CORRELATION BETWEEN VETIVER ROOT BIOMASS WITH SOIL ORGANIC CARBON AND CO_2 EMISSION IN AGRICULTURAL AREAS OF THE SOUTHERN PART OF THAILAND

K. Wattanaprapat, K. Kanjanathanaset I. Meesing and P. Nopmalai
Land Development Department, Chatuchak, Bangkok 10900, Thailand
E-mail: kamalapa_w@hotmail.com

ABSTRACT

The relationship and correlation of vetiver root biomass with soil organic carbon and CO_2 emission in the agricultural areas of the southern part of Thailand was studied and carried out at the Land Development Station, Surat Thani province in 2008-2010. The objectives of this experiment are compare root growth and biomass of 6 ecotypes of vetiver grass, changes in soil organic carbon and CO_2 emissions from the soil surface, and estimate the correlation between such factors to study changes of soil carbon stock. The experimental design was a randomized complete block design (RCBD) consisting of a control (no vetiver planted) compared with 4 ecotypes of *Chrysopogon zizanioides* and 2 ecotypes of *C. nemoralis.* The result showed that the vetiver root length of the 6 ecotypes were not different and had an average root length of 54.06-58.60 cm. The root length remained constant between 8 months and 24 months during this experiment. The root biomass changes followed a similar pattern to that of root length with no significant differences between 8 and 24 months. The average organic carbon content in the roots is in range of 3.98-5.16 t ha^{-1}, and Prarat Chatan ecotype has the highest average organic carbon content at 5.16 t ha^{-1}. The organic carbon content in the roots at 8 months are significantly different between the 6 ecotypes, but are not different at 12, 16, 20 and 24 month time periods. Soil bulk density increases with the depth of the soil from 15 to 50 cm. This means that soil compaction increases as soil depth increases. Vetiver planting in the soil clearly promotes bulk density decreases, and soil bulk density is highly correlated with root biomass. This negative relationship is Y = -1.629X + 2.774 (R^2 = 0.77). Additionally soil bulk density is the one factor to regulate root length and biomass because of soil compaction. The soil organic carbon content in the soil surface layer (0-15 cm) is higher than in the deeper layer of this soil. Planting vetiver clearly encourages increases in soil organic carbon, especially in subsoil levels 15-30 and 30-50 cm. The correlation between soil organic carbon with CO_2 emissions from the soil surface is positive as Y = 329.2X + 92.06 (R^2 = 0.734). This relationship shows that increasing amounts of soil organic carbon promotes CO_2 emission from the soil surface. Moreover, the correlation between root biomass and CO_2 emission is Y = 30.36 + 276.0 (R^2 = 0.736). Assessment of carbon stocks in the soil where the six vetiver ecotypes were planted versus the control with no vetiver planted, shows that the amount of soil carbon stock is lost in the control plot equal to -4.19 t ha^{-1}. But in the vetiver plots, the amount of carbon stock increased by +2.44 to +6.38 t ha^{-1}, especially under the Prarat Chatan ecotype treatment that has the highest soil carbon stock increase at 6.38 t ha^{-1}. The high correlation between root biomass with the amount of carbon stock is positive as Y = 0.703X + 2.641 (R^2 = 0.832).

Keywords: Vetiver grass, root biomass, soil organic carbon, soil carbon stock, CO_2 emission, correlation between vetiver root biomass with soil organic carbon and co_2 emission

INTRODUCTION

The degradation of soil resources is very important problem in agricultural sector of Thailand, which soil loss and erosion is the main factor effect to decrease of soil fertility and productivity. Soil and water conservation measure play the important role to prevent such soil loss and erosion in slopping agricultural area. Then application of vetiver grass for soil and water conservation is a measure to solve such problem. Moreover, environmental degradations are also the important problem of Thailand which are the effects of socio-economic and environmental changes. In addition, the activities of forest encroachment and land uses changes will accelerate in increasing green house gas emission and global climate changes. Therefore the carbon sequestration into soil is very obviously necessary process to decrease green house gas. Appropriate soil management do highly affect to increase soil carbon storage and decrease CO_2 gas emission from soil surface, and soil carbon storage by plant is an important process. Plant drive photosynthesis process by absorbs CO_2 from the air and converts to organic carbon in its cellular tissue of plant. The residue of plant, including root part in soil, will be decomposed by microorganism and some part of carbon will release from soil surface as CO_2 emission and the main part is stored into the soil. However, root system of plant should has mechanism in regulate carbon cycling in soil.

