Study on Carbon Storage and Carbon Balance in Vetiver Grass Cultivation Areas in Northern Thailand

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ABSTRACT

The study on carbon storage and carbon dioxide emission from the soil surface and carbon balance in vetiver grass cultivation areas, was conducted at the Chiang Mai Land Development Station, northern Thailand during 2008-2010. The experimental design used was a randomized complete block design (RCBD) consisting of 3 replications with 7 treatments, control (non- vetiver grass) compared with 6 ecotypes of two vetiver species, *Chrysopogon zizanioides* and *Chrysopogon nemoralis*. *C. zizanioides* consisted of 4 ecotypes, Sri Lanka, Surat Thani, Mae Har, and Prarat Chatarn. *C. nemoralis* consisted of 2 ecotypes, Prachuab Khirikhan and Roi Et. Results showed that Prarat Chatarn produced the highest biomass of 35.6 t ha^{-1}. The remaining ecotypes produced biomass amounts in the range of 31.2-35.2 t ha^{-1}. Carbon accumulation in leaves and roots of various ecotypes varied with the growth period. The Prarat Chatarn ecotype produced the highest carbon accumulation of 7.45 t ha^{-1}. For the plots with vetiver grass plantings, there was an increased amount of organic matter, soil moisture and decreased soil bulk density compared to the plots without vetiver grass. Mulching with cut leaves increased soil carbon storage. Carbon dioxide emissions in the plots with vetiver grass were higher than in the control plots. For carbon balance estimates, the plots with *C. zizanioides* produced carbon storage of +1.53 kgC m^{-2} y^{-1} and that was higher than for *C. nemoralis* plots with carbon storage of +1.37 kgC m^{-2} y^{-1}. While the plots without vetiver grass caused a soil carbon loss of –0.31 kgC m^{-2} y^{-1}.

Keywords: soil carbon storage, CO_2 efflux, biomass, carbon balance

INTRODUCTION

Soil carbon derived from plant biomass by photosynthesis process converting CO_2 gas or inorganic carbon in the atmosphere to organic carbon in plant biomass. The dead parts of plant falling to the ground, will be decomposed by soil microorganism and transformed to organic carbon storage in the soil. Therefore, plants including vetiver grass, on the global are capable to reduce the global warming by photosynthesis process. Vetiver grass is a Gramineae growing by tillering as a dense clump. It is a perennial plant since it always germinate new tillers. In the growing period, it produces a high amount of biomass. It has long leaves when trimming it can germinate easily. Its leaves is strong and resists to decomposing. Long fibrous roots system interwines tightly that is an interesting plant to mitigate the global warming (Limtong, 2008a).

Besides, vetiver grass helps to conserve soil and water and rehabilitate the soil. It is assumed that it is an important role to reduce CO_2 in the atmosphere. Vetiver grass planting in the agricultural areas will accumulate carbon into the soil by photosynthesis process. It adsorbs carbon into plant components. The dead plants will be decomposed and releasing carbon back into the soil. It stores as soil organic matter. Therefore, appropriate management of soil and plant in planting vetiver grass system is an important process to increase soil carbon storage. Since most agricultural areas are rainfed agriculture, having water shortage, conserving soil moisture by vetiver grass will be appropriate. Therefore, a good soil management increases soil organic matter storage.

Consequently, it will increase efficient accumulation of organic carbon, especially in the degraded areas. Study of Khanema and Thamma Thaworn (2009) on 11 ecotypes of vetiver grass. It was found that ecotype of Prachuab Khirikhan, Kamphaeng Phet 1, Sri Lanka, Songkhla 3 and Loei produced amount of carbon content in biomass higher than the remaining ecotypes. Ratchaburi ecotype produced the highest carbon storage. Carbon content accumulation was the highest in top soil at 0-10 cm depth and decreasing as the soil depth. Carbon content in the plot with vetiver grass was significantly higher than the control plot. For biomass evaluation, average amount of shoot and leaves was 48.51 g/plant and roots was 48.39 g/plant, totaling 96.90 g/plant. Therefore, carbon storage of the aboveground part was 21.64 g C/plant and the underground part was 18.24 g C/plant (ORDLM, 2012)

OBJECTIVES

1) To determine biomass of some ecotypes of vetiver grass and carbon storage
2) To determine carbon emission from soil and carbon balance in non- vetiver grass and vetiver grass cultivation areas

MATERIALS AND METHODS

1. Description of Experiment Sites and Treatment

The study site was located at the Chiang Mai Land Development Station ,Marim District, Chiang Mai Province, northern 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). Soil was classified as fine, kaolinitic, isohyperthermic Typic Kandiustults (Soil Survey Staff, 2006) (Figure 1).

