Carbon Sequestration and Carbon Dioxide Emission in Vetiver Grass Cultivation Areas in Thailand.

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Abstract

Vetiver grass with long root systems and high biomass content not only plays important roles in erosion control but also in carbon sequestration processes that reduce carbon dioxide in the atmosphere. The objectives of this study were to determine the amount of carbon sequestration and carbon dioxide emission from soil in vetiver grass cultivation areas comparing to non-vetiver grass cultivation area and to introduced the obtain data for soil quality improvement and soil and water conservation program. The experimental site was located in Prachuap Khiri Khan Province during the years 2008 - 2010 as part of the *Chai Phatthana-Mae Fa Luang Re-Forestation Project*. Four ecotypes of vetiver grasses were studied: Sri Lanka, Prachuap Khiri Khan, Surat Thani and Roi Et. They were compared to non-vetiver grass cultivation area. Carbon sequestration was calculated from carbon content in vetiver grasses and soil carbon stock. The carbon dioxide emissions from soil were measured monthly by using the closed chamber technique. Soil properties such as soil organic carbon, and moisture were also monitored along with weather conditions. The results show that the biomass accumulation of vetiver grasses harvested was not significantly different amongst the four ecotypes. The highest total biomass (above and underground) yield was observed in Roi Et ecotype and the lowest in Prachuap Khiri Khan ecotype, which were 114.7 and 84.4 tons ha^{-1} respectively. The total of soil carbon stock was higher in vetiver grass cultivation areas than for the non-vetiver grass cultivation areas. Soil carbon stock in vetiver grasses cultivation areas increased from 63.4 to 67.9, 68.7 to 96.8, 62.3 to 81.3 and 57.4 to 71.2 tons C ha^{-1}, respectively, which was in direct contrast to the non-vetiver grass cultivation area in which this parameter decreased from 48.6 to 36.3 tons C ha^{-1}. Considering CO_2 emission rate, the rate of soil CO_2 emission was not significantly different in vetiver cultivation areas compared to non-vetiver grass cultivation areas. The average of CO_2 emission rates in rainy, dry and summer seasons ranged from 593.8-717.7, 313.5-405.6 and 265.9-376.6 mg CO_2 m^{-2}·h^{-1}, respectively. The emission of CO_2 showed a seasonal dependence in which CO_2 emitted from soil to atmosphere was highest in the rainy season and lowest in the dry season. Carbon sequestration of vetiver grasses cultivation areas and non-vetiver grass cultivation areas were 95.6 and 36.3 tons ha^{-1}, respectively. Therefore, this study indicated that vetiver grasses increased carbon sequestration by enhancement of soil organic carbon with subsequent reduction of carbon dioxide in the atmosphere.

Keywords: soil carbon stock, CO_2 flux, soil respiration, carbon cycle, vetiver grass

INTRODUCTION

Soils are now known to be a significant carbon sink and soil carbon sequestration is an important process to mitigation of global warming and climate change. The total terrestrial carbon stock in the soil is estimated to be around 2500 Gt C and in plant and microbial biomass, it is estimated to be 560 and 110 Gt C respectively. The soil carbon pool, which is 3.3 times the size of the atmospheric carbon pool, includes about 1550 Gt C of soil organic carbon and 950 Gt C of soil inorganic carbon (Lal, 2004, 2008; Jansson et al, 2010). Change in land use and activities can lead to changes in the rate of soil carbon dioxide emission due to changes in the rate of soil organic decomposition, and also the rate of carbon sequestration due to changes of biomss production. Both are key processes govering soil carbon balance. Furthermore decrease in soil organic matter results in land degradation. Appropriate soil management therefore should increase the amount of soil organic carbon and reduce emission of CO_2 to the atmosphere.

Carbon sequestration is the process through which carbon dioxide from the atmosphere is absorbed by trees, plants and crops via the process of photosynthesis and subsequently stored as carbon in biomass. Half of the biomass is in the form of carbon and will ultimately be available for decomposition and incorporation into the soil either directly as dead plant material or as organic matter that has passed through the animal food chain (Casper, 2010). Therefore, in order to promote carbon sequestration in soils, the plant needs to have greater potential in carbon assimilation, below-ground biomass accumulation and enhanced growth in varieties of soil textures, soil moisture, soil nutrients, and climate environments.

Recently, interest in utilizing plants with high biomass potential and deep rooting systems has increased for terrestrial carbon sequestration studies (Jansson et al, 2010). Vetiver grass, for example, is a tropical plant that has sticky culms, huge biomass, and long massive roots– characteristics not found generally in plants. In Thailand, vetiver has been widely used for soil conservation and reclamation of degraded land. With such remarkable morphological characteristics and attractive functions such as rapid growth, deep root penetration and strong resistance to adverse conditions, vetiver grasses should present an effective model for sequestering carbon into the 'less disturbed deep soil profile' as to mitigate the effects of CO_2 on global warming.

