Impact of Rice Straw Addition and Soil Tillage on Density of Organic Carbon Components in Paddy Soil, the Contribution of Methane Emission into Atmosphere and Global Warming Potential

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Abstract

Rice production caused methane emissions from rice fields into the atmosphere. This experiment aimed to elucidate the impact of soil tillage and rice straw addition on the density of organic carbon components in the paddy soil, the contribution of methane emission into the atmosphere and the global warming potential. The experiment was conducted in irrigated area during the second rice cropping season in 2008. Completely randomized design of 2 x 3 factorial treatments with 2 levels of rice straw addition; with and without rice straw addition, and 3 conditions of soil tillage; 1) no tillage, 2) incorporation of rice stubble, and 3) incorporation of rice stubble, harrowing and then puddling. The total 6 treatments were carried out with 3 replications. Using the Chainat 1 rice, the result found that soil tillage affected the density of organic carbon components in paddy soil. The increasing number of soil tillage accelerated the decomposition of rice straw and stubble leading to the decreasing density of total organic carbon (TOC) and each component, i.e., rice roots (RR), particulate organic residue (POR) and soil organic carbon (SOC). The addition of 4 tons of rice straw per rai to paddy soil in one growing season had no effect on the accumulation of organic carbon in soil. The experiment further revealed that total methane emission (TME) increased with increasing number of soil tillage and ranged from 20.6 to 102.3 $gCH_4\ m^{-2}$ equivalent to Global Warming Potential (GWP) of 129 to 642 $gC_{eq}\ m^{-2}$. Furthermore, stubble incorporating, harrowing and then puddling released higher TME by 53% compared with no tillage while incorporation of 4 tons of rice straw per rai, harrowing and puddling released higher TME and GWP by 65% compared with no rice straw and no tillage. However, reduction of tillage and soil preparation with stubble incorporation under moist-soil condition alone could decrease methane emission and mitigate global warming potential (GWP) by 32% compared with no tillage.

Keywords: methane, organic carbon, global warming

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Introduction

The world community is currently facing with the crisis of climate change affecting the cultivation of agricultural product further resulting in some areas the lack of food security. Thailand itself has the stability of food as being a number one exporter of rice with total rice cultivated area of 70,187,000 rais while 12,801,226 rais can produce two rice croppings with second rice 687 kilograms per rai on an average (Office of Agricultural Economics, 2007). The government has encouraged farmers to follow sustainable agriculture to increase the productivity of organic rice and environmental restoration (Office of the National Economic and Social Development Board, 2009). In rice production, farmers usually added rice straw into the soil during the tillage process which normally comprised the stage of stubble incorporating, harrowing and puddling. The added rice straw became a source of nutrients and restored both chemical and physical properties of soil which would enhance rice growth. Additionally, rice straw, the roots of rice, and dead organic substances in soil would decompose under anaerobic condition leading to the formation and emission of greenhouse gases (CH_4 and CO_2). Consequently, the present research studied the impact of soil tillage and rice straw addition on the density of organic carbon components in soil, quantity of methane emission and global warming potential.

Methodology

Studied areas and Experiments

The research was conducted in the irrigated area located in Moo 3, Tambol Nong Toom, Amphur Muang, Khon Kaen Province during the second cropping season in 2010. The soil was classi fied as sandy loam Paleustults. Factorial treatments in CRD were arranged with the first factor comprising 2 levels of rice straw addition: with and without rice straw addition. The decomposed rice straw used was black and dark brown with C:N ratio of 42, tested at a rate of 4 tons per rai. Factor 2 comprised different conditions of soil tillage: 1) no tillage, 2) incorporation of rice stubble[4], and 3) incorporation of rice stubble, harrowing[5] and then puddling[6]. The total 6 treatments were carried out with 3 replications. The amount of rice stubble before experiment was around 1,242 kilograms per rai. The “Chainat 1” rice was sown with a rate of 10 kilograms per rai.

Collection of Soil Sample

Fresh soil samples were collected at 34 and 94 days after sowing and after the experiment. Using PVC pipe of 0.27 meter in diameter pressing the soil to a depth of 0.15 meters, fresh soil and rice plants inside the pipe were collected to measure the density of particulate organic residue (POR), rice root (RR), soil organic carbon (SOC) and total organic carbon (TOC) in soil. The gas samples were collected once a week during 9.00-11.00 a.m. by using closed chamber method and analyzed the concentration of methane gas using a gas chromatograph (Saenjan et al., 2002). Methane emission rate (MER) in $mgCH_4\,m^{-2}day^{-1}$, total methane emission (TME) in $gCH_4\,m^{-2}$ during the cropping season (Saenjan et al., 2002) and global warming potential (GWP) in CO_2-C equivalent were calculated.