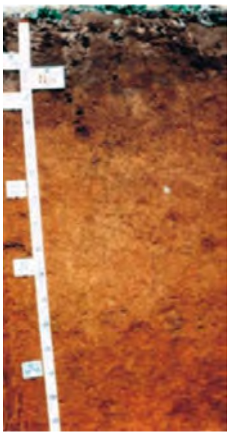

Figure 1 soil profile of Nong Mot soil series

The experiment design is randomized complete block design (RCBD) consisting of 7 treatments and 3 replications . The 7 treatments consists of non - vetiver grass cultivation areas as control and 6 ecotypes of two vetiver species; *Chrysopogon zizanioides* and *Chrysopogon nemoralis*. *C. zizanioides* consisted of 4 ecotypes; Sri Lanka, Surat Thani, Mae Har and Prarat Chatarn. *C. nemoralis* consisted of 2 ecotypes; Prachuab Khirikhan and Roi Et. The 6 ecotypes were compared to non - vetiver grass cultivation areas. Plot size was 4x6 m with planting spacing 50x50 cm. All vetiver grasses were planted on June 2008 and allowed to naturally grow for 2 years without applying fertilizer or irrigation. After planting, vetiver leaves were cut 5 times, when aged 8 (March 2009), 12 (July 2009), 16 (November 2009), 20 (March 2010) and 24 (July 2010) months after planting. The leaves were cut from area 4x5 m and mulched in each plot on soil surface for improving soil physical and chemical properties.

2. Sampling and Analysis of Vetiver Grass, Soil and CO_2 Gas

2.1 Vetiver Grass Sampling and Analysis

Vetiver grasses were cut at each sampling time for 5 times as the above mentioned (Figure 2). The above (leaves) and belowground biomass (roots) were determine plant biomass. The fresh vetiver grasses were subsequently oven-dried at 70 ^{o}C for 24-27 hours to determine the remaining dry mass. The plant material analyses consisted of organic carbon by Walkley and Black wet digestion method, total nitrogen by micro Kjeldahl method, phosphorus by Bray II and potassium by ammonium acetate extraction 1N,pH 7


Figure 2 Cutting and sampling vetiver grasses biomass

2.2 Soil Sampling and Analysis

Undisturbed and disturbed soil samples (Figure 3) were collected 2 times: Before planting vetiver grasses and at the end of experiment. In each plot, soil samples were randomly collected from the root zone at 3 levels of soil depth: 0-15, 15-30 and 30-50 cmdepth. The undisturbed soil was collected to determine bulk density. Soil samples were oven-dried at temperature 105 ^{o}C for 2 days. Gravimetric soil moisture content was determined in each sampling time. A soil temperature also was measured near the gas chamber at 5 cm depth. Soil samples analyses consisted of soil pH, soil organic carbon, available phosphorus and exchangeable potassium. The selected soil profile was described according to U.S. soil taxonomy methodology (Soil Survey Staff, 2006).


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

2.3 Gas Sampling

CO_2 emission from soil was measured by using a Hand-Held CO_2 Meter (model GM70, as shown by Figure 4) fitted 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. At 3 cm from the top, an O-ring was inserted to facilitate sealing during enclosure by cover. Two small holes; one for gas sampling and another for inserting thermometer, were opened through the cover. The chamber base was set (or installed) at the selected area in all plots. Soil CO_2 emission was measured in the closed chamber every 15 seconds for 15 minutes. While soil CO_2 measurement, the cover was gently placed on the top of the chamber until tightly sealed. The CO_2 efflux was recorded once a month before noon for 2 years experiment. Meanwhile, soil CO_2 measurement, the temperature of soil and closed chamber was also measured by thermometer.