This research has realized the important role of vetiver grass to accumulate carbon into the soil. Since root of vetiver grass has a special characteristic, perennial plant with long leaves when cutting easily germinates new leaves, and vetiver grass propagates by tiller. So cutting of vetiver leaves and mulching on soil surface every 3–4 months will continuously stimulate germination of new tiller of vetiver. Consequently, in growing period it produces the high amount of biomass in both leave and stem above ground, and root in underground. Besides, its long and thick root system is another special characteristic to accumulate carbon into the soils. In addition, vetiver grass is a plant that Land Development Department has promoted and extended farmers to grow for soil and water conservation. However, vetiver grass will be utilized to grow in soil both in agricultural and non–agricultural areas.

The relationship and correlation of vetiver root biomass with soil organic carbon and CO_2 emission in the agricultural area of the southern part of Thailand was studied and carried out at the Land Development Station, Surat Thani province in 2008-2010. The main objective of this research work emphasized comparison of root growth and biomass of 6 ecotypes of vetiver grass, changes in soil organic carbon and CO_2 emissions from the soil surface, and estimate the correlation between such factors to study changes of soil carbon stock. And the importance matter is to clarify the accumulation of soil carbon in condition, where it planted with vetiver grass and observed the importance role of vetiver root in soil. In general, soil management by using organic fertilizer, incorporate of green manure and plant residue will increase soil carbon stock even some part of carbon in that soil should release CO_2 from soil surface. In case of vetiver plantation in this experiment also try to clarify the net soil carbon stock in treatment where vetiver was planted in this soil.

MATERIAL AND METHODS

1. Description of Experiment Sites and Treatment

The study site was carried out at Surat Thani Land Development Station, Kanchanadit district, Surat Thani Province during year 2008-2010. The studied soil is Phatthalung soil series. Its characteristic is fine loamy, loam, 0-2% slope, deep profile, moderately low to low drainage, low infiltration and water runoff, loamy to clay loam texture. The original soil fertility is low and decreasing as soil depth. (Soil survey staff, 2006)

Figure 1 Soil profile of Phatthalung soil series

Figure 2 The experimental plot at Surat Thani Land Development Station

The experimental design was randomized complete block design (RCBD) consisting of 7 treatments and 3 replication. The treatments consist of non-vetiver grass cultivation area (control) and 6 ecotypes of two vetiver species; *Chrysopogon zizanioides* and *C. nemoralis*. And *C. zizanioides* consists of 4 ecotypes; Sri Lanka, Surat Thani, Songkla 3 and Prarat Chatarn, in case of *C. nemoralis* consists of 2 ecotypes; Prachuab Khirikhan and Roi Et. Vetiver grass was planted with spacing 50x50 cm in plot size 4x6 m^2 without applying fertilizer. Leaves were cut and mulched on soil surface every 4 months for 5 times, and the first cutting was at 8 months of this experiment.

2. Data Collecting

Soil samples were collected from each experimental plot as composite sampling in each plot at 3 soil depth: 0-15, 15-30 and 30-50 cm. The soil samples were collected before experiment and every 4 months for 2 years, and determined some physical and chemical of soil properties such as organic carbon content and soil bulk density. Undisturbed soils were collected by core method.

Figure 3 Soil sampling and collecting of undisturbed (left) and disturbed soil (right)

Vetiver grasses were sampled and collected as leaves and roots part in 1 clump in each plot. Root length and biomass of root and leaves were measured. The samples were oven dried at 70^{o}C for 24-72 hr until the weight was stable. Dried samples of leave and root were separated collection and measured and determined organic carbon content in laboratory.

Figure 4 Sampling of root biomass of vetiver grasses in the experimental plot

Gas emission (CO_2) sampling from the soil surface was measured by using portable CO_2 meter (model GM70, as showed in Figure 5) with a static closed chamber. The chamber composed of two parts including chamber base and cover. The chamber was made from PVC with an inner diameter of 20 cm and height of 25 cm. The chamber base was setted up at the selected area in all plots. CO_2 emission from soil surface was measured in the closed chamber every 15 seconds for 15 minutes. The CO_2 efflux was recorded once a month for 2 years of this experiment. Meanwhile, soil CO_2 measurement, the temperature of soil and closed chamber was also measured by portable thermometer.

Figure 5 Gas chamber for sample collection (left) and measurement of CO_2 emission rate by portable CO_2 meter (right)

Estimation of total amount of organic carbon from vetiver root was derived from organic carbon content of root (%) multiply by dry weight of root biomass are as follow, $C_{root\ vetiver}$ = OC x Biomass, When OC is organic carbon content (%), biomass is dry weight of vetiver root (t ha^{-1}). In case of estimation of soil carbon stock was calculated from summation of soil organic carbon content in 3 layers of soil depth; 0-15, 15-30 and 30-50 cm. In each layer, total amount of organic carbon is derived from soil organic carbon content multiply by bulk density and volume of soil. When C_{soil} is soil carbon stock (kg C m^{-2}), OC is soil organic carbon (%), D is soil bulk density (g cm^{-3}) and V is soil volume/area (m^3) as described by following equation;

$$C_{0-15} = OC_{0-15} \times D_{0-15} \times V_{0-15}$$
$$C_{15-30} = C_{15-30} \times D_{15-30} \times V_{15-30}$$
$$C_{30-50} = OC_{30-50} \times D_{30-50} \times V_{30-50}$$
$$C_{soil} = C_{0-15+} C_{15-30} {+}C_{30-50}$$