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[4] *The first disc plowing using tractor to incorporate rice stubble into the moist soil, turning subsoil round the surface.*

[5] *Using walking tractor to destroy large soil aggregates into smaller aggregates, commonly done in wet soil condition.*

[6] *Puddling muddy soil to make it soft and easy to germinate rice seeds or transplanting.*

Statistical analysis

Analysis of variance in density of various organic carbon components (RR, POR, SOC and TOC) in soil, MER, TME, GWP and comparison of treatments by using Duncan's multiple range test (DMRT) with MSTAT-C program.

Results and discussion

1. Impact of rice straw addition and soil tillage on the density of various organic carbon components in paddy field soil during rice growing season

1.1 Density of rice root (RR) in paddy soil

The density of fresh rice root during rice growing season increased when comparing to that before the experiment (Figure 1a). At 34 days after sowing, the density of rice root ranged around 216-428 grams per square meter per 0.15 meters. The result was similar to the study of Kruapukdee (2009) who found that the density of rice roots at 40 days after sowing would range around 216-377 grams per square meter per 0.15 meter. The same study also found that the addition of rice straw compost together with incorporation of rice stubble and harrowing would increase the density of rice root from 216 to 377 grams per square meter per 0.15 meter. In the present experiment, at 94 days after sowing, the density of rice root increased to a range of 1,194-2,121 grams per square meter per 0.15 meter. The treatment without tillage (NT) and the treatment with rice straw with no tillage (RSNT) had the highest density of rice root in soil. This result showed higher density of rice root comparing with Kruapukdee's result (2009) which exhibited the density of rice root at 101 days after sowing ranged 667-1,174 grams per square meter per 0.15 meter. After the harvest of this experiment, rice density ranged from 793-1,434 grams per square meter per 0.15 meter. The no-tillage treatment (NT) had the highest density of rice root statistically significant during the growing season comparing with treatment with tillage especially at 94 days after sowing and at harvest. It might be because of no-tillage made the soil suitable for growth of roots throughout the growing season. However, the density of rice after 34 days and 94 days and after the harvest for both rice straw addition and without rice straw decreased substantially due to the puddling.

1.2 Density of particulate organic residue (POR) in the paddy soil

The density of particulate organic residue (Figure 1 b) increased after preparing the soil for 34 days and was in the range from 1,464 to 4,062 grams per square meter per 0.15 meter. The treatment with no tillage (NT) and the treatment with rice straw and no tillage (RSNT) generated the highest density of POR. This was due to the addition of rice straw, some of which was dead roots, and the no tillage practice caused an increase in POR. After 94 days of soil preparation, the density of POR reduced in the range of 608 to 1,553 grams per square meter per 0.15 meter. No tillage treatments and stubble incorporation treatments (NT, I, RSNT and RSI) generated higher density of POR than those with incorporation of rice stubble, harrowing and puddling (IHP and RSIHP) since the puddling accelerated microclimate change in soil suitable for the decomposition of organic substances in flooded soil (Parton et al. 1996). Consequently, the density of the POR remained less than that of stubble incorporation throughout the growing season. And at harvest, the density of POR decreased with a range from 344 to 664 grams per square meter per 0.15 meter. It was obvious that the density of POR after preparing the soil at 34 days, 94 days and after harvest for the treated soil either with or without rice straw would decrease due to puddling. This result corresponded with Kruapukdee's findings in 2009 that the puddling would result in lower density of POR than the incorporation of rice stubble significantly. Besides, the increasing number of tillage especially puddling would accelerate decomposition of organic substances in the flooded soil leading to smaller amounts of remaining POR.