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

3. Calculation of Carbon Content in Vetiver Grasses and Soil

In vetiver grass, carbon content was estimated from biomass and percentage of organic carbon which was calculated according to the equation as shown below:

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

Where $C_{vetiver}$ is total carbon content (t ha^{-1}), C_{leaf} and C_{root} are total carbon content in leaf and root (t 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 (t ha^{-1})

In soil sample, carbon content was determined in 3 soil layers; 0-15, 15-30 and 30- 50 cm depth. Total carbon content was calculated by summation of soil carbon in each layer as described by following equation:

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

Where C_{soil} is soil carbon stock of 3 soil layers 0-15, 15-30 and 30-50 cm depth (t ha^{-1}), C_{0-15}, C_{15-30} and C_{30-50} are soil carbon content in each layers; 0-15, 15-30 and 30-50 cm depth (t ha^{-1}), % OC_{0-15}, % OC_{15-30} and % OC_{30-50} are percentage of organic carbon in each layers; 0-15, 15-30 and 30-50 cm depth (%), D_{0-15}, D_{15-30} and D_{30-50} are soil bulk density carbon in each layers; 0-15, 15-30 and 30-50 cm depth (g cm^{-3}) and V_{0-15}, V_{15-30} and V_{30-50} 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;

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

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

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

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 $\frac{\Delta Ci}{\Delta t}$ 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 DISCUSSIONS

1. **Soil Characteristics**

Soil was classified as fine, kaolinitic, isohyperthermic Typic Kandiustults (Soil survey staff, 2006). Soil data was collected at 3 layers: 0-15, 15-30 and 30-50 cm. Table 1 shows some soil physical and chemical properties at the study site. Soil bulk density was ranged from 1.43 to 1.64 g cm^{-3}. Soil pH was strongly to very strongly acid (4.7-5.3). Soil organic matter was moderately low to low (0.90-1.14%). Phosphorus was low to very low in range of 1-5 mg kg^{-1}. Potassium was low to very low in range of 29-36 mg kg^{-1} (Table 1). Soil fertility was estimated as low to moderate level.

Table 1 Initial soil physical and chemical properties

Soil depth (cm)	Bulk density (g cm^{-3})	pH	OM (%)	P (mg kg^{-1})	K (mg kg^{-1})
0-15	1.56	4.7	1.12	5	36
15-30	1.43	5.3	0.90	2	29
30-50	1.64	5.2	1.14	1	34

2. Biomass of Vetiver Grass

The total amount of biomass of 6 ecotypes planted on Nong Mot soil series, Chiang Mai Land Development station were recorded (Table 2). For 2 years experiment , cutting leaves and root data collection was taken for 5 times at 8, 12, 16, 20 and 24 months after planting. Amounts of biomass accumulated in each ecotype were not significantly different. Prarat Chatarn had the highest biomass (35.6 t ha^{-1}) followed by Surat Thani (35.2 t ha^{-1}), Sri Lanka (34.4 t ha^{-1}), Mae Har (34.2 t ha^{-1}), and Roi Et (33.1 t ha^{-1}), respectively. While Prachuap Khirikhan ecotype was the lowest (31.2 t ha^{-1}). In addition, biomass of *C. zizanioides* was higher than *C. nemoralis*. This result is similar to. Pongkarnchana and Wattanaprapat (2009) also reported that *C. zizanioides* produced the growth and roots system better than *C. nemoralis*. The amount of biomass was different in various ecotypes and the growth stage. At the early growth stage, there was low accumulation of biomassin all ecotypes. It addition, we found that the amounts of biomass were increased followed by plant age, especially in the rainy season, as influenced by the sufficient soil moisture content helps to increase biomass accumulation.

