CHAPTER 4

CARBON BUDGET IN RICE FIELDS WITH DIFFERENT RICE STRAW MANAGEMENT

4.1 Introduction

Carbon is essential for plant growth due to its effects on soil conditions. Soil organic carbon is important since it binds soil particle together for soil structural stability. It is also involved in cation adsorption, such as Ca^{2+}, Na^{+}, Mn^{2+}, and Fe^{2+} which is important in plant nutrient, and can significantly influence soil water holding capacity. Carbon in soil organic matter also maintains soil fertility for sustainable agriculture. Rice field is unique agroecosystem, which soil flooding is general practice for rice cultivation. During the rice cultivation, the ecosystem is divided into floodwater, plow layer, and subsoil layer underneath the plow layer. The plow layer is specific niches for soil microorganisms, which consist of surface oxidized layer, reduced bulk soil, rhizosphere and percolating water. Carbon budget in cropland can be estimated by integrating the amounts of net carbon supply and removal. In rice field, the carbon supplies to the soil are root exudated, rice litter, stubble and some other addition organic matter incorporation. While carbon in soil lost by CO_2 and CH_4 emission and by leaching to the subsoil layer. The level of organic carbon in the soil is affected by land management history, climate, drainage, soil type, and land form. Therefore, a study on carbon budget provides a good measure of the impact of land management on soil fertility.

The future of rice cultivation under the constraint of greenhouse gas reduction and uncertainty of climate change risk become corrupt to rice production, rice field management and soil fertility. The integrated study of suitable agricultural practice with field management and utilization of rice residue are the key issue of sustainable development to reduce greenhouse gas emission from paddy fields with avoidance of air pollution from open field burning including use of rice straw conversion to energy. One of the sustainable cultivation of rice field is to maintain or increase carbon stock in the soil. Despite the improvement of soil fertility, increase carbon stock may indicate rice field as the sink of carbon. Therefore our experiments focus on carbon budget analysis in the rice field as the tool to evaluate sustainable cultivation practices with rice straw management.

4.2 Methodology

4.2.1 Carbon cycle in rice field ecosystem

A large variety of organic matter is incorporated into rice soil. Main sources of organic supply to paddy soil are plant residues (rice, weeds, and algae) and rhizodeposition from rice and weed roots. The field management and rice growth control quantity and quality of organic materials to be supplied to rice field. The photosynthesis of rice and decomposition of plant residue are the important process in carbon cycling in rice field. Rice releases photosynthates into the rhizosphere in form of dead leaves (litter), rhizodeposition and roots remaining after harvesting rice. Many reviews and articles have been published on the decomposition process of organic matter in rice field. Kimura, Murasa and Lu (2004) reviewed and concluded the distribution of photosynthates between the aboveground and root parts of rice at the harvesting. They assimilated the rice plant, total dead leaves, microbial biomass and decomposed as 75-79%, 1-5%, 0.41% and 19.5% of the total dry matter production of rice. End products of organic matter decomposition are CO_2 and CH_4 in the rice field, and they exit the system by water percolation to the subsoil layer and by flux to the atmosphere. Figure 4.1 shows the carbon cycle in a rice plant-soil-atmosphere system. The processes of carbon dynamics in submerged paddy soil have been investigated in the previous studies. For example, Kimura, Murasa and Lu (2004) summarized a review paper in which carbon cycling in rice field ecosystem. Nishimura et al. (2008) studied the effect of land use change from rice cultivation to upland crop cultivation on carbon budget. However, studies on comprehensive carbon dynamics are limited in paddy fields in China and Japan. Despite that soils in the tropica are less fertile than in temperate regions in terms of soil organic matter content because of the faster decomposition of soil organic matter in Thailand under higher soil temperature (Kimura et al., 1990). Therefore, study comparing carbon budget in Thailand paddy field with different agriculture practice should be clarified.