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;

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

When 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, CO_2 emission rate (F) was calculated using linear portion of gas concentration change over time as following equation (Hutchinson and Mosier, 1981);

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

When F is emission rate (mg CO_2 m^{-2} hr^{-1}), V is the volume of chamber (m^3), A is surface area of the chamber (m^2) and $\Delta Ci/\Delta t$ 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. Root Length

Vetiver root length of 6 ecotypes planted on Phatthalung fine loamy, Surat Thani Land Development Station, throughout of the experiment was determined at 8, 12, 16, 20 and 24 months. The results of this experiment indicated that vetiver root length of 6 ecotypes were not significantly different with average length 54.06-58.60 cm. And ecotype Songkla 3 had a trend of the highest root length 58.60 cm. However, all vetiver types at 8 months of plantation had the highest root length 57.3-71.0 cm. as showed in Table 1. In addition, the vetiver root was very difficult to collect all of root sample in the natural soil as especially in this experiment. So the root length was not long as descript in previous report, which it depended on method of root sample collection, soil bulk density, soil texture and also soil nutrient.

Table 1 Vetiver root length (cm) at 8, 12, 16, 20 and 24 months after planting

Ecotype	Time (month)					average
	8	12	16	20	24	
Sri Lanka	70.3	54.3	48.3	52.7	48.3	54.78
Surat Thani	57.3	57.7	53.3	51.3	50.7	54.06
Songkla 3	71.0	55.3	59.0	54.7	53.0	58.60
Prarat Chatarn	59.0	59.7	53.0	53.3	51.0	55.20
Prachuab Khirikhan	61.0	59.7	44.7	57.7	49.3	54.48
Roi Et	61.3	61.0	58.0	58.0	46.0	56.86
F test	ns	ns	ns	ns	ns	-

ns - non significant

2. Biomass and Organic Carbon Content in Vetiver Roots

2.1 Root Biomass (dry weight)

Results indicated that at age of 8 months, Prarat Chatarn produced the highest biomass 15.71 t ha^{-1}, that was significantly different from the remaining. *Chrysopogon zizanioides* such as Sri Lanka, Surat Thani and Songkla 3 produced root biomass in range of 9.98-11.32 t ha^{-1} and was greater than *Chrysopogon nemoraris*. As C. *nemoraris* such as Prachuab Khirikhan and Roi Et produced moderately low of root biomass 9.11 and 6.24 t ha^{-1} respectively. However, accumulation of root biomass along 12 months, there were not significant difference in each ecotype. And root biomass of these ecotypes was in range of 7.63-11.07 t ha^{-1}. And Prachuab Khirikhan, Surat Thani and Songkla 3 had a trend of biomass higher than Prarat Chatarn, Sri Lanka and Roi Et. All vetiver types in these intervals at 16, 20 and 24 months produced root biomass insignificant difference with in range of 9.23-14.22, 7.68-11.05 and 7.87-11.07 t ha^{-1} respectively. At 16 months, Roi Et produced the highest biomass and Surat Thani was the lowest, but at 20 months, Prarat Chatarn produced the highest biomass and Songkla 3 was the lowest. And at 24 months of this experiment, Prachuab Khirikhan, Surat Thani, Songkla 3 and Prarat Chatarn produced the high biomass as the same trend but Sri Lanka was the lowest as showed in Table 2.

Table 2 Biomass of vetiver grasses root (t ha^{-1}) at 8,12,16,20 and 24 months after planting

Ecotype	Time (month)					average
	8	12	16	20	24	
Sri Lanka	11.32 b	7.63	10.09	8.86	7.87	9.15
Surat Thani	9.98 bc	10.73	9.23	8.24	10.73	9.78
Songkla 3	10.16 b	10.65	11.39	7.68	10.65	10.11
Prarat Chatarn	15.71 a	9.58	11.78	11.05	9.82	11.59
Prachuab Khirikhan	9.11 bc	11.07	10.83	7.88	11.07	9.99
Roi Et	6.24 c	8.73	14.22	9.48	8.73	9.48
F test	**	ns	ns	ns	ns	-

ns - non significant
** - significant at $p < 0.01$

2.2 Organic Carbon Content in Vetiver Roots

In case of organic carbon content in vetiver root at 8 months, the results showed that 6 ecotypes accumulate organic carbon content in range of 2.63-7.00 t ha^{-1}. Prarat Chatarn produced the highest amount of organic carbon in vetiver root 7.00 t ha^{-1}. There was highly significant difference from other ecotypes. The followings were Sri Lanka, Surat Thani and Songkla 3 with insignificant difference of 4.92, 4.63 and 4.59 t ha^{-1} respectively. It obviously indicated that at 8 months of *C. zizanioides* can accumulate organic carbon content in root greater than *C. nemoralis.*