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

Ecotypes	Months after planting					Total
	8	12	16	20	24	
Sri Lanka	4.4	6.1	5.5	9.1	9.3	34.4
Surat Thani	5.0	5.7	7.2	8.8	8.5	35.2
Mae Har	4.7	6.2	5.4	8.9	9.0	34.2
Prarat Chatarn	5.9	5.5	5.4	9.2	9.6	35.6
Prachuap Khirikhan	4.7	5.1	4.1	8.4	8.9	31.2
Roi Et	4.6	5.8	5.9	8.1	8.7	33.1
F- test	ns	ns	ns	ns	ns	

ns = non significant

The contents of organic carbon in leaves and roots of 6 ecotypes were not significantly different. The total organic carbon (TOC) in *C. zizanioides* was ranged from

6.42 to 7.45 t ha^{-1} which higher than *C. nemoralis* (5.87-6.76 t ha^{-1}). Prarat Chatarn had the highest TOC, while the lowest was found in Prachuab Khirikhan (Table 3). This result indicated that *C. zizanioides* of Prarat Chatarn ecotype can grow and produce biomass higher than *C. nemoralis*. Limtong (2008b) reported that the *C. zizanioides* it was appropriate for growing in the northern of Thailand. This result is similar to Wattanaprapat et al. (2014)who reported that TOC was found in , according to TOC in year 2 of experiment, that *C. zizanioides* had total carbon content 5.59 t ha^{-1}, while *C. nemoralis* had 5.54 t ha^{-1}.

Table 3 Total organic carbon (TOC) content (t ha^{-1}) in vetiver grass (leaves and roots) at 8,12,16, 20 and 24 months after planting

Ecotypes	Months after planting					Total
	8	12	16	20	24	
Sri Lanka	0.91	1.22	1.10	1.85	1.90	6.98
Surat Thani	0.91	1.05	1.31	1.60	1.55	6.42
Mae Har	0.96	1.27	1.12	1.83	1.85	7.03
Prarat Chatarn	1.24	1.15	1.13	1.93	2.00	7.45
Prachuab Khirikhan	0.88	0.95	0.79	1.57	1.68	5.87
Roi Et	0.94	1.18	1.20	1.68	1.76	6.76
F-test	ns	ns	ns	ns	ns	

ns = non significant

3. Changes in Soil Properties

3.1 Soil Chemical Properties

We found that the amount of organic matter (OM), phosphorus, potassium and pH at 0-15 cm depth, was increased significantly different, We found that the amount of organic matter (OM), phosphorus, potassium and pH at 0-15 and 15-30 cm depth. While, there was not much different at 30-50 cm depth, except the phosphorus was increased. At the end of experiment (24 months), OM was increased in all treatments (Table 4). The increasing in OM in the soil is derived from decomposing of biomass mulching (leaves) and roots at belowground. (Limtong, 2008b).

The result was confirmed to the study of Sriyaem and Thepsupornkul (2008). It was found that in sugar apple plantation mulching with cut leaves of vetiver grass, increased soil fertility. Since using its cut leaves to mulch the soil surface promoted the natural balances. These were such as increasing soil organic matter and nutrients. In addition, it increased the amount of soil microorganism and fauna, resulted to be living soil. The cut leaves of 4 months age mulched the soil surface, decomposed and released plant nutrients to the soil. It was average phosphorus 0.2 % and potassium 1.3% of dry weight (ORDPB, 2006).

Table 4 Soil chemical properties at before and after planting vetiver grass

Soil depth (cm)	Before experiment				After experiment			
	pH	OM (%)	P (mg kg^{-1})	K (mg kg^{-1})	pH	OM (%)	P (mg kg^{-1})	K (mg kg^{-1})
0-15	4.7	1.12	5.0	36.7	5.7	1.26	11.00	45.00
15-30	5.3	0.90	2.0	29.1	5.2	1.04	9.16	32.30
30-50	5.2	1.14	1.0	34.3	5.3	1.17	11.06	33.96

3.2 Soil Bulk Density

Soil bulk density in the control (no planting vetiver grass) at 0-15,15-30 and 30-50 cm depth were 1.56, 1.43 and 1.64 g cm^{-3}, respectively. According to 2 years vetiver grass planting, bulk density was decreased as compared to with the control. It is obviously decreased at soil depth 0-15 cm, since vetiver grass roots help increase soil organic matter which affect to soil bulk density directly (Table 5). The result was confirmed to the study of Wattanaprapat et.al. (2014) found that the bulk density was decreased in the vetiver grass planting, especially in soil at 0-30 cm depth. Furthermore, Puangwarin and Sukviboon (1994) reported that soil porosity had greater in the soil with cover crop than the soil without cover crop. Vetiver grass is a plant with long and dense fibrous roots, act as penetrating deep down into the soil profile. These beneficial characteristics lead to increase the distribution of soil porosity and soil space volume, eventually resulting in decreasing in bulk density.