OBJECTIVES

1) To determine the amount of carbon sequestration and CO_2 emission from soil in vetiver grass cultivation areas comparing to non-vetiver grass cultivation area.
2) To introduce the obtained data for soil quality improvement and soil and water conservation program.

MATERIALS AND METHODS

1. Description of Experiment Sites and Treatment

The study site was located at the Chai Phatthana-Mae Fa Luang Re-forestation Project (581584N/1394964E, 126 m above sea level), Hua Hin District, Prachuap Khiri Khan Province, central of Thailand during the years 2008-2010. The climate is sub humid-tropical with 3 seasons; dry season (November-February), hot season (March-June) and the rainy season (July-October). Mean annual temperature ranges between 22.6 and 33.4 °C, the mean annual rainfall is 937 mm/year and the average annual evaporation rate is 4.4 mm/day. The soil, is classified as coarse-loamy, mixed, superactive, and isohyperthermic Typic Haplustalfs (Soil survey staff, 2006). Pineapple is the primary crop cultivated in this area.

Figure 1 Pictures of study site (left) and soil profile (right)

The experimental design consisted randomized complete blocks with 5 treatments and 3 replications. The 5 treatments were composed of non-vetiver grass cultivation area serve as control and 4 ecotypes of two vetiver species: *Chrysopogon nemoralis* and *Chrysopogon zizanioides*. *Chrysopogon nemoralis* consisted of 2 ecotypes: Prachuap Khiri Khan and Roi Et, whereas *Chrysopogon zizanioides* consisted of the remaining two ecotypes, Sri Lanka and Surat Thani. The 4 vetiver ecotypes were compared to non-vetiver grass cultivation areas. The area of each plot was approximately 4x6 m^2. All vetiver grasses were planted on June 2008 and allowed to naturally grow for 2 years without applying fertilizer or irrigation. After planting, vetiver grasses were cut 5 times, while aged 8 (March 2009), 12 (July 2009), 16 (November 2009), 20 (March 2010) and 24 (July 2010) months, after planting. The dry leaves were added in each plot in the soil for improvement of the physical and chemical properties.

2. Sampling and Analysis of the Vetiver Grasses, Soils and CO_2 Gas

2.1 Vetiver Grass Sampling and Analysis

Vetiver grasses were cut 5 times. The sampling times occurred 8 (March 2009), 12 (July 2009), 16 (November 2009), 20 (March 2010) and 24 (July 2010) months after planting (MAP). In each time, vetiver grasses were sampled (Figure 2) from areas of 1x1 m^2 after harvesting by random sampling in the field. The above- and underground (leaves and roots) were included to determine plant biomass. The sampled of leaves and roots were weighted as fresh weight and then dried in oven at temperature 80 degrees Celsius until dried. The dried sampled were weighted again as a dry weight of each part of biomass. In farm practice, however, biomass of the above- and underground was added in the soil for improvement of the chemical and physical properties.

The samples of the above- and underground were sent to laboratory to analyze by the Walkley and Black method to estimate organic carbon content.

Figure 2 Pictures of vetiver grass cutting and sampling

2.2 Soil Sampling and Analysis

Undisturbed and disturbed soil profile samples (Figure 3) were collected 3 times: before the experiment (June 2008), during the experiment (July 2009), and after the experiment (July 2010) at 15 plots. In each plot, soil samples were collected from the root zone at 3 levels of depth: 0-18, 18-40 and 40-70 cm. The undisturbed soil was taken by using core method to determine bulk density. The soil core samples were dried at temperature 105 degrees Celsius for 2 days. The disturbed soil was taken to estimate soil organic carbon by Walkley and Black method. Soil moisture was determined in every period time of gas sampling collection and analyzed by a gravimetric method. A soil temperature also was measured near the chamber at 5 cm depth. The soil sample were also analyzed approximate the chemical and physical properties. For example, available phosphorus was determined using Bray and Kurt method, exchangeable potassium was estimated by Jackson method and pH was predicted with a glass-electrode pH meter on a 1:1 ratio soil/water suspension of air-dried soil sample.

Soil profiles were studied and described according to U.S. soil taxonomy methodology (Soil survey staff, 2006).