However, amount of organic carbon storage in root of each ecotype at 12, 16, 20 and 24 months was not significantly different in range of 3.32-5.08, 4.28-6.01, 3.47-4.92 and 3.42-5.08 t ha^{-1} respectively. Organic carbon content in root part alters as root biomass. During 2 years experiment it was found that ecotype Prarat Chatarn produces the highest amount of organic carbon 5.16 t ha^{-1} as showed in Table 3.

Table 3 Organic carbon (OC) of vetiver grasses root (t ha^{-1}) at 8,12,16,20 and 24 months after planting

Ecotype	Time (month)					average
	8	12	16	20	24	
Sri Lanka	4.92 b	3.32	4.39	3.85	3.42	3.98
Surat Thani	4.63 b	4.98	4.28	3.82	4.98	4.54
Songkla 3	4.59 b	4.82	5.15	3.47	4.82	4.57
Prarat Chatarn	7.00 a	4.26	5.25	4.92	4.37	5.16
Prachuab Khirikhan	4.17 bc	5.08	4.96	3.61	5.08	4.58
Roi Et	2.63 c	3.69	6.01	4.00	3.69	4.00
F test	**	ns	ns	ns	ns	-

ns - non significant
** - significant at $p < 0.01$

3. **Soil Properties Changes**

3.1 Soil Bulk Density

At beginning of the experiment, soil bulk density at soil depths 0-15, 15-30 and 30-50 cm were in range of 1.59-1.68, 1.50-1.64 and 1.64-1.71 g cm^{-3} respectively. And after 2 years of this experiment, the control plot (no vetiver planting), soil bulk density were not change of all 3 layers of depths 1.60, 1.65 and 1.60 g cm^{-3} respectively. The average of soil bulk density at 0-50 cm. from soil surface was 1.62 g cm^{-3}. Moreover, soil bulk density at 2 years of this experiment in the vetiver planting plots, was decreased significantly different from the beginning of the experiment and in control plot as showed in Table 4. In the plot planting with vetiver grass, it clearly showed that soil bulk density was decreased to 1.42-1.48 and 1.39-1.52 g cm^{-3} especially in soil depth 0-15 and 15-30 cm, respectively. And at soil depth 30-50 cm, soil bulk density was decreased comparing to the same layer of this soil at beginning of the experiment with 1.47-1.66 g cm^{-3}. However, there was not significantly different in soil bulk density in the control plot.

Table 4 Soil bulk density (g cm^{-3}) in each experimental plot of planting vetiver plot and control plot

Ecotype	Before experiment				After experiment			
	0-15 cm	**15-30 cm**	**30-50 cm**	**average**	**0-15 cm**	**15-30 cm**	**30-50 cm**	**average**
Control	1.60	1.64	1.65	1.63	1.60 a	1.65 a	1.60	1.62
Sri Lanka	1.64	1.59	1.69	1.64	1.48 b	1.52 b	1.51	1.50
Surat Thani	1.61	1.50	1.71	1.61	1.44 b	1.44 bc	1.66	1.51
Songkla 3	1.68	1.58	1.68	1.64	1.42 b	1.48 bc	1.61	1.50
Prarat Chatarn	1.61	1.59	1.67	1.62	1.47 b	1.45 bc	1.47	1.46
Prachuab Khirikhan	1.59	1.54	1.64	1.59	1.45 b	1.39 c	1.53	1.46
Roi Et	1.64	1.60	1.71	1.65	1.45 b	1.52 b	1.54	1.51
F-test	ns	ns	ns	-	*	**	ns	-

ns - non significant

* - significant at $p < 0.05$

** - significant at $p < 0.01$

Estimation of correlation between soil bulk density and vetiver root weight, it was a highly correlation (R^2=0.77) and linear regression is negative relationship as Y = -1.629X + 2.774 as showed in Figure 6. Since elongation and penetration of vetiver root in soil resulted to increase in soil porosity and has direct affected to reduce soil bulk density. On the other hand, in case of this experiment the soil property with high bulk density will restrict to root growth. The average of vetiver root biomass in this experiment was determined as in range 9.15-11.59 t ha^{-1}, which it is not high because of soil bulk density. The different in soil texture such as in clayey soil has soil bulk density greater than sandy and loamy soil. Moreover, the compacted soil from operation of heavy agricultural machine and continuous cultivation in agricultural practices resulted to increase soil bulk density. This affects to reduce growth and penetrate of vetiver root and directly decrease in root biomass. Nopmalai *et al*. (2013) reported that vetiver of root, in loamy soil with average of soil bulk density was 1.49 g cm^{-3}, and had 3 times higher than as mention in this study.

