportation development.

10.3 The Dedication and Supports

10.3.1 The Individuals: It is impossible to list all individuals whose experiences, observations, experimentation, ideas, lectures, demonstrations, exhibits, etc., have contributed to the present stage of knowledge of the vetiver system. However, the pioneering works of John Greenfield in Fiji and India, P.K. Yoon in Malaysia deserve a record here as the ones who were among the first to work on vetiver and have contributed much to our present knowledge. The name of Richard Grimshaw should also be recorded here as the person who worked so hard to unite all of us, as the person who provided financial as well as moral supports to research scientists in the developing countries, and to help organize so many international and national meetings on vetiver. Above all, His Majesty the King of Thailand, the father of Thai vetiver and 'Glory to the Land', has devoted all his life time for the welfare of the Thai people and much of these involves the work on vetiver. He has shown us the way to work on this miracle grass from the very beginning a decade ago, and still he talks about vetiver in every occasion he has. As you all know, we are just scientists with little or no influence. It is magnificently heartening to have a person of His Majesty's stature interested, involved and standing beside us as colleague and true friend of vetiver. Last, but not least, is Her Royal Highness Princess Maha Chakri Sirindhorn, a most dedicated person who closely follows her father's footstep in almost every thing, including the devotion to vetiver works. HRH has recently accepted TVN's invitation to become the Patron of TVN, and that means all vetiver networks around the world. This is really a good news and great honor for all of us, the vetiverites (i.e. those who work on vetiver) in the developing countries. HRH has been well known among us, the vetiverites, especially those who participated in the last two ICVs in Thailand in 1996 and 2000. Not only graciously chairing the opening ceremonies, HRH actually participated in both conferences. In addition, HRH has been instrumental in convincing the Chinese authorities to accept being the host of ICV-3 in 2004 in Guangzhou, Guangdong, China with the theme of "Vetiver and Water". The lecturer hopes to see each and every one of the trainees there with the result of your good work presenting in this Conference.

10.3.2 The Public Sector: The World Bank has provided supports to the vetiver program from the very beginning until the late 1980's. Many governments have also contributed grants to run the TVN. These funds support the overall objectives of Vetiver 2000 project. Altogether, this amounts to nearly $400,000. These fundings are to be used to leverage additional funding from other donors such as UK, Holland, Germany, Sweden, Norway as well as from the private sector.

In addition to the above, the Royal Danish Government has recently made a generous grant of $ 114,000 to TVN in support of dissemination of technical information. These funds will be used to maintain TVN's newsletters, home page, reprinting of technical handbooks, production of CD-ROMs, etc. Some of these funds will be granted by TVN to national and regional networks to help them produce technical data specifically for their areas of operation.

10.3.3 The Private Sector: Many foundations and NGOs have also provided financial supports either directly to the TVN or to national agencies, like the case of the Heineken Breweries Co. Ltd. (see below). Among these are:

♦ The William Donner Foundation has made a generous grant of US$100,000 to TVN. Approximately half of these funds have been allocated by TVN to support a continuation of its Vetiver System (VS) research grants program. In anticipation of the Third International Conference on Vetiver in China in 2004, TVN wishes to encourage research on the theme "Vetiver and Water". TVN will award grants totaling $45,000, for research on water-related aspects of vetiver. TVN will fund up to 50% of the proposed research, the remaining 50% to be provided by additional sources. Applications for funding under $2000 are strongly encouraged, and small enabling grants ($100-$1000) are especially favored, as is collaborative and interdisciplinary research. The maximum funding for an individual grant is $9000, which with matching funds would require a total budget of at least $18,000.

♦ In addition, several other private organizations have recently contributed grants to TVN for various activities related to vetiver. Among the recent ones are: Amberstone Trust with the total amount of $55,000; and the Wallace Global Foundation, $76,000.

♦ The Office of the Royal Development Projects Board (ORDPB) of Thailand received $ 50,000 from the Heineken Breweries Co. Ltd. to be used in the promotion of the uses and utilization of vetiver. This fund will be used in: (i) organizing international and national training courses on the Vetiver System, and (ii) VS technology transfer through publications and CD ROMs.

The US Internal Revenue Service has recently confirmed the status of the Vetiver Network as a tax exempt Foundation.

10.4 The Benefits

Originally, the lecturer planned to say something about the benefits of vetiver in agricultural and non-agricultural applications. But during the last ten days, the trainees have learned from the lectures, the study tours and the on-the-job training all such benefits that there is no need for the lecturer to repeat those benefits. Thus, he will talk about some other indirect benefits that vetiver can give us. These are: (1) Sustainability, (2) Global Warming, and (3) Free Fertilizers, and (4) New Products from Vetiver.