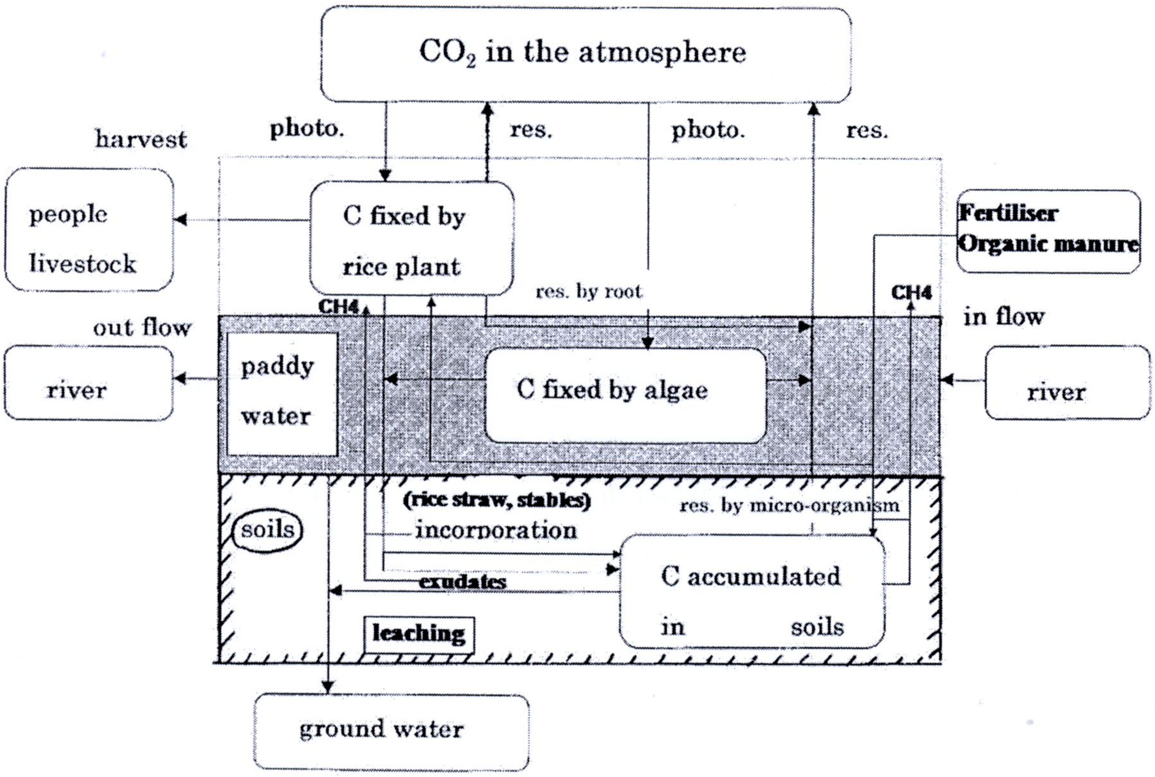

Figure 4.1 Carbon cycle in a rice plant-soil-atmosphere system (by Koizumi, and modified by Tsuruta)

4.2.2 Experimental design and assumption

The experimental field's carbon budget at Samutsakorn was evaluated during the rice cultivation in order to study the migration of carbon in paddy soil with different cultivation practices in the context of rice straw management. The field experiment was conducted in 1st crop during the wet season (Middle of April – August, 2007) and 2nd crop in dry season (September – December, 2007). The experiment plots consist of 1) stubble incorporated plot; S, 2) rice straw burning plot; B and 3) rice straw and stubble incorporated plot; I. After rice harvest, the rice straw was removed from S plot, remaining approximately one-third of the aboveground biomass of the rice plants which is stubbles as approximately 300 g/m^2. In B plot, the rice straw was burned on field as a cultural practice in irrigation rice field. While in I plot, the whole rice straw was soaked for few days, after that rice straw was incorporated into the soil at an amount of approximately 500-680 g/m^2.

The studied rice field was a double cropping irrigated rice field, so the supply of plant residues from the previous crop was important for the next crop. The amount of carbon input depends on the field management and rice growth. In this experimental field, intensive weed control was performed, so small organic materials, such as weed and algae, were not evaluated. The chemical fertilizer was applied in all treatments whence null carbon in term of fertilizer application. The kind and amount of organic materials input to each treatment showed in Table 4.1.

The carbon cycle in rice ecosystem initiates when plants fix CO_2 from air and convert it to organic carbon compounds through photosynthesis. Some of the organic carbon compounds are used to grow plant tissues. Some are broken down to supply the plants with energy through plant respiration. During rice cultivation, the rice litter and rhizodeposition were decomposed, we assumed in this study that carbon supply from rice litter and rhizodeposition were balanced with CO_2 emissions from root respiration. The rice plants at the end of cultivation were the carbon supply to ecosystem after CO_2 fixation from air through photosynthesis neutral with plant respiration. At the same time, CO_2 is released back into the atmosphere through microbial respiration. Microbial respiration was assumed as decomposition of rice residue and soil organic matter (SOM).

Percolating water transports inorganic and organic carbon from the plow layer to the subsoil layer. Kimura et al. (2004) concluded that about 90% of CO2 in percolation water accumulated in the subsoil layer by adsorbing at clay minerals, soil organic matter and Fe oxides/hydroxides. Therefore, carbon loss due to percolation was negligible in this study.

Table 4.1 The amounts of organic matter supplied to the paddy soil during land preparation

Organic matter apply	**S**		**B**		**I**	
	1st crop	**2nd crop**	**1st crop**	**2nd crop**	**1st crop**	**2nd crop**
Seed	15.62	15.62	15.62	15.62	15.62	15.62
Rice stubble	293±85	314±88	-	-	-	-
Rice straw and stubble	-	-	-	-	490±141	665±9
Residue after farm burning*	-	-	84.74±24	110±32	-	-
Total (g/m)	309±11	330±89	100±10	126±1	506±2	680±3

*fraction burn on field experiment = 82.73% (Kanokkanjana, 2010)

Table 4.2 Biomass load of experimental site (Kanokkanjana, 2010)

Year	2007	2008		2009
	2nd crop	1st crop	2nd crop	1st crop
rice straw (g/m2)	440 ± 372	259 ± 135	424 ± 202	368 ± 89
stubble (g/m2)	186 ± 66	236 ± 25	186 ± 35	677 ± 124

4.2.3 Carbon content in rice plant and soil

The harvested plants, rice straw and stubble were dried in an oven at 80 °C for three days and then their dry weights were measured. The rice plants were separated in five groups consisting of grain, root, straw, stubble and plant above ground. Each parts of rice plants were analyzed the C, N, H and S content with CHNS analyzer (NC-900 model).

Total carbon and total nitrogen in soil were analyzed with CN soil analyzer (Leco model TruSpec CN) as show in Figure 3.7(b). Soil sample 0.25 g packed in tin foil cup was burned in furnace at 850 – 950 °C. The homogeneous combustion gases in the ballast are then purged through the CO_2 infrared detector (IR) and the 3 CC aliquot loop. Once the gases have equilibrated, carbon is measured as CO_2. The gases in the aliquot loop are transferred to the helium carrier flow, swept through hot copper to remove O_2 and change NO_x to N2 and then flow through Lecosorb and Anhydrone to remove CO_2 and H_2O. Finally, a thermal conductivity (TC) cell is used to determine the nitrogen content in unit of percentage by weight.