1.3 Density of soil organic carbon (SOC) in paddy soil

Density of SOC always altered during the growing season (Figure 1 c). During the 34 days after soil preparation, density of SOC slightly dropped comparing with pre-experiment period. Soil with rice straw and no tillage (RSNT) had the highest content of organic carbon; the density of SOC in such treated soil increased till 94 days after sowing. Afterwards density of SOC of the whole experiment declined to be 1,290 kilograms per rai at harvesting comparing with 2,363 kilograms per rai prior experiment. This indicated that the addition of 4 tons of rice straw per rai to paddy field soil for one cropping season did not induce accumulation of SOC. Additionally, Vityakon (1991) found that a long-term addition of organic carbon in soil including the new addition or the recycling of dead crops could increase organic substances in soil. Potter et al. (1997) also found that minimal soil tillage or even no tillage enhanced organic substance accumulation. In addition, carbon sequestration in soil was beneficial to the environment and was an alternative to reducing emissions of carbon dioxide and methane into the atmosphere (IPCC, 2001).

1.4 Density of total organic carbon (TOC) in paddy soil

The density of total organic carbon (TOC) in paddy soil obtained by summing up the density of rice root (RR), particulate organic residue (POR) and soil organic carbon (SOC) in paddy soil which was collected at 0-0.15 meter in depth. The TOC ranged from 1,840 to 6,309 grams per square meter per 0.15 meter (Figure 1d). The density of TOC increased significantly during the rice growing season and later declined to a lower level than the prior-cropping season. After 34 days of soil preparation, the TOC ranged 2,407-5,561 grams per square meter per 0.15 meter. Soil with no tillage (NT) and rice straw with no tillage (RSNT) had highest organic carbon content, i.e. the density of TOC at 94 days after soil preparation for both mentioned treatments ranged from 3470-6309 grams per square meter per 0.15 meters. It was observed that no tillage soil with and without rice straw (NT and RSNT) possessed highest TOC. In such soils TOC decreased substantially at 34, 94 days after soil preparation and at harvest due to the puddling. The increasing frequency of tillage related to decreasing the density of each organic carbon component because puddling enhanced decomposition of organic carbon. The puddling was expected to cause microorganisms to access into each component of organic carbon easily, thereby accelerating the decomposition of organic substances in soil