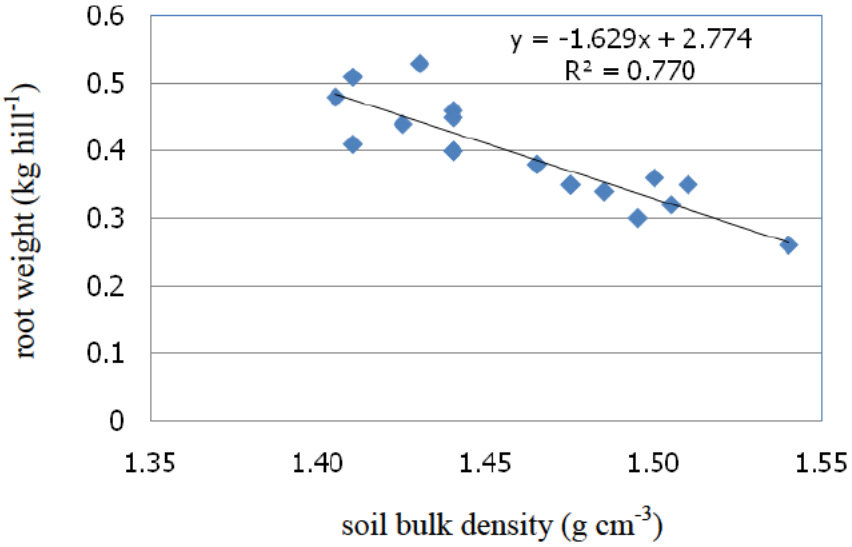

Figure 6 Correlation between soil bulk density and vetiver root weight at 24 month

3.2 Soil Organic Carbon Content

At beginning of this experiment, soil organic carbon content at soil depth 0-15, 15-30 and 30-50 cm from soil surface are in range 29.8-32.1, 17.0-19.1 and 21.1-23.0 t ha^{-1} respectively. And after experiment, there indicated clearly different in soil organic carbon content in the control plot and vetiver planting plot. Whereas, soil organic carbon content in control plot (at 0-15 cm of soil depth) decreased to 27.3 t ha^{-1}, but in the planting vetiver plots its increased to 31.2-34.4 t ha^{-1}. However, soil organic carbon content in all treatment of ecotypes in both 15-30 and 30-50 cm of soil depth were not significantly different. Soil organic carbon content in the control plot and at beginning of experiment was 18.8 and 26.8 t ha^{-1} respectively. Moreover, soil organic carbon content in the vetiver planting plots had trend to increase in range 19.2-21.0 and 25.1-29.3 t ha^{-1}, respectively. In addition, Roi Et and Prachuab Khirikhan produced the highest organic carbon content as showed in Table 5.

Table 5 Soil organic carbon content (t ha^{-1}) at before and after planting of this experiment

Ecotypes	Before experiment			After experiment		
	0-15 cm	15-30 cm	30-50 cm	0-15 cm	15-30 cm	30-50 cm
Control	31.6	18.7	22.2	27.3 c	18.8	26.8
Sri Lanka	32.1	19.1	22.8	34.4 a	19.2	25.1
Surat Thani	29.8	18.1	22.3	32.6 ab	20.0	28.8
Songkla 3	30.8	17.0	21.1	31.2 b	20.2	26.8
Prarat Chatarn	31.0	17.3	21.9	34.4 a	20.3	25.4
Prachuab Khirikhan	29.9	17.5	21.6	31.7 b	20.7	29.3
Roi Et	30.8	17.6	23.0	31.7 b	21.0	28.3
F-test	ns	ns	ns	**	ns	ns

ns - non significant

** - significant at $p < 0.01$

3.3 CO_2 Emission

For estimation of carbon content from CO_2 emission from the soil surface above mentioned, it was found that 4 ecotypes of *C. zizanioides* released carbon from soil surface in range of 1.26-1.35 kg C m^{-2} y^{-1}, while 2 ecotypes of *C. nemoralis* released carbon in range of 1.19-1.24 kg C m^{-2} y^{-1}. It showed that *C. zizanioides* released carbon higher than *C. nemoralis* as showed in Table 6. In case of control plot as non vetiver plantation released 0.95 kg C m^{-2} y^{-1}. Therefore, all 6 ecotypes of vetiver plantation plot compared to control plot released net carbon in range of 0.31-0.40 kg C m^{-2} y^{-1} as showed in Table 6. However, many factors will affect to CO_2 emission from the soil surface. This experiment had clearly indicated that the increase of plant biomass in soil or organic matter is highly related to CO_2 emission. Then, vetiver grass plantation area had CO_2 emission rate higher than the non vetiver plantation but the importance point is plantation of vetiver had obviously increased accumulation in soil organic carbon content more than CO_2 emission from soil surface. This research result was related to previous report of Nopmalai *et al*. (2013).