Table 5 Soil bulk density (g cm^{-3}) under vetiver grass plot and no planting

Ecotypes	Soil depth (cm)			Average
	0-15	15-30	30-50	
No planting	1.56	1.43	1.64	1.54
Sri Lanka	1.42	1.63	1.72	1.59
Surat Thani	1.47	1.63	1.59	1.56
Mae Har	1.38	1.63	1.63	1.55
Prarat Chatarn	1.44	1.57	1.56	1.52
Prachuab Khirikhan	1.52	1.65	1.63	1.60
Roi Et	1.41	1.50	1.58	1.49

3.3 Soil Moisture Content

At the end of experiment, the soil moisture content in the control was 7.4%. While the soil moisture content under the vetiver grass planting had ranged from 10.2 to 12.3% (Table 6). The high soil moisture content is related to the root system which acts as absorbing and storing water in the soil. Mulching of cut leaves reduced water evaporation from soil surface. This confirmed to the study of Kittiyarak et al. (1997) that the plot with vetiver grass maintained soil moisture higher than the control. Vetiver trimmed leaves for mulching cultivation plots protected the sunshine. Consequently, it reduced soil temperature and stored moisture in the soil (Chomchalow, 2009).

Table 6 Soil moisture in no planting and vetiver grass cultivation plot at various soil depth (%)

Ecotypes	Soil depth (cm)			Average
	0-15	15-30	30-50	
No planting	8.4	5.9	7.9	7.4
Sri Lanka	12.9	11.6	12.6	12.3
Surat Thani	11.7	9.7	10.3	10.6
Mae Har	12.1	9.9	10.3	10.8
Prarat Chatarn	11.6	8.9	10.1	10.2
Prachuab Khirikhan	12.1	11.7	10.5	11.4
Roi Et	10.9	9.8	12.1	10.9

4. Change of Soil Organic Carbon

The amount of soil organic carbon in the plot with vetiver grass and control were obviously different. At soil depth 0-15 cm, the control had organic carbon content 0.36% and the planting vetiver grass was increased to 0.54-0.75%. The research confirmed to the study of Hannamthieng (2010) finding that in the non-vetiver cultivation plot had the lowest organic carbon content of 0.19 %. It indicated that organic carbon content in the non-vetiver plot, there was little change. This was because of no organic matter or organic carbon adding. Therefore, soil organic carbon content decreased gradually. For the soil depth at 15-30 and 30-50 cm, there were the similar change. The plot planting with Roi Et, Sri Lanka, Prachuab Khirikhan and Surat Thani produced the highest organic carbon content in the soil in range of 0.67-0.72 %. The lowest organic carbon content was in Mae Har ecotype (Table 7).

Table 7 Soil organic carbon content at various soil depth (%)

Ecotypes	Soil depth (cm)		
	0-15	15-30	30-50
No planting	0.36	0.38	0.40
Sri Lanka	0.65	0.71	0.59
Surat Thani	0.54	0.68	0.51
Mar Har	0.75	0.46	0.68
Prarat Chatarn	0.70	0.60	0.64
Prachuab Khirikhan	0.68	0.67	0.63
Roi Et	0.64	0.72	0.62

5. Carbon Dioxide Emission

Planting vetiver grass increased CO_2 emission comparing to control. The plot planting with Surat Thani produced the highest amount of CO_2 accumulation of 6,518 mg C $m^{-2}h^{-1}$. The following as Roi Et was 5,812 mg C $m^{-2}h^{-1}$. For Sri Lanka was the lowest of 4,263 mg C $m^{-2}h^{-1}$. While in the non-vetiver grass plot produced the lowest CO_2 accumulation of 3,496 mg C $m^{-2}h^{-1}$. There was the same trend of CO_2 accumulation in various ecotypes, but it was different in the CO_2 accumulation (Figure 5).