10.4.1 Sustainability: The big buzzword today is ‘sustainable’. Whatever we do anywhere must be sustainable although the lecturer still have some doubt about the true meaning of the term ‘sustainable’, and whether or not the term ‘sustainable’ itself is sustainable. Almost everyday, millions of dollars are being spent in arguing what is and what is not sustainable. Surprisingly, those which are doing things which they think are sustainable, are not even considering the solid substances that lies at the heart of sustainability. What else other than ‘soil’, where we come from and where we shall return. If one cannot hold onto soil, one cannot hold onto anything. Without stable soil, ‘sustainability’ is just an empty word that will disappear from everybody’s vocabulary. In other words, the term ‘sustainable’ is not sustainable!

Please don’t get the lecturer wrong about his interpretation of sustainability, which by itself is a very valuable concept, and an important challenge. Now, what makes ‘sustainable’ means what it says. It is our old friend, vetiver, a key to unlocking the heart of sustainability. Vetiver can literally make ‘sustainability’ sustainable because it can hold soil. The trainees should recall what the lecturer has just said a minute ago that, “If one cannot hold onto soil, one cannot hold onto anything” (Vietmyer 1997).

With all our dedications, let’s make vetiver sustainable, and the rest will be taken care of by vetiver.

10.4.2 Global Warming: During our ten-day period (20-29 November 2000) in this training course, while we were in the classrooms, participating in on-the-job training and visits, and even enjoyed listening to the many songs and jokes on the coach during our long journey, a large number of people were suffering from flood, landslides, mudslides, in the land not so far from where we are, that is in southern Thailand and northern Malaysia. Hundreds of people died, much more injured, and the loss of their properties is incalculable. It’s another disaster caused by heavy rains. But what is the main reason for such heavy rains. It is the global warming, the El Nino or La Nina, or both which originated as the result of massive deforestation and the release of large amount of CO_2 to the atmosphere, resulting in the greenhouse effect which ultimately ends up in the rise of temperature and several other related phenomena, like heavy rain falls, the melting of polar ice, the rise of mean sea level, etc. Is there a solution to solve this problem or just to mitigate such a disaster. Here again our hero comes, the vetiver. How a simple and humble grass like vetiver can do such a big thing?

Let’s look at a recent publication in ‘Nature’ a few years ago by CIAT scientists who claimed that two grass species in the savannas of South America may remove as much as 2 billion tons of CO_2 - a green house gas - from the atmosphere annually. One of these grasses is *Andropogon guyanus*, a closely related species of vetiver. CIAT researchers said that it stores as much as 53 tons of CO_2 as organic matter per hectare per year. This is because the extensive roots of these grasses deposit the organic matter as deep as one meter in the savanna soil. Just imagine our 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 fullgrown clump of vetiver would absorb at least 5 kg of CO_2 annually. If we could plant just a million clumps of vetiver in your own country, they will absorb 5,000 tons of CO_2. The Doi Tung Development Project alone used to plant 100 million vetiver plants a 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 as emitted by 100,000 cars, each driven 20,000 km. As the annual global increase in atmospheric carbon dioxide 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 around us (Vietmyer 1997; Enoch 1998).

10.4.3 Free Fertilizers: Through several lectures given during the first two days, you must realize that vetiver is not a greedy plant. In fact, it can even grow in the sandy desert in China having no nutrient; it can thrive in acid and alkaline soils, it can absorb toxic substances, pollutants and heavy metals, etc. It can even enrich the soil through the accumulation of organic matter and moisture. But what we have learned from Dr. Settha Siripin of Majo University the other day during our field trip to Chiang Mai that vetiver is actually releasing fertilizer to itself and, sooner or later, becomes available to other plants. These are bacteria and fungi associated with the root system of vetiver that provide nitrogen and phosphorus fertilizers to the vetiver plant through the processes such as nitrogen fixation and phosphate solubilization, producing nitrogen and phosphorus in an available form to plant; and, as we all know, both elements are essential to every plant. In addition, certain associated microorganisms can produce growth hormones, building up organic matter through decomposition by cellulolytic microorganisms, and even kill other pathogenic microorganisms that cause diseases to plants (Siripin 2000).

10.4.4 New Products from Vetiver: Although our main concern in planting vetiver is for soil and water conservation, yet we can make money out of the vetiver plant, either directly through the use of its leaves and culms in handicraft making or other processes such as in making roof thatching, mushroom production, or indirectly through various industrial processing, like the ones we saw at the exhibitions at AIT (essential oils and related products, vetiver pulp, use of vetiver in engineering applications, decorative products from vetiver), Chiang Mai University, Queen Sirikit Botanic Garden (award winning handicraft products), Chiang Rai Land Development Station (handicraft products), and Doi Tung Development Project (handicraft products, vetiver products made from machine weaving, biodegradable vetiver pots, etc.).

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