Figure 3 Pictures of Undisturbed (left) and disturbed soil collecting (right)

2.3 Gas Sampling

The CO_2 emission from soil to atmosphere was measured by using a Hand-Held CO_2 Meter (model GM70) fitted with a static closed chamber (Figure 4). The chamber was composed of two parts; chamber base and cover. The chamber was made from PVC with an inner diameter of 20 cm and height of 25 cm (0.031 m^2 surface area covered). At about 3 cm from the top, an O-ring was inserted to facilitate sealing during enclosure by cover. The cover was also made from PVC with compatible size to chamber base. 2 small holes; one for gas sampling and another for inserting thermometer, were open through the cover. The bottom edge of chamber base was inserted approximately 5 cm into the soil. The chamber base was located at 15 selected spots in study site.

Soil CO_2 emission was measured every 15 second for 15 minutes. When soil CO_2 efflux was measured, the chamber cover was gently placed on the top of the base until tightly sealed. CO_2 efflux was recorded once a month from July 2009 to June 2010. The measurements were always conducted between 09:00 hours to 12:00 hours. In during time of CO_2 efflux measurement, soil and chamber temperature were measured with a thermometer. The soil moisture (close to the chamber) was also collected and analyzed by the gravimetric method.

Figure 4 Soil chamber (left) and measurement of CO_2 emission rate by using a Hand-Held CO_2 Meter (right)

3. Carbon Content in Vetiver Grasses and Soil

In vetiver grasses, carbon content was estimated from vetiver grass biomass and organic carbon, which was estimated from the following equation:

$$C_{vetiver} = C_{leaf} + C_{root}$$
$$C_{leaf} = \%OC_{leaf} \times M_{leaf}$$
$$C_{root} = \%OC_{root} \times M_{root}$$

Where $C_{vetiver}$ is Total carbon content (ton ha^{-1}), C_{leaf} and C_{root} are total carbon content in leaf and root (ton ha^{-1}), $\%OC_{leaf}$ and $\%OC_{root}$ are percentage of organic carbon in leaf and root (%) and M_{leaf} and M_{root} are biomass of leaf and root (ton ha^{-1})

In soil samples, carbon content was determined in 3 soil layers; 0-18, 18-40 and 40-70 cm depth by the Walkley and Black method. Total carbon content was calculated by summation of soil carbon of each layer as described by following equation:

$$C_{soil} = C_{0\text{-}18} + C_{18\text{-}40} + C_{40\text{-}70}$$

$$C_{0\text{-}18} = \%OC_{0\text{-}18} \text{ x } D_{0\text{-}18} \text{ x } V_{0\text{-}18}$$

$$C_{18\text{-}40} = \%OC_{18\text{-}40} \text{ x } D_{18\text{-}40} \text{ x } V_{18\text{-}40}$$

$$C_{40\text{-}70} = \%OC_{40\text{-}70} \text{ x } D_{40\text{-}70} \text{ x } V_{40\text{-}70}$$

Where C_{soil} is soil carbon stock of 3 soil layers 0-18, 18-40 and 40-70 cm depth (ton ha^{-1}), $C_{0\text{-}18}$, $C_{18\text{-}40}$ and $C_{40\text{-}70}$ are soil carbon content in each layers; 0-18, 18-40 and 40-70 cm depth (ton ha^{-1}), $\%OC_{0\text{-}18}$, $\%OC_{18\text{-}40}$ and $\%OC_{40\text{-}70}$ are percentage of organic carbon in each layers; 0-18, 18-40 and 40-70 cm depth (%),$D_{0\text{-}18}$, $D_{18\text{-}40}$ and $D_{40\text{-}70}$ are soil bulk density carbon in each layers; 0-18, 18-40 and 40-70 cm depth (g cm^{-3}) and $V_{0\text{-}}18$, $V_{18\text{-}40}$ and $V_{40\text{-}70}$ are soil volume of each layers (m^3 m^{-2}).

4. CO_2 Emission Rate

The CO_2 emission rate is expressed in term of mass per unit area per unit of time (g CO_2 m^{-3} hr^{-1}). Firstly, the mixing ration or concentration obtained from the chamber is converted to a mass or molecular basis using the ideal gas law, thus depending on temperature and pressure of the enclosed air as shown in equation;

$$\text{Ci} = \frac{qiMP}{RT}$$

Where Ci is mass per volume concentration (mg CO_2 m^{-3}), qi is volume per volume concentration (m^3 m^{-3}), M is molecular weight of CO_2 (44 g mol^{-1}) P is atmospheric pressure (1 atm), R is gas constant (8.2058×10^{-5} $m^3.atmK^{-1}$ mol^{-1}) and T is average temperature inside the chamber (K)

Normally, linear regression has been proposed to describe the relationship between gas and time. The first few minute during the measurements were discarded from the regression to avoid any caused by closing of the chamber. Only the data showing a linear increase in CO_2 concentration were used to calculate the emission rate. Thus, the CO_2 emission rate (F) was calculated using linear portion of gas concentration change over time following equation (Hutchinson and Mosier, 1981) as:

$$F = \frac{V}{A}\frac{\Delta \text{Ci}}{\Delta t}$$

Where F is emission rate (mg CO_2 m^{-2} h^{-1}) V is the volume of chamber (m^3), A is surface area of the chamber (m^2) and $\frac{\Delta \text{Ci}}{\Delta t}$ is the increase of CO_2 concentration in the chamber as the function of time (mg m^{-3} hr^{-1}) and determined from linear regression of CO_2 concentration changing with time during the measurement period.