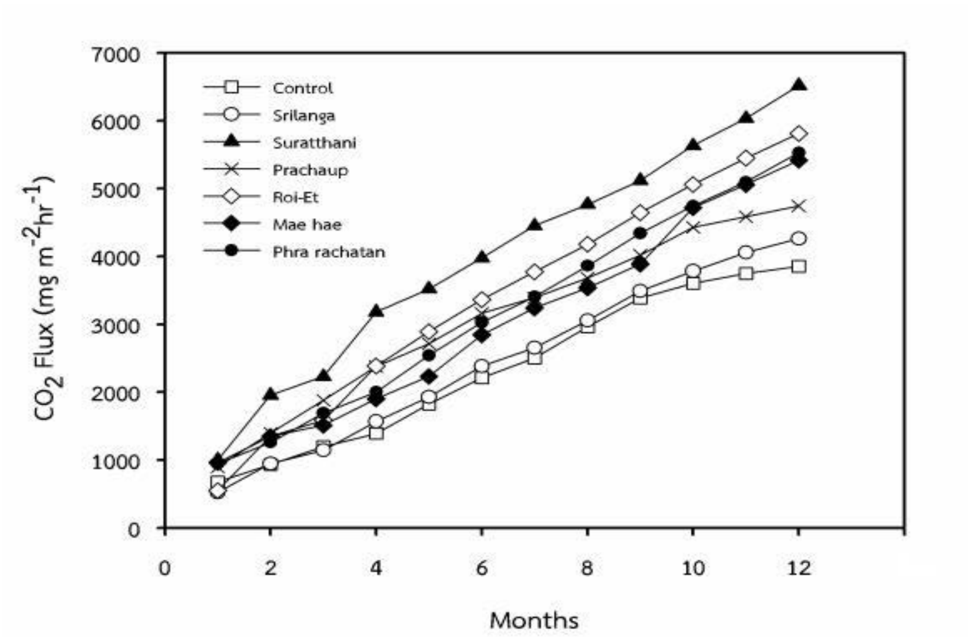

Figure 5 Carbon dioxide gas emission from soil surface

6. Soil Carbon Balance

In the non-vetiver grass plot, soil organic carbon content was 1.58 kg C $m^{-2}y^{-1}$ and carbon dioxide emission was 1.89 kgC m^{-2} y^{-1}. Therefore, it was found that soil carbon balance of this system was 0.31 kgC m^{-2} y^{-1}. It showed that the cropping pattern without vetiver grass planting caused soil carbon loss of 0.31 kgC m^{-2} y^{-1}. (Figure 6 and Table 8)

For *C. zizanioides* plot, there was organic carbon in soil 3.15 kgC $m^{-2}y^{-1}$ and 0.62 kgC $m^{-2}y^{-1}$ from root part. In leaves part consisting 2.75 kgC $m^{-2}y^{-1}$ used for mulching soil surface will decompose and release CO_2 of 0.92 kgC $m^{-2}y^{-1}$. The remaining organic carbon stored in the soil was 1.83 kgC $m^{-2}y^{-1}$. For estimating of soil carbon balance in *C. zizanioides* plot, it was +1.53 kgC $m^{-2}y^{-1}$. It indicated that in *C. zizanioides* cultivation areas increased carbon storage of 1.53 kgC $m^{-2}y^{-1}$ (Figure 6 and Table 8)

For *C. nemoralis* plot, there was organic carbon in soil 2.98 kgC $m^{-2}y^{-1}$and 0.49 kg C $m^{-2}y^{-1}$from root part. In leaves part consisting 2.69 kgC $m^{-2}y^{-1}$ used for mulching soil surface will decompose and release CO_2 of 0.90 kgC $m^{-2}y^{-1}$.The remaining organic carbon stored in the soil was 1.79 kgC $m^{-2}y^{-1}$. When estimating soil carbon balance in *C . nemoralis* plot, it was 1.37 kgC $m^{-2}y^{-1}$. It indicated that in *C. nemoralis* cultivation areas increased carbon storage of 1.37 kgC $m^{-2}y^{-1}$. (Figure 6 and Table 8)

From results of estimating soil carbon balance , it obviously indicated that soil carbon in non-vetiver grass cultivation system caused soil carbon loss. While, in vetiver grass cultivation areas, increased soil carbon storage. Furthermore, the finding indicated that *C.zizanioides* cultivation areas raised carbon storage higher than *C.nemoralis* cultivation areas.