4.2.4 Gases sampling and analysis

Methane (CH_4) and carbon dioxide (CO_2) fluxes were usually measured twice a week by the closed chamber method. The opaque chamber was used to avoid photosynthesis effect in daytime which used to trap gases emitted from plant and soil into atmosphere throughout the investigation period. The detail of Gases sampling and analysis was explained in the methodology, Chapter 3.

Gases from open field burning

In B plot, the emissions of CO_2, CH_4 and N_2O from rice straw burning were estimated by IPCC method as in revised guidelines 1996 in the topic of field burning of agricultural residues. The methodology for estimating greenhouse gas emissions from burning of agricultural wastes is based on (1) total carbon released, which is a function of the amount and efficiency of biomass burned and the carbon content of the biomass, and (2) the application of emission ratios of CH_4 and CO to total carbon released, and of N_2O and NOx to total nitrogen released from biomass fires which are available from the scientific literature on biomass burning. It is generally recommended for all emissions from agriculture (IPCC, 1996).

For this carbon budget study, we considered only carbon from field burning, therefore CO_2, CH_4 and CO were included in terms of total carbon released calculated by the equation below (adapted from IPCC 1996 revised guidelines):

Total carbon released (grams of carbon/area) = (biomass of residue) x (the average dry matter fraction of residue) x (the fraction actually burned in the field) x (the fraction oxidized) x (the carbon fraction)

Where the fraction actually burned in the field was assessed in the experimental field (0.82) by Kanokkanjana, (2010). The fraction oxidized = 0.9, as in IPCC guidelines (IPCC, 1996).

4.2.5 Estimation of carbon budget in rice field

In this experiment, carbons supplied to the rice field soil (input) account for seedling, burnt residue, rice straw, stubble and rice plant. At the same time, carbon in the soil is lost by gaseous emissions such as CO_2 and CH_4. Other lost of carbon from the soil are grain yield and straw removal. Carbon budget can be estimated by integrating the amounts of this net carbon in term of carbon supply and removal.

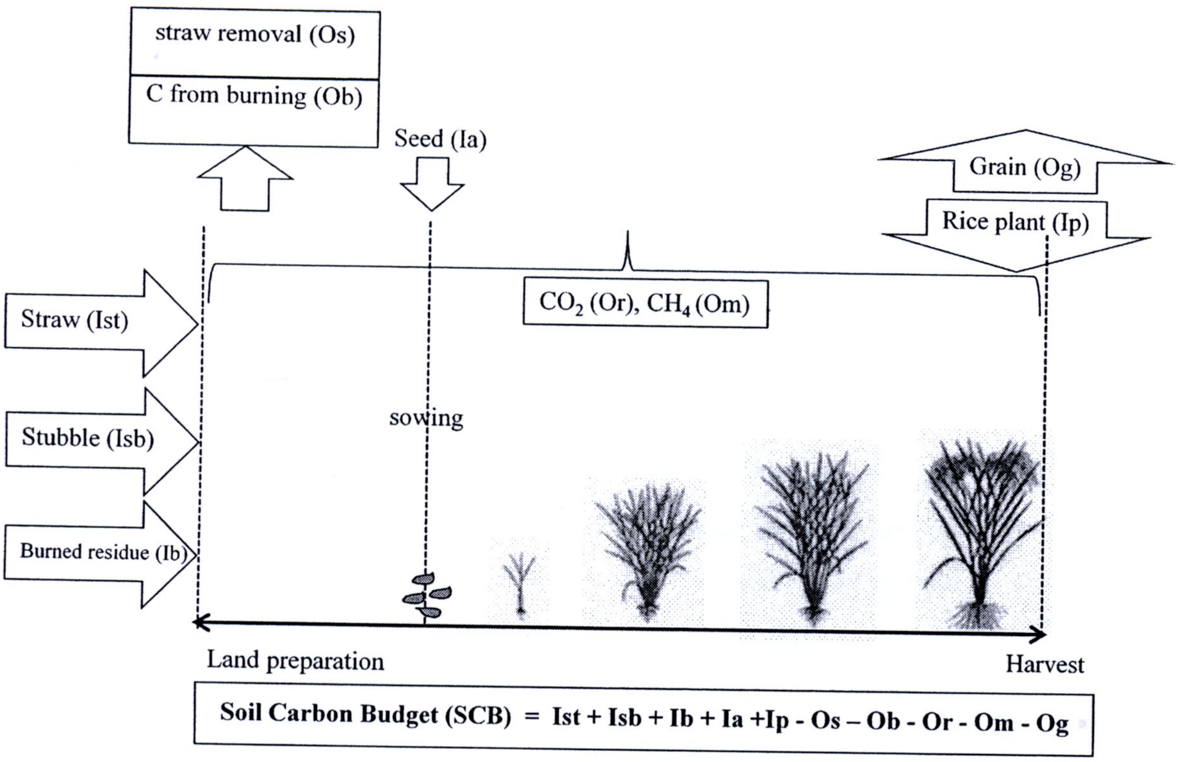

Figure 4.2 The schematic of carbon budget in experiment rice field

Figure 4.2 shows the schematic of carbon budget in rice field. The carbon budget in each plots were calculated using carbon balance equation. The carbon accumulation into the soil is designated positive, and carbon loss from the soil is negative.

$$\text{Carbon budget} = Ist + Isb + Ib + Ia + Ip - Os - Ob - Og - Om - Or$$

Where, Ist is the carbon supplied to the soil by straw incorporation,

Isb is the carbon supplied to the soil by stubble incorporation,

Ib is the carbon supplied to the soil by residue after field burning,

Ia is the carbon supplied to the soil by seed/seedling and chemical fertilizer (urea),

Ip is the carbon supplied to the soil by above ground rice plant,

Os is the carbon removed by straw removal,

Ob is carbon emitted to atmosphere when open field burning for land preparation in burnt plot (B plot),

Og is the carbon removed by grain yield, Om is the carbon emitted to the atmosphere in the form of CH_4.