RESULTS AND DISCUSSION

1. Soil Characteristics

Soil was classified as Coarse-loamy, mixed, superactive and isohyperthermic Typic Haplustalfs (Soil survey staff, 2006). The soil profile was divided into 5 main layers within a 160 cm depth. These consisted of A_p (0-18 cm), BA (18-40 cm), Bt1 (40-70 cm), Bt2 (70-120 cm) and Bt3 (120-160 cm). Table 1 shows the results of physical and chemical soil properties. The physical properties included soil texture, bulk density and soil moisture. The texture of the A_p layer was loam and of the other layers were gravelly loam. The bulk density (Db) was between 1.4-1.6 g cm^{-1}. The soil moisture (SM) percentage values were 15.8 in both A_p and BA layers, and decreased as soil depth increases. The chemical properties consisted of soil pH, organic matter (OM), phosphorus (P) and potassium (K) content. Soil reactions were more basic than neutral (pH 7.6-8.3), however in the case of the Bt3 layer that was acidic (pH 5.2). Soil OM, P and K were at the maximum value in the topsoil and then decreased with increasing soil depth. Soil fertility was identified as low to moderate.

Table 1 Some physical and chemical properties of soils collected from the study site

Soil Depth (cm)	**Soil texture**	**Db (g cm^{-3})**	**SM (%)**	**pH (1:1 H_2O)**	**OM (%)**	**P (mg kg^{-1})**	**K (mg kg-^{1})**
0-18 (A_p)	loam	1.6	15.8	7.7	1.24	35	145
18-40 (BA)	gravelly loam	1.6	15.8	7.6	1.07	15	155
40-70 (Bt1)	gravelly loam	1.4	15.7	8.0	0.71	6	61
70-120 (Bt2)	gravelly loam	1.5	12.4	8.3	0.76	7	89
120-160 (Bt3)	gravelly loam	1.5	7.7	5.2	0.34	4	42

2. Biomass Input to Soils

The samples of vetiver grasses were collected 5 time increments of; 8, 12, 16, 20 and 24 months after planting. The biomass; aboveground and belowground, accumulation at each is shown in Table 2. It can be noted that biomass accumulation of 4 ecotypes of vetiver grass harvested were not significantly different. The highest total biomass yield was observed in the Roi Et ecotype and the lowest in the Prachuap Khiri Khan ecotype, which were 114.7 and 84.4 tons ha^{-1} respectively.

The result of the total organic carbon from the biomass did not significantly differ among the 4 ecotypes of vetiver grass (Table 2). The highest total organic carbon was observed in the Roi Et ecotype and the lowest in the Prachuap Khiri Khan ecotype as following to total biomass yield which were 51.9 and 37.6 tons ha^{-1}, respectively. The biomass of vetiver grasses, incorporated into the soil after each harvesting time, was considered as carbon input into soil and must be included in soil carbon budget. Jansson et al. (2010) reported that plants can perform an important function as carbon sinks by capturing atmospheric CO_2 and storing large amounts of organic carbon in above and belowground biomasses. This is particularly relevant for perennial trees and herbaceous plants with extensive root systems and other characteristic of plants. For example, Khanema (2009) studied the internal leaf structure, phytolithic abundance and chemical components in vetiver grasses. Vetiver grass is able to gain high photosynthetic capacity and great gas circulation through confirmations of Kranz structure and large intercellular spaces, respectively. The structure in phytolith, for example, can stabilize carbon. The results showed that vetiver grasses have a high potential for carbon sequestration.

Table 2 Biomass accumulation (DW) and organic carbon (OC) of vetiver grasses (ton ha^{-1}) collected in 5 time increments of; 8, 12, 16, 20 and 24 months after planting.