Table 6 Carbon content loss from the soil (kg C m^{-2} y^{-1})

Ecotypes	year 1	year 2	Average	Net
Control	1.00	0.90	0.95	0
Sri Lanka	1.30	1.22	1.26	0.31
Surat Thani	1.34	1.20	1.27	0.32
Songkla 3	1.36	1.18	1.27	0.32
Prarat Chatarn	1.43	1.27	1.35	0.40
Prachuab Khirikhan	1.30	1.17	1.24	0.29
Roi Et	1.22	1.16	1.19	0.24

In addition, soil moisture and soil texture are important factors to CO_2 emission. The relation of CO_2 emission and amount of rainfall from 2 years experiment (August 2008-July 2010), it was found that there was high CO_2 emission in the period of high amount of rainfall. Vatcharathai (2008) studied on soil carbon balance and carbon storage in the cropping area, and results indicated that CO_2 emission in the rainy season (August-September) was higher than in the dry season (February-April) about 19%. The same as Sueadee (2000) reported that CO_2 emission of the Mangrove forest in the rainy season was 73% higher than in the dry season.

However, soil organic carbon content in the control plot at 24 months of this experiment decreased because of no application of organic matter into soil and release of CO_2 from soil surface. The estimation of correlation between soil organic carbon content and CO_2 emission are highly correlation at R^2=0.734, and linear regression is positive relation as Y = 329.2X + 92.06 showed in Figure 7. This correlation expressed that increasing in soil organic carbon content had highly related to increasing in CO2 emission. This correlation expressed that increasing in soil organic carbon content had highly related to increasing in CO_2 emission. Moreover, the estimation of correlation between vetiver root biomass and CO_2 emission are also highly correlation at R^2=0.736, and linear regression is positive relation as Y = 30.36 + 276.0 showed in Figure 8. This correlation expressed that increasing in vetiver root biomass had highly related to increasing in CO_2 emission.

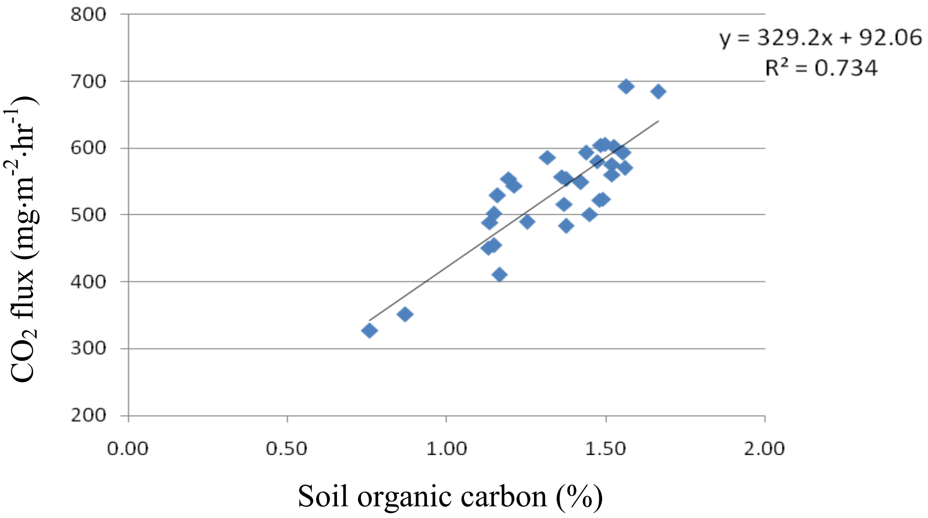

Figure 7 Correlation between soil organic carbon content and amount of CO_2 emission from soil surface