Or is the carbon emitted to the atmosphere in the form of CO_2 (microbial respiration)

Figure 4.3 and Table 4.3 clarify terms of application and discharge carbon in each experimental plot with different rice straw management. The rice straw managements consist of stubble incorporated (S), rice straw burning (B), and rice straw and stubble incorporated (I). After rice harvesting by machine, the rice plants were separated to rice straw and stubble. This study defined the "stubble" in S plots as a part of stem above ground 20-30 cm height that stand in the field, the other part is "rice straw" that was cut and removed from field. The rice straw and a part of stubble were burned on field and the residue from field burning was incorporated into soil as B plots.

Above ground plants biomass (Ip) was assumed carbon input to ecosystem as neutral of plant fix CO_2 from air through photosynthesis subtract with plant respiration.

In agroecosystem, the soil microbes decompose the crop residues, releasing as CO_2 some 85% of the carbon in the residues, and less than one-thirds remains in the soil as humus. Such a soil cultivated for row crops would typically lose about 2.5% of its organic carbon by soil respiration each year (Brady and Weil, 2002). In our experiment this loss amounts to some 64 gC/m^2, when the beginning of the rice cultivation, the upper 10 cm of soil contained 2,558 g/m^2 total carbon. Therefore, microbial respiration (Or) was assumed as decomposition of rice residue and soil organic matter (82-208 $gC/m^2/crop$). In the other study, Iqbal et al. (2009) assumed microbial respiration in paddy field by measure CO_2 fluxes from bare soil, in the absence of vegetation. Soil CO_2 flux from bare soil (148-241 gC/m2-season) and inter row (289-403 gC/m2-season) that no significant different among different fertilizer treatments were observed.

Table 4.3 The description terms of carbon in rice ecosystems

Term	Description	Equal (dry mass): unit; g/m^2/crop
Ia	carbon supplied to the soil by seedling	(mass of seed x %carbon in seed)
Ist	carbon supplied to the soil by straw incorporation	(mass of straw incorporated x %carbon in straw)
Isb	carbon supplied to the soil by stubble incorporation	(mass of stubble incorporated x %carbon in stubble)
Ib	carbon supplied to the soil by residue after open burning	(mass of straw and stubble - (mass of straw and stubble x %fraction burn)) x %carbon in straw and stubble
Ip	carbon supplied to the soil by above ground rice plant	(mass of above ground rice plant x %carbon in above ground rice plant)
Og	carbon removed by grain yield	(grain yield x %carbon in seed)
Os	carbon removed by straw removal	(mass of straw removed x %carbon in straw)
Ob	carbon from open field burning	(mass of straw and stubble x %fraction burn x %carbon fraction)
Or	carbon emitted to the atmosphere in the form of CO_2 (microbial respiration)	85% of carbon in residues incorporate into the soil + 64 g/m2, as decomposition of rice residue and soil organic matter
Om	carbon emitted to the atmosphere in the form of CH_4 emission	accumulate CH_4 flux x (12/16)