Ecotypes	**Biomass Accumulation and Organic Carbon of Vetiver Grasses (tons ha^{-1})**											
	8 MAP*		**12 MAP**		**16 MAP**		**20 MAP**		**24 MAP**		**Total**	
	DW	**OC**	**DW**	**OC**	**DW**	**OC**	**DW**	**OC**	**DW**	**OC**	**DW**	**OC**
Non-Vetiver grass	-	-	-	-	-	-	-	-	-	-	-	-
Sri Lanka	8.9	3.9	27.3	13.3	21.1	9.4	9.5	4.1	24.6	10.9	91.4	41.6
Surat Thani	3.5	1.6	18.9	9.1	15.8	7.0	7.1	3.0	45.6	20.4	90.9	41.1
Prachuap Khiri Khan	6.1	2.1	19.5	9.4	16.9	7.5	10.7	4.6	31.2	13.9	84.4	37.6
Roi Et	7.2	3.1	28.0	13.6	27.2	12.1	9.1	3.8	43.3	19.4	114.8	51.9

3. Change in Soil Carbon Stock

The total soil carbon content was evaluated at 70 cm depth and was collected before, during and after the experiments. Using the bulk density and the soil organic carbon as mention above, the soil carbon stocks were estimated and shown in Table 3. It showed that, in vetiver grass cultivation areas, soil carbon stocks for the 4 ecotypes increased from 63.4 to 67.9, 68.7 to 96.8, 62.3 to 81.3 and 57.4 to 71.2 tons C ha^{-1}, respectively. The performance of the non-vetiver grass cultivation area, in stark contrast, decreased from 48.6 to 36.3 tons C ha^{-1}. The data revealed two trends. First, that the amount of soil carbon is significantly less in controls than in any of the 4 ecotypes; and secondly, that the non-vetiver grass cultivation area showed a reverse trend in soil carbon sequestration. When considering management activity to sequester carbon in soil, it indicates that soil management with mixed plant biomass (both above- and belowground) with soil has a result in enhancing organic carbon accumulation in soil. Live roots are also considered as carbon biomass, this compartment can contribute the greater part of soil carbon (FAO, 2001). In contrary, without plant input to the soil organic carbon losses were observed**.** Khanema (2009) studied about the potential of carbon sequestration of various vetiver ecotypes after continuous cultivation of vetiver grass for 1, 2, 3, 5 and 7 years and reported that levels of the soil organic carbon increased significantly due to continuous vetiver cover. Khanema found that the mean carbon storage levels in the soil at 120 cm depth were 23.63, 28.62, 66.30, 28.68 and 228.90 tons ha^{-1} for the 1, 2, 3, 5, to 7 year site, respectively. Therefore, after continuous vetiver plantation for 7 years, the carbon storage at 120 cm increased approximately 10 times. Fisher et al. (1994) stated that replacement of the native tropical savanna with productive, deep-rooting exotic grasses results in a significant soil organic carbon increases for several years (800 to 1300 g C m^{-2} y^{-1} over the first 3 to 6 years). Neil et al. (1997) studied in eleven of fourteen pasture sites in Brazil. The result showed that amount of soil carbon is increase with rates as high as 74.0 g C m^{-2} y^{-1} over 20 years. Substantial gains or losses in soil organic carbon are also possible with the conversion of the land and activities that management for enhanced soil productivity (Post and Kwon, 2000; Marland et al., 2004).

Table 3 Soil carbon stock (ton ha^{-1}) at 70 cm soil depth which collected before, during and after the experiment

Ecotypes	Soil Carbon Stock (tons ha^{-1})		
	Before the experiment	**During the experiment**	**After the experiment**
Non-Vetiver Grass	48.6	49.8	36.3
Sri Lanka	63.3	65.5	67.9
Surat Thani	68.7	69.3	96.8
Prachuap Khiri Khan	62.3	54.3	81.3
Roi Et	57.4	58.6	71.2

4. CO_2 Emission from Soil

CO_2 emissions were measured in vetiver grass and non-vetiver grass cultivation areas. To investigate the influences from the environmental factors, data of the monthly rainfall and air temperature were obtained from a meteorological site near by the Chai Phatthana-Mae Fa Luang Re-forestation Project. Soil moisture and soil temperature were measured in all plots along with gas emission levels (Figure 5). The range of soil moisture percentages and rainfall in rainy season are shown to be 7.6-11.7 % and 74-174 mm, respectively. During the dry and summer seasons, soil moisture percentages ranged from 1.6-7.6 and 2.4-6.2 % and the range of monthly rainfalls were 0-12 and 34-136 mm, respectively. For the average maximum soil temperature at 5 cm soil depth ranged from 28-34 degree Celsius, which ranged from 28-30, 30-33 and 32-34 degree Celsius in the rainy, dry and summer seasons