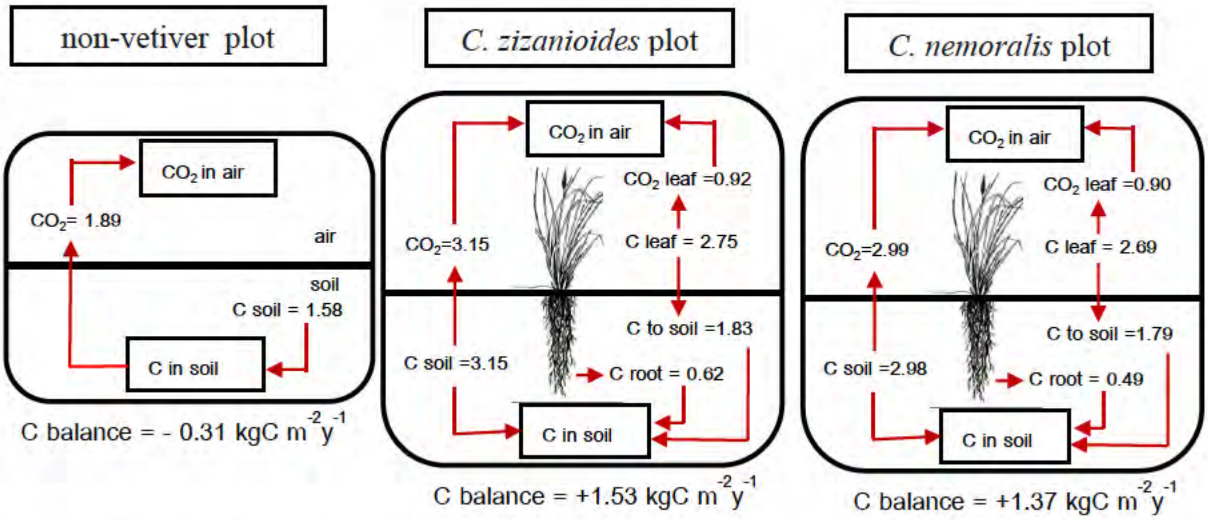

Figure 6 Soil Carbon balance in non-vetiver grass and vetiver grass cultivation areas

Table 8 Carbon balance and organic carbon content in soil, leaves and roots of *C. zizanioides* and *C. nemoralis* (kgC $m^{-2}y^{-1}$)

Carbon content in the system	Non-vetiver grass	*C.zizanioides*	*C.nemoralis*
C in soil	1.58	3.15	2.98
C in roots	-	0.62	0.49
C in leaves	-	2.75	2.69
-C stored in soil	-	1.83	1.79
-C released as CO_2	-	0.92	0.90
C emission as CO_2	1.89	3.15	2.98
Carbon balance	-0.31	+1.53	+1.37

CONCLUSIONS

The study showed vetiver grass cultivation areas with mulching of cut leaves comparing to non- vetiver grass cultivation areas increased soil carbon storage and CO_2 emission from soil surface. Vetiver grass cultivation increased soil carbon storage to 1.37-1.53 kgC $m^{-2}y^{-1}$. While in non- vetiver grass cultivation areas resulted in loss of soil carbon about 0.31 kgC $m^{-2}y^{-1}$. Results from this study obviously showed that the agricultural cropping system with vetiver grass cultivation helps to increase carbon storage in soil and improve soil properties such as soil chemical and physical properties. Uses of vetiver grass is a simple and cheap technology. Farmers can practice by themselves easily. Therefore, it is a sufficient and sustainable farming in the communities.

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