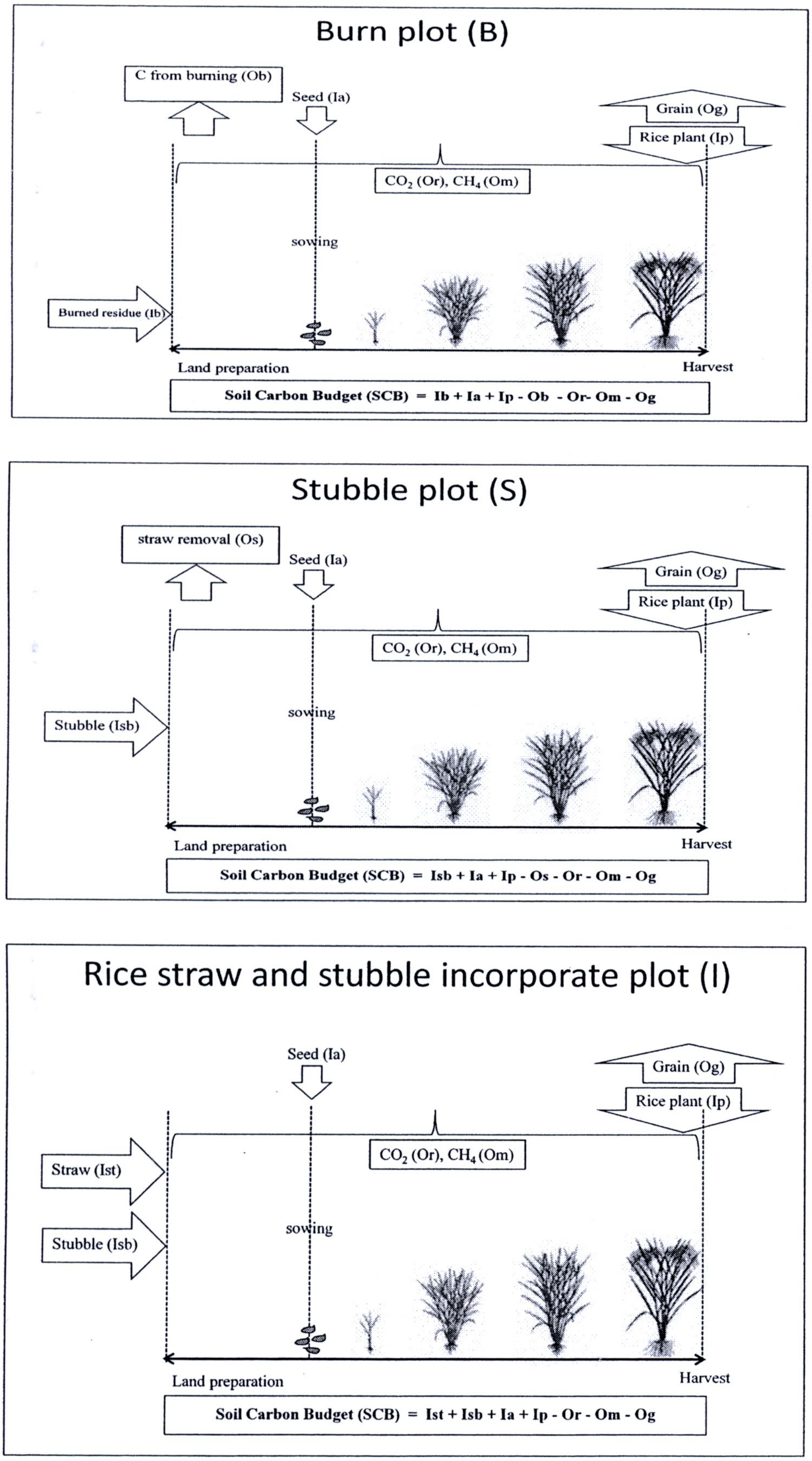

Figure 4.3 The carbon budget in 3 different rice straw management systems

4.3 Results and discussion

4.3.1 Seasonal CO_2 fluxes

In this study, the CO_2 fluxes included plant respiration and soil respiration. The seasonal CO_2 fluxes were divided into the following three treatments: stubble plot (S), burning plot (B), straw and stubble incorporate plot (I) which there were measured in 1st crop (Mid of April – August, 2007) and 2nd crop (September – December, 2007). Seasonal average CO_2 flux for each experimental plot was computed and summarized in Table 4.4. The seasonal variation had a significant difference (P value = 0.029) effect on the seasonal CO_2 emission with cumulative CO_2 generally higher in 2nd crop than in 1st crop. While, the rice straw management did not show any significant difference effect between each plot. However, the highest seasonal flux averages were obtained in stubble plot (3.67 kg/m^2 in dry season and 3.05 kg/m^2 in wet season).

Table 4.4 Seasonal CO_2 emission and in term of CO_2-C emissions from experimental plot

Treatment	Seasonal CO_2 emission (kg/m^2)		CO_2-C emission (kgCO_2-C/m^2)	
	1st crop	2nd crop	1st crop	2nd crop
S	3.05±0.13^a	3.67±0.22^b	0.83±0.04	1.00±0.06
B	2.94±0.03^a	3.24±0.47^b	0.80±0.01	0.88±0.13
I	2.87±0.67^a	3.35±0.15^b	0.78±0.18	0.91±0.04

Values after ± indicate SD. Values of total seasonal within a column followed by the same letter are not significantly different at $P < 0.05$ using ANOVA test.

The carbon sequestered in the soil can also be calculated by measuring the carbon input in terms of crop residue and other sources, and the amount of carbon released as CO_2 is measured. Duiker and Lal, (2000) found no significant differences in CO_2 flux (0.4-4.2 gC/m^2) between crop residue treatments, as similar with our experiment. Among the various environmental factors, soil temperature is the most major factor which determines soil CO_2 flux (Luo and Zhou, 2006). In addition, the straw applied into soil enhanced the seasonal CO_2 flux and, CO_2 emission from bare plot responded faster to temperature change (Jacinthe, Lal and Kimble, 2002). In the other hand, CO_2 emissions from the soil surface were limited in low level during the submerged period due to the restriction of CO_2 production under anaerobic soil condition (Nishimura et al., 2008). This experiment included the CO_2 flux from rice plant and soil respiration with disregard the photosynthesis process. The results show that the effect of rice straw management has not been clarified for CO_2 fluxes. On the other hand, the seasonal variation had a significant effect on cumulative fluxes.

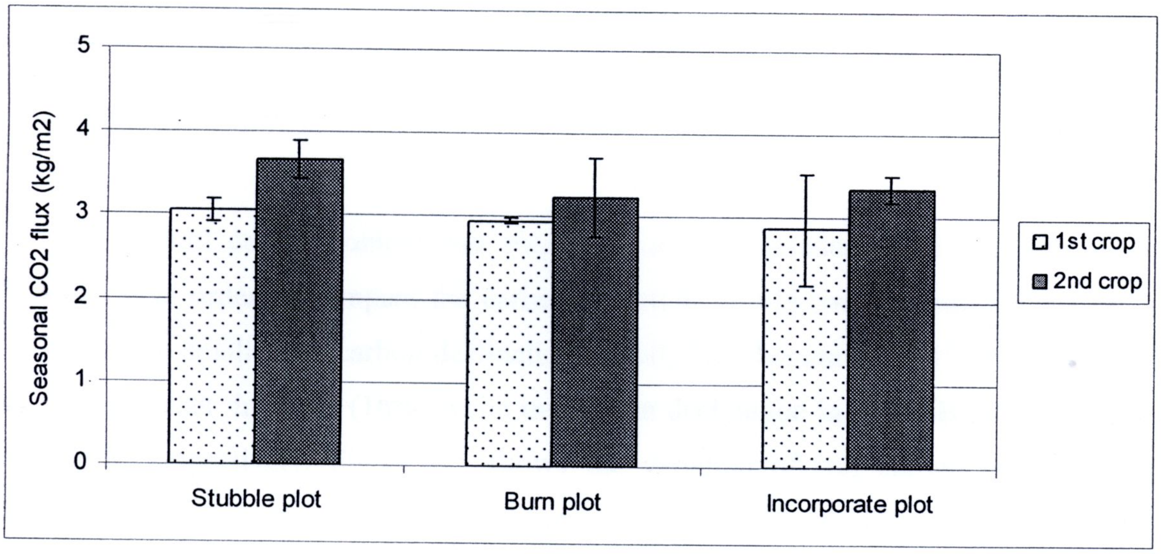

Figure 4.4 Cumulative seasonal CO_2 fluxes from three treatment of rice straw management. Errors bars indicate ± standard deviation.