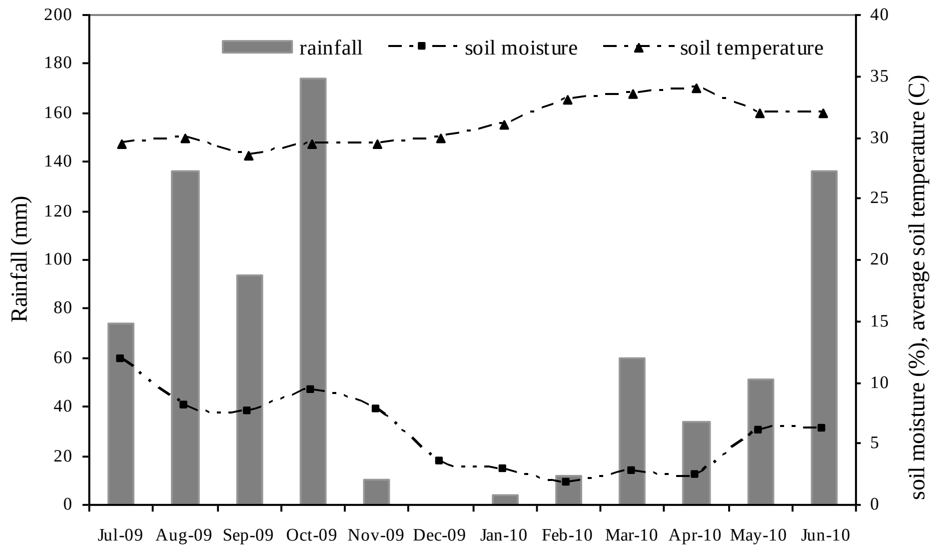

Figure 5 Monthly rainfall, average soil moisture and soil temperature at study site from July 2009 to June 2010.

Across all plots, it was found that emission rates of CO_2 were not significantly different in vetiver grass cultivation areas compared with non-vetiver grass cultivation areas although the trend of CO_2 emissions in vetiver grass cultivation areas was higher than in non-vetiver grass cultivation areas (Figure 6). The highest average of CO_2 emissions was recorded during September to October (727.6-758.4 mg CO_2 m^{-2} h^{-1}) and lowest average of CO_2 emissions was recorded during January to February (181.2-195.2 mg CO_2 m^{-2} h^{-1}).

The average of CO_2 emission in vetiver grass cultivation and non- vetiver grass cultivation areas were compiled for the three seasons. The values for the rainy season (July to October), dry season (November to February) and summer season (March to June) ranging from 593.8-717.7, 313.5-405.6 and 265.9-376.6 mg CO_2 m^{-2} h^{-1} respectively. Seasonal variation in CO_2 emission rate was related to soil moisture and monthly rainfall. The results clearly show that CO_2 emission rate varied with season. The results corresponded to other experiments (Lichaikul et al, 2006; Panuthai, 2007; Watcharathai, 2008) in both forest and agriculture land in Thailand, which reported that the highest average of CO_2 emissions occurred during the rainy season (August to October) and lowest in during the dry season (January to March). Salimon et al (2004) studied in CO2 flux from soil in pastures and forests in southwestern Amazonia. The results shown that the highest fluxes at all sites were observed during the rainy season (November to May). The lowest fluxes were observed in August which was one of the driest months. The same seasonal trends were observed by Davidson et al. (2000) in forests and pastures. CO_2 emission increased sharply between the August and September sampling dates, corresponding to the transition from dry to wet seasons, when both precipitation and air temperature increased.

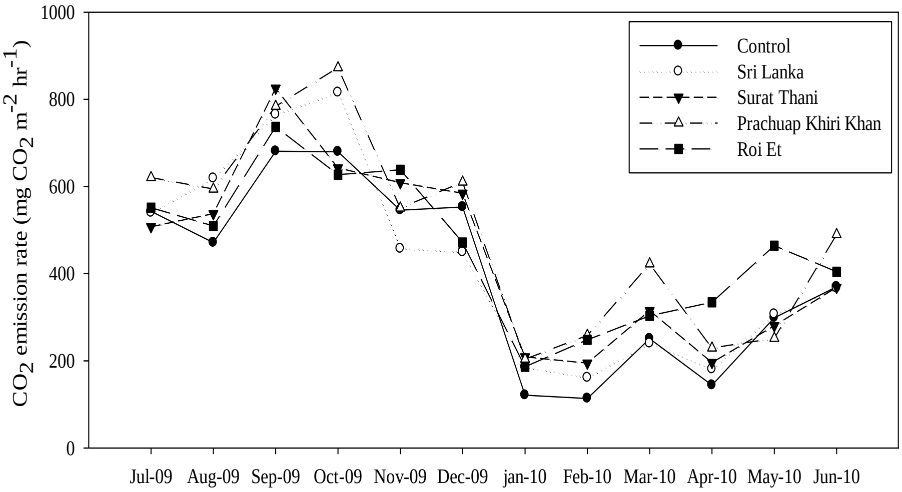

Figure 6 Average CO_2 emission rate from vetiver grass cultivation areas and non-vetiver grass cultivation area from July 2009 to June 2010.