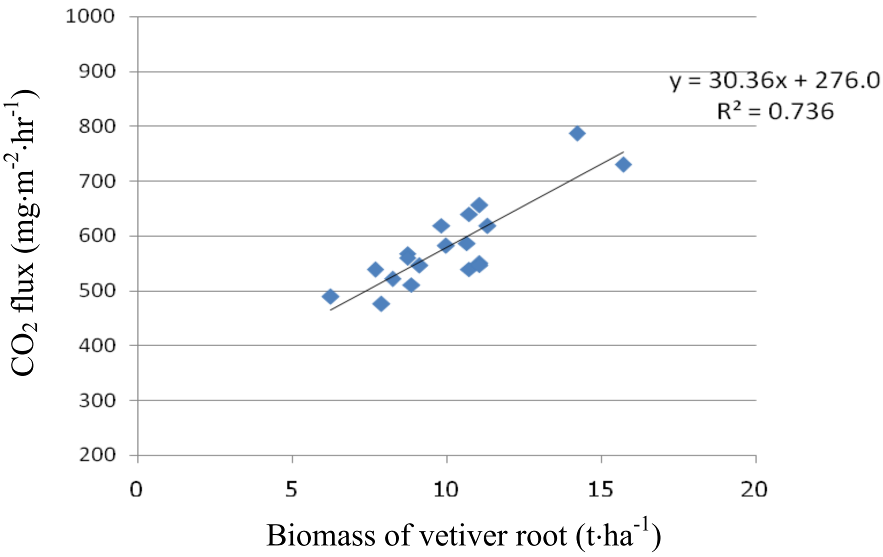

Figure 8 Correlation between vetiver root biomass and amount of CO_2 emission from soil surface for 2 years

4. Soil Carbon Stock

The amount of soil carbon at 0-30 cm of soil depth in control plot and vetiver planting plot are significantly different. The results showed that soil in this layer increased and accumulated organic carbon to 2.44-6.38 t ha^{-1}. And vetiver ecotype Prarat Chatarn indicated the highest soil carbon stock, but Sri Lanka was the lowest in accumulate soil carbon stock. In addition, the control or no vetiver planted plot decreased in soil carbon stock to - 4.19 t ha^{-1} as showed in Table 7. That means soil management by using organic fertilizer, incorporate of green manure and plant residue will increase soil carbon stock, even some part of carbon in that soil should release CO_2 from soil surface. In case of vetiver plantation in this experiment also try to clarify the net soil carbon stock obviously increase in treatment where vetiver was planted in this soil.

Table 7 Soil carbon stock at 0-30 cm soil depth before and after the experiment (t·ha^{-1})

Ecotypes	Before experiment	After experiment	Change in soil carbon stock
Control	50.31	46.13	-4.19
Sri Lanka	51.19	53.63	+2.44
Surat Thani	47.88	52.63	+4.75
Songkla 3	47.81	51.38	+3.56
Prarat Chatarn	48.31	54.69	+6.38
Prachuab Khirikhan	47.38	52.38	+5.00
Roi Et	48.38	52.69	+4.31

Remark : - means organic carbon lost from soil
+ means organic carbon storage into soil

The result of this experiment obviously indicated that vetiver plantation can accumulate soil carbon in such soil and can express in soil carbon stock, greater than in control plot. Since growth of vetiver grass will release organic carbon into soil because of advantage characteristic of vetiver root and root system. Moreover, vetiver root can increase amount of soil organic carbon to 2.44-6.38 t ha^{-1}. The estimation of correlation between root biomass and amount of carbon stock are highly correlation at $R^2 = 0.832$, and linear regression is positive relation as Y = 0.703X + 2.641 showed in Figure 9. This correlation expressed that increasing in soil carbon stock had highly positive related to increasing in root biomass as showed in Figure 9. It showed that amount of carbon stock resulted from root biomass, high amount of root biomass will increase high amount of carbon stock in soil. Lal (1999) reported that management of soil by cattle grazing grass and cover cropping can accumulate carbon into soil at 0.1-0.2 and 0.1-0.3 t ha^{-1} y^{-1} respectively. Moreover, Chidthaisong and Lichaikul (2005) reported that application of *Acacia mangium* to improve agricultural areas for 16 years, can increase soil carbon through 50 cm soil depth as 9 t ha^{-1}.