4.3.2 Carbon content in rice plant and soil

The carbon content of rice plants were measured separately into 5 parts in order to evaluate the carbon input and output. The results of carbon analysis from plants are shown in Table 4.5. The carbon contents in plants were used for evaluating the carbon input from plants in each part of rice straw management. The percentage of C, N and H content in rice plant was the highest in grain, and the lowest in root, which is a feature of a food plant. The C/N ratio of rice straw and rice stubble are 15.65 and 33.6, respectively. C/N ratio in organic residues incorporated to soils is important because intense competition among microorganisms for available soil nitrogen occurs when residues having a high C/N ratio are applied to soil (Brady and Weil, 2002).

Table 4.5 Carbon content in rice plant

Part of rice plant	% C	% N	% H	% S
Root	12.72 ± 0.32	0.98 ± 0.73	2.03 ± 0.14	0.30 ± 0.04
Plant above ground	22.17 ± 0.19	1.54 ± 0.76	3.35 ± 0.08	0.15 ± 0.06
Grain	36.06 ± 0.14	1.87 ± 0.33	5.55 ± 0.10	0.02 ± 0.03
Stubble	26.88 ± 0.12	0.80 ± 0.75	3.94 ± 0.03	0
Straw	23.33 ± 0.38	1.49 ± 2.19	2.89 ± 0.83	0.06 ± 0.05
Average (stubble and straw)	25.11 ± 2.51	1.15 ± 0.49	3.42 ± 0.74	0.06 ± 0.05

The soil carbon content was measured in the beginning and harvesting of rice cultivation in order to compare the carbon depletion in different rice straw management systems. The smallest of carbon declination in soil, from beginning of 1st until harvesting in 2nd crop, was in I plot (16%) while the carbon declination in S and B plots were 25% and 26%, respectively. Figure 4.5 shows the variation of soil carbon content which increased in land preparation period and decreased in harvest period.

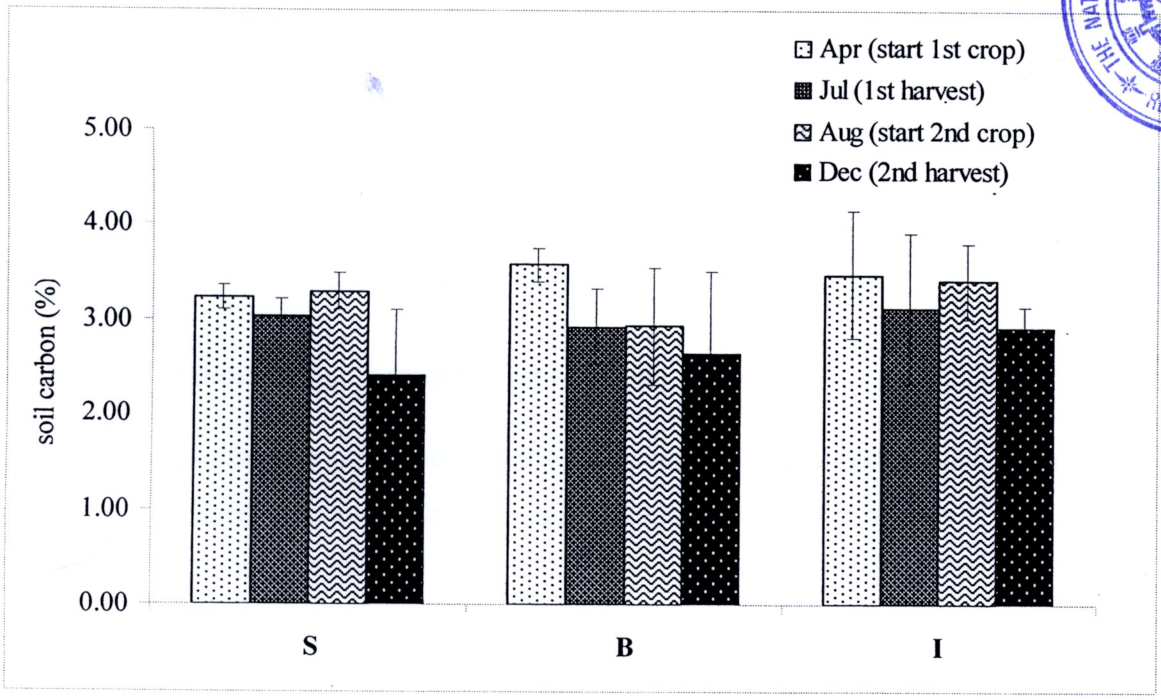

Figure 4.5 Average soil carbon content in three different rice straw management systems

4.3.3 Carbon budget in rice field with different rice straw management

A carbon mass balance was constructed for the carbon budget in stubble plot (S), burning plot (B), straw and stubble incorporate plot (I). The proper management of rice straw requires an understanding of the factor and processes influencing the cycle and balance of carbon in an ecosystem. To consider the dynamics of carbon in term of carbon budget in the rice field, gas fluxes data and the amount of carbon supplied and removed by agricultural management practices such as stubble, straw incorporation and crop harvest were estimated. Figure 4.6 shows the estimated carbon budget in 3 plots of rice straw management system that separate the carbon supply and carbon removal in each plot.