Soil emission rate has been known to be affected by environmental factors. Temperature and soil moisture are the most important factors regulating the rate of soil emission. The relationship (Figure 7a) between CO_2 emission and soil moisture was found in positive relation (R^2 = 0.63). Higher CO_2 emission occurred during the rainy season, particularly with higher soil moisture content. On the other hand, lower CO_2 emissions occurred in the dry and summer seasons with lower soil moisture content. Rastogi et al. (2002) point out that soil moisture content affects soil respiration and hence CO_2 evolution. An increase in moisture content is assumed to cause an increase in respiration (Ouyang and Zheng, 2000). However, CO_2 emissions from the soil surface related to microorganism activities in soil and therefore fluctuates over time and locality (Rastogi et al., 2002; Limthong et al., 2008)

Soil temperature also plays a key role in soil emission rates (Kirschbaum, 1995). In the rainy season, soil temperature was lower than in the dry and summer seasons but the CO_2 emissions were higher. There was a trend for a negative relationship between soil CO_2

emission and soil temperature (Figure 7b). According from the results, the highest fluxes observed in all plots occurred during the rainy season with peaks in September and October. The lowest fluxes occurred in January and February, the driest months. Craine and Wedin (2002) found that the soil temperature effect explained the variation observed for soil CO_2 emission, the negative relationship between soil CO_2 flux and soil temperature over the 20 °C variation in soil temperature (10 cm depth). The data correlated well with that of Rastogi et al. (2002) who reported that at higher temperature inhibition of microbial respiration due to inactivation of biological oxidation systems.

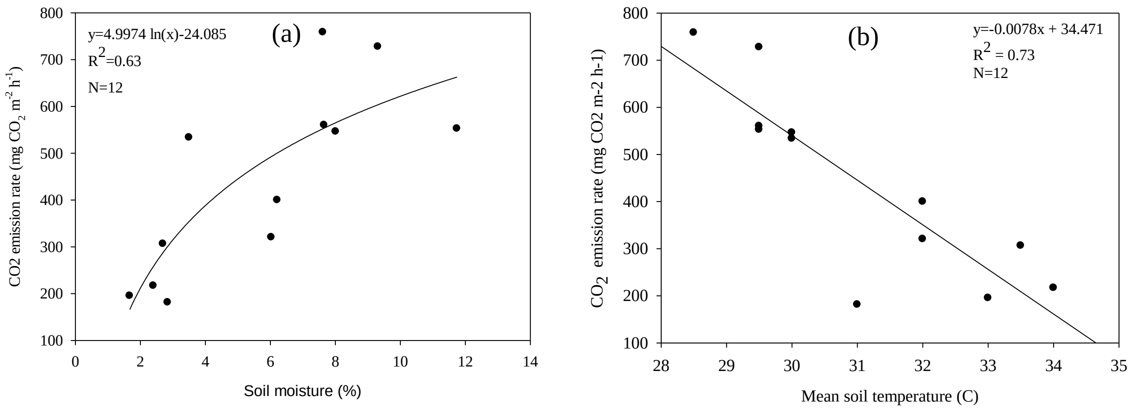

Figure 7 Regression between CO_2 emission from soil and soil moisture content (a) and mean soil temperature (b)**.** Data extracted from study sites and dates of sampling from July 2009 to June 2010.

5. Carbon Sequestration

Carbon sequestration of vetiver grasses and non- vetiver grass cultivation areas were estimated and summarized in Table 4. The total carbon sequestration in non-vetiver grass cultivation area was found to be 36.3 tons ha^{-1}, which was amount of soil carbon stock (70 cm soil depth) at 24 months after planting.

In contrary, total carbon sequestration in 4 ecotypes of vetiver grass cultivation area; Sri Lanka, Surat Thani, Prachuap Khiri Khan and Roi Et were 78.8, 117.2, 95.2 and 90.6 tons ha^{-1}, respectively, which was separated into carbon sequestration in plan, biomass was estimated as carbon sequestration in the area, and in soil. Carbon sequestration in vetiver is carbon content of each vetiver grass at 24 months after planting.