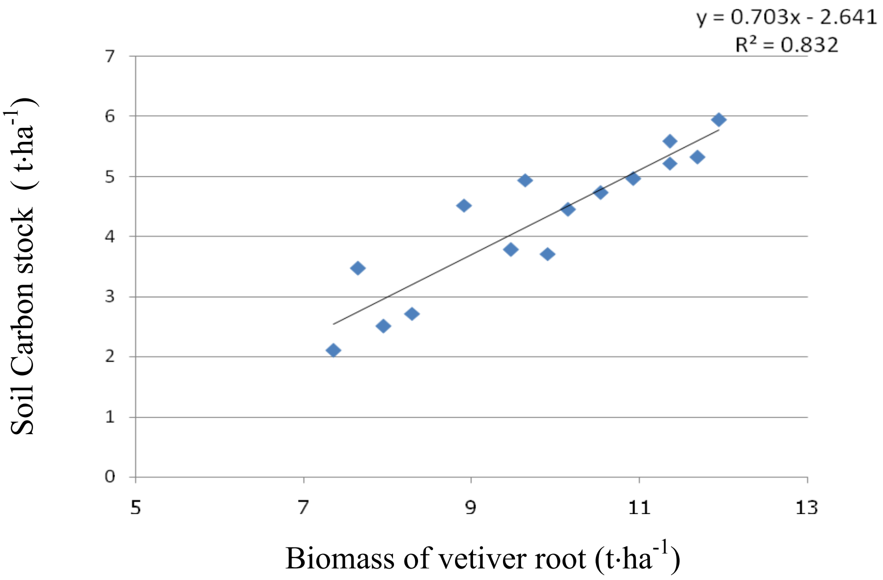

Figure 9 Correlation between root biomass and amount of soil carbon stock

CONCLUSION

The vetiver root length of the 6 ecotypes were not different and had an average root length of 54.06-58.60 cm. The root length remained constant between 8 months and 24 months during this experiment. The root biomass changes followed a similar pattern to that of root length with no significant differences during 12 to 24 months. Soil bulk density increases with the depth of the soil from 15 to 50 cm. This means that soil compaction increases as soil depth. Vetiver planting in the soil clearly promotes bulk density decreases, and soil bulk density is highly correlated with root biomass. This negative relationship is Y = -1.629X + 2.774 (R^2 = 0.77). In Addition soil bulk density is the one factor to regulate root length and biomass because of soil compaction.

The soil organic carbon content in the soil surface layer (0-15 cm) is higher than in the deeper layer of this soil. Planting vetiver clearly encourages increases in soil organic carbon. The correlation between soil organic carbon with CO_2 emissions from the soil surface is positive as Y = 329.2X + 92.06 (R^2 = 0.734). This relationship shows that increasing amounts of soil organic carbon promotes CO_2 emission from the soil surface. Moreover, the correlation between root biomass and CO_2 emission is Y = 30.36 + 276.0 (R^2 = 0.736).

Assessment of carbon stocks in the soil where the 6 vetiver ecotypes were planted versus the control with no vetiver planted, shows that the amount of soil carbon stock is lost in the control plot equal to -4.19 t ha^{-1}. But in the vetiver plots, the amount of carbon stock increased by +2.44 to +6.38 t ha^{-1}, especially under the Prarat Chatan ecotype treatment that has the highest soil carbon stock increase at 6.38 t ha^{-1}. In case of vetiver plantation in this experiment also try to clarify the net soil carbon stock obviously increase in treatment where vetiver was planted in this soil.

REFERENCE

Bharat, M.S. 2007. Land use and land use changes effects on organic carbon pools, soil aggregate associated carbon and soil organic matter quality in a watershed of Nepal. Ph.D. Thesis, Norwegian University of Life Sciences. 119 p.

Chidthaisong, A., and Lichaikul, N. 2005. Carbon storage and carbon dioxide emission in dry evergreen forest, plantation forest and agricultural soil. pp. 95-105. In Proceeding of conference on climate change on forest. 4-5 Aug. 2005, Maruay Garden hotel, Bangkok.

Hutchinson, G.L. and A.R. Mosier. 1981. Improved soil cover method for field measurement of nitrous oxide fluxes. Soil Sci. Soc. Am. J. 45:311-316.

Lal, R. 1999. Global carbon pools and fluxes and the impact of agricultural intensification and judicious land use. pp. 45-52. *In* Prevention of land degradation, enhancement of carbon sequestration and conservation of biodiversity through land use change and sustainable land management with a focus on Latin America and the Caribbean. World Soil Resources Report 86. FAO, Rome.

Nopmalai, P., Sukkasem, A., Wattanaprapat, K., Meesing, I., and Taranet, P. 2013. Study on carbon storage and carbon dioxide emission in vetiver grass cultivation areas in northern Thailand. pp. 150-160. In Proceeding of conference on Land Development Department in a half century, year 2013, vol.2, 7-9 Sept 2013, Sida resort hotel, Nakhon Nayok province.

Soil survey staff. 2006. Key to soil taxonomy. Tenth Edition. United States Department of Agriculture, Natural Resources Conservation Service, Washington, D.C. 332 p.

Sueadee W. 2000. Rate of CO_2 exchange and biomass of mangrove plantation area at Cha-am district, Phatchaburi province. Master Thesis, Kasetsart University, Bangkok. 79 p.

Vatcharathai S. 2008. Study on soil carbon balance and carbon sequestration in clay and silty sand soil of Sabu-dum plantation. Master Thesis, Kasetsart University, Bangkok. 49 p.

Walkley, A. and I.A. Black. 1934. An examination of Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil Sci. 37(1): 29-37.