The carbon budget in burning plot (B plot)

The gains come primarily from rice plants and from applied organic materials. The carbon in rice plant approximated 161, 157 gC/m^2 in 1^{st} and 2^{nd} crop, respectively. Small amounts of carbon supply into soil, due to rice straw management by burnt, remained 21, 28 gC/m^2 of residue after burned in 1^{st} and 2^{nd} crop, respectively. Other supply of carbon is seed that applies in all treatments (6 gC/m^2). The carbon losses are due mainly to grain removals, CO_2 losses from burning, microbial respiration and methane emission. The primarily part of carbon removal in every plot is grain yield that show the highest in B plots but there are no significant differences between the rice straw management systems. Moreover, in B plot, the carbon released from rice straw burned was a large amount of carbon removal from traditional practice of rice straw management. Carbon release in terms of gases during field burning approximated 92, 120 gC/m^2 in 1^{st} and 2^{nd} crop, respectively, which cause the negative carbon budget in B plot which can be seen in Figure 4.6 and 4.7.

The carbon budget in stubble plot (S plot)

The main carbon apply into soil are rice plant and carbon in term of stubble left in rice field. The input carbon of rice plant approximated 132, 157 gC/m^2 in 1^{st} and 2^{nd} crop, respectively. The input carbon of stubble was approximated 79 and 84 g/m^2 in 1^{st} and 2^{nd} crop, respectively which depends on the rice straw management. In S plots, the carbon input was less than haft of I plot because the biomass proportion of straw:stubble was 40:60 in this studied. Therefore, we can control the amount of carbon incorporated by controlling the height of stubble that abandon in the rice field. The losses are due mainly to microbial respiration and grain removals (164 and 101 gC/m^2). High addition of organic matter results to increase of CO_2 from microbial respiration (131 and 136 gC/m^2). The minor carbon output in S plots were carbon in terms of rice straw removal and methane emission.

The carbon budget in straw and stubble incorporate plot (I plot)

The abundance of organic materials supplied to rice fields varies according to the rice straw management system at the beginning of cultivation. I plots were incorporated mostly carbon supply in terms of rice straw and stubble, plurality of carbon apply into soil was 125, 170 gC/m^2 in 1st and 2nd crop, respectively. The carbon in rice plant approximated 167, 157 gC/m^2 in 1st and 2nd crop, respectively. While the carbon departure from I plot were microbial respiration, grain removal and methane emission. The main losses are microbial respiration as 170 and 208 gC/m^2 in 1st and 2nd crop. Grain removed carbon from rice system about 166 and 103 gC/m^2 in 1st and 2nd crop. Methane emission during rice cultivation showed small effect to carbon budget in rice ecosystem (Figure 4.6).

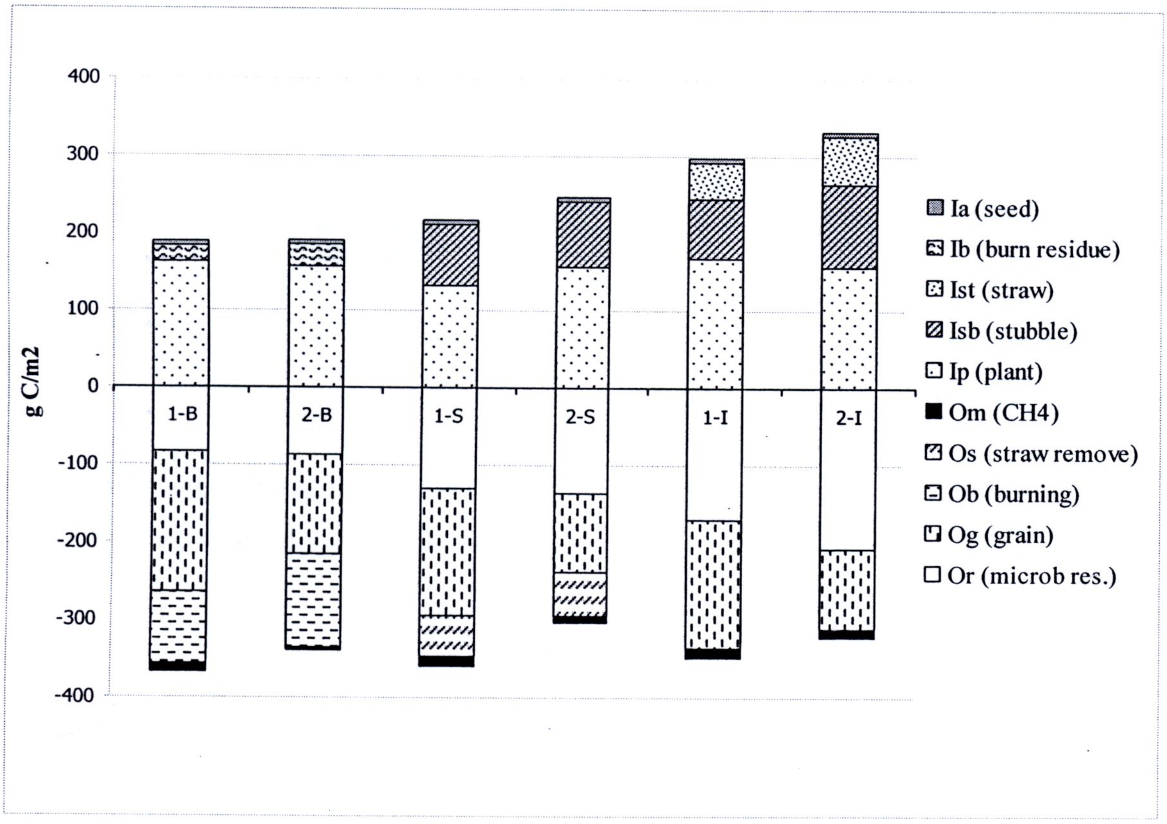

Figure 4.6 Carbon input and output of three plots, stubble incorporation (S), rice straw burning (B) and stubble with rice straw incorporation (I)