Table 4 The Carbon sequestration of vetiver grass and non- vetiver grass cultivation areas

Ecotypes	**Carbon sequestration (tons ha^{-1})**		
	Plant organic carbon*	**Soil carbon stock****	**total**
non-vetiver grass	-	36.3	36.3
Sri Lanka	10.9	67.9	78.8
Surat Thani	20.4	96.8	117.2
Prachuap Khiri Khan	13.9	81.3	95.2
Roi Et	19.4	71.2	90.6

* Carbon content in vetiver grass 4 ecotypes at 24 months after planting
**Soil carbon stock at 24 months after planting

The results show that carbon sequestration in vetiver grass cultivation areas was significantly higher than non-vetiver grass cultivation areas by two-three times. It presented that area covered with vetiver grasses can gain amount of carbon content not only in its biomass but also in its soil. It correspond to FAO (2001) that reported that the main ways to achieve an increase in organic matter in the soil is through conservation agriculture, involving to a largely continuous protective cover of living or dead vegetal material on the soil surface. Reeder et al. (2001) found the same result when they studied the effects of grazing management strategies over 12 years on carbon distribution and sequestration. They concluded that all types of grazing treatments increased the levels of carbon 6-9 tons ha^{-1} within 15 cm of the soil surface. Increased soil carbon with grazing is likely due to increased in carbon cycling from aboveground plant residues seeping and redistribution of carbon within the plant: soil, system due to changes in the plant community composition (Schuman et al., 1999). The result of this study could be summarize that vetiver grass and management had influence on level of soil carbon stock and carbon sequestration of that area

CONCLUSION

Climate change is one of the environmental concerns throughout the world. CO_2 is the main greenhouse gases that contribute to the current global warming. Understanding in CO_2 dynamics is crucial. Carbon sequestration in terrestrial such as carbon in biomass (trees, plants, crops) and soils contain large portion of the global carbon pool, the carbon flux from soil emission is one of the pathways responsible to the release of CO_2 to the atmosphere. On the global scale, agricultural and forestry activities can be both the accumulation of greenhouse gases in our atmosphere, as well as be used to help prevent climate change, by avoiding further emissions and by sequestering additional carbon. In generally, small change in these processes could potentially result in large change of global carbon cycle.

There are two main objectives of this study: 1) to investigate the amount of carbon sequestration and carbon emission under vetiver grasses and non-vetiver grass cultivation areas and 2) to introduce the obtained data for soil quality improvement and soil and water conservation program. The experiment was conducted in the Chai Phatthana-Mae Fa Luang Re-forestation Project, Prachuap Khiri Khan Province during the year 2008-2010. The results show that the biomass accumulation of vetiver grasses harvested was not significantly different amongst the four ecotypes. The highest total biomass (above and underground) yield was observed in Roi Et ecotype and the lowest in Prachuap Khiri Khan ecotype, which were 114.7 and 84.4 tons ha^{-1} respectively. The total of soil carbon stock was higher in vetiver grass cultivation areas than for the non-vetiver grass cultivation areas. Soil carbon stock in vetiver grasses cultivation areas increased from 63.4 to 67.9, 68.7 to 96.8, 62.3 to 81.3 and 57.4 to 71.2 tons C ha^{-1}, respectively, which was in direct contrast to the non-vetiver grass cultivation area in which this parameter decreased from 48.6 to 36.3 tons C ha^{-1}. Considering CO_2 emission, the rate of soil CO_2 emission was not significantly different in vetiver cultivation areas compared to non-vetiver grass cultivation areas. The average of CO_2 emission rates in rainy season, dry season and summer season ranged from 593.8-717.7, 313.5-405.6 and 265.9-376.6 mg CO_2 $m^{-2} \cdot h^{-1}$, respectively. The emission of CO_2 showed a seasonal dependence in which CO_2 emitted from soil to atmosphere was highest in the rainy season and lowest in the dry season. Temporal variability in soil CO_2 emission was regulated by soil temperature and moisture content. Carbon sequestration of vetiver grasses cultivation areas and non-vetiver grass cultivation areas were 95.6 and 36.3 tons ha^{-1}, respectively. Therefore, this study indicated that vetiver grasses increased carbon sequestration by enhancement of soil organic carbon with subsequent reduction of carbon dioxide in the atmosphere.

As mentioned earlier, CO_2 is the most important amongst the greenhouse gases. While nations effort to lower the greenhouse gas emissions at source, consequent efforts must be made to enlarge the sinks of these gases. The carbon sequestration is one of the active means by reducing CO_2 in the atmosphere. Soil management strategies for carbon sequestration include in several approaches such as management of soil to maintain higher than existing levels of soil organic matter and enlarged soil organic matter pools by improving soil fertility. These strategies are involve about accumulating organic carbon in vegetation and in soil, if suitable plants are grown along with proper soil conservation measures. Another approach could be to increase the soil organic pool, is increase of sub-soil organic carbon. Sub-soil organic carbon can be increased by growing deep-rooted plants. Therefore, the massive root system, deep root penetrate to soil and high biomass of vetiver has presented itself as an effective candidate for storing the captured carbon into the soil profile. Thus vetiver grasses can dramatically enhance general soil quality by improving soil quality, as well as sequestration of carbon. So that, the obtain data from this study was transferred to soil and water conservation program and used to soil quality improvement by introduced the concept to agricultural land in Thailand.

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