Continuing carbon budgets in three different rice fields

The carbon budgets of B plot showed the most negative with both crops (-180 gC/m^2 and -150 gC/m^2), which indicated carbon loss from ecosystem. The results of carbon budgets in S plot shows negative value, but in second crop the carbon budget increases (-143 gC/m^2 and -57 gC/m^2, in 1st and 2nd crop, respectively). In the other hand, I plot lost carbon in first crop, but carbon budget increased to positive in second crops (-52 and 9 gC/m^2), which indicated the accumulation of carbon in the soil, as shown in Figure 4.7. In burn plots, the carbon departed from soil preparation by open field burning cause the input residue smaller than incorporated plots (S and I). Although carbon removal from stubble incorporate plots is rice straw remove after harvest but the stubble was incorporated (remaining part) into the soil as carbon input.

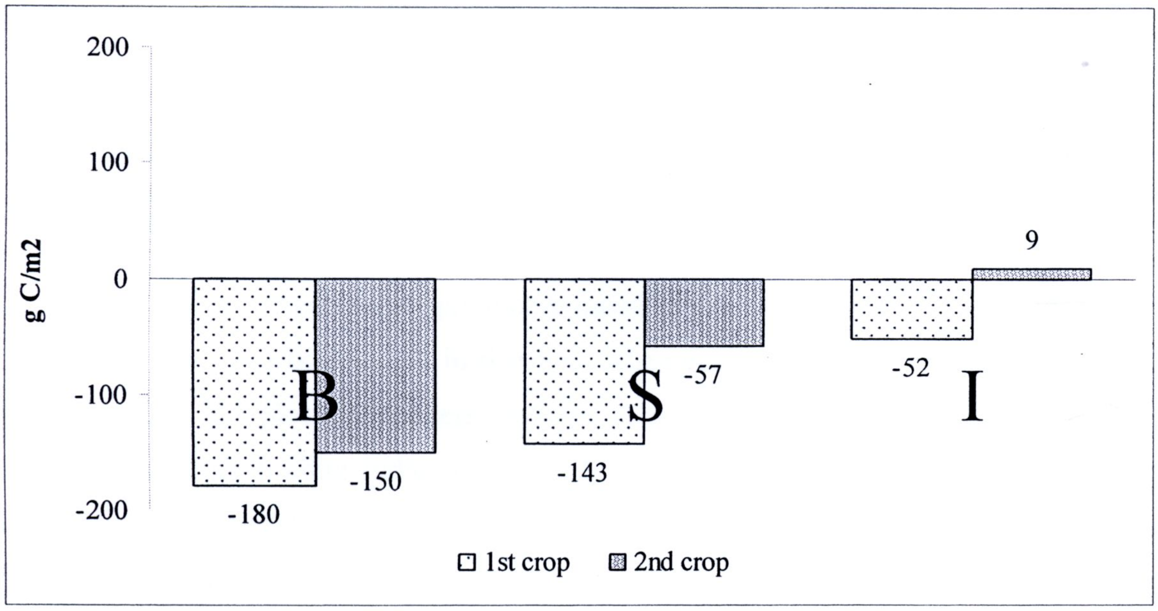

Figure 4.7 Carbon budgets in three plots, stubble incorporation (S), rice straw burning (B) and stubble with rice straw incorporation (I).

The trend of carbon budget in every plot was adopted to increase in the 2nd crop. The mass balance approach performed well in the case of rice straw management by incorporated into the soil. Although the addition of carbon in to the soil and anaerobic condition in paddy field encourage the rising of methane emission, but the application of water drainage during flowering period mitigated the methane emission. The contribution of CH_4 emissions to carbon budget was minor when comparing with other parts.

Normally, amount of carbon removed by the crop harvest was higher than the carbon supply, and therefore, the estimated carbon budget became negative and could not be compensated by only straw or stubble incorporation. The amount of carbon supply required for maintaining soil carbon content may be quite high (Nishimura et al., 2008). Another previous field experiment by Minamikawa et al. (2005) showed that the soil carbon budget in a Japanese rice field was a loss of 65-100 gC/m^2/season. Witt et al. (2000) reported an increased amount of soil carbon induced by rice-rice double cropping for 2 years in the Philippines. Iqbal et al. (2009) estimated soil carbon sequestration in subtropical paddy soil. The amount of carbon sequestration ranged from -176 to -89 gC/m^2/season with the highest value observed from NPK fertilizer and straw added treatment.

4.4 Summary

The amount of carbon supply incorporated by the rice straw and stubble resulted in the better value of carbon budget in rice field when compare to the rice straw burnt field. Carbon budget in I plot showed less negative value in first crop and became positive in second crop. This finding indicated that the incorporated residues can slow down the carbon loss from soil. Moreover, in the long term, the continuous incorporate residues tend to increase the potential for carbon storage in soil. On the other hand, the burning rice straw practice induced the soil carbon loss from rice field more than unburned practice did.