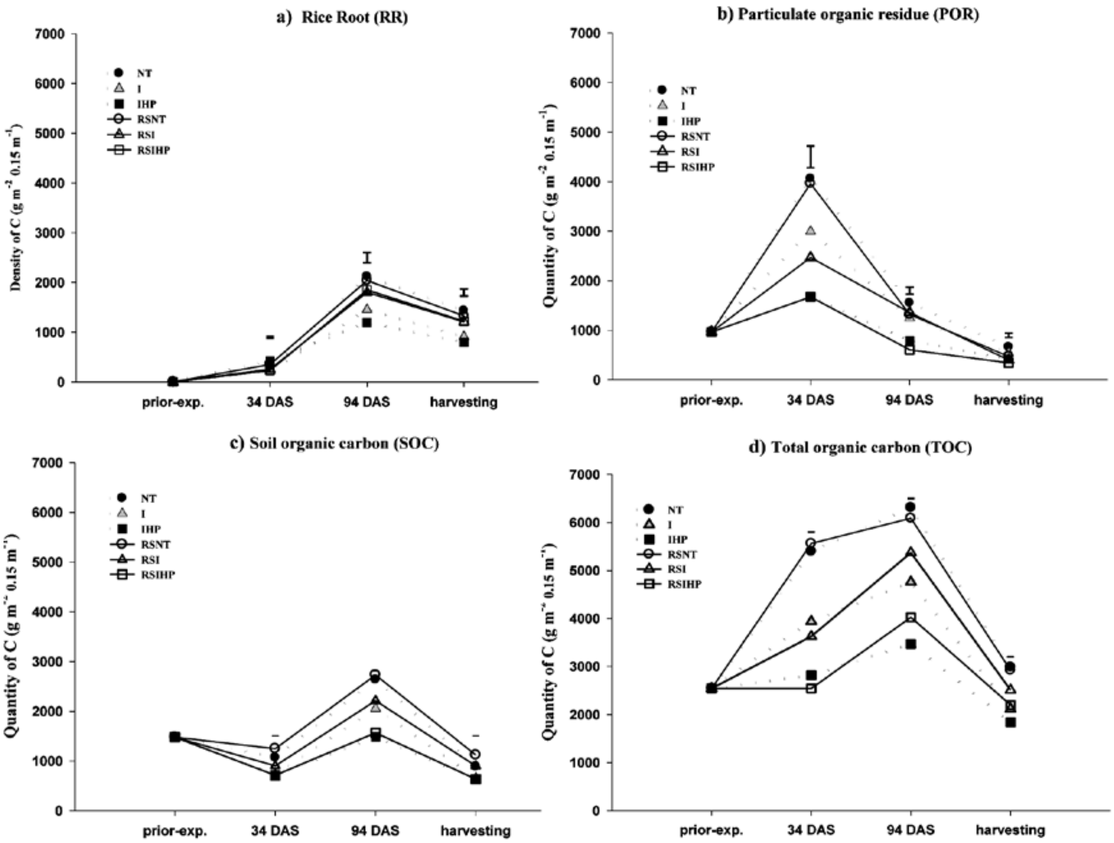

Figure 1. Dynamics of different parts of the organic carbon in soil throughout the growing season:-

a) Rice Roots, b) Particulate Organic Residue, c) Soil Organic Carbon and

d) Total Organic Carbon. Vertical line means the error bar with confidence level of 99%.

NT:No Tillage; I:Incorporation of Stubble; IHP:Incorporation of Stubble, Harrowing and Puddling; RSNT:Rice Straw and No Tillage; RSI: Rice Straw and Incorportating Tillage; RSIHP:Rice Straw, Incorporating Harrowing and Puddling

2. The effect of rice straw addition and soil tillage on methane emission rate (MER) throughout the cropping season

In soils without rice straw (Figure 2a) generated low MER after sowing and gradually increased until the rice reached the heading stage (89 days after sowing). Soil with incorporation of stubble, harrowing and puddling (IHP) emitted the highest amount of methane at 1,511 mg m^{-2}d^{-1} followed by no tillage (NT) plot with 897 mg m^{-2}d^{-1}. And the incorporation of rice stubble (I) plot had the lowest methane level of 634 mg m^{-2}d^{-1}.

For the treatments with rice straw (Figure 2b), there was remaining rice stubble approximated to 1,242 kilograms per rai and another 4 tons of rice straw per rai was added and flooded with water. The MER in the early period (0-40 days after sowing) reached the highest rate for the paddy field with RSIHP treatment of 1,406 mg m^{-2}d^{-1} at day 28 after the sowing. This was due to the fact that the produced methane was derived from incorporated organic residue in flooded soil which was done one day before sowing. Organic substances decomposed under anaerobic condition to produce methane and released it from soil by diffusion through the layer of water above the surface, and also moving of methane bubbles to rise over the surface (ebullition) (Le Mer and Roger, 2001).

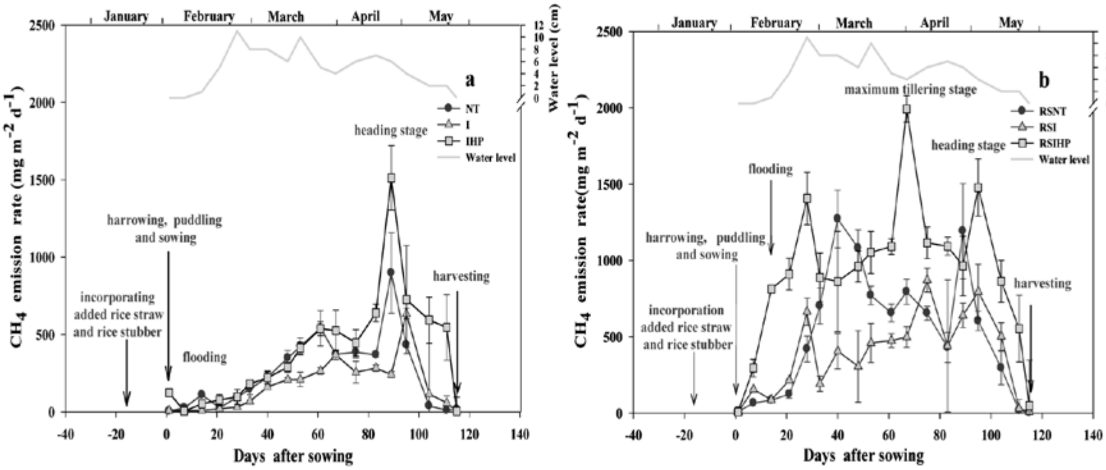

Figure 2. The effect of rice straw addition and tillage on methane emission rate from the paddy soil which: a) no rice straw and b) with rice straw

NT:No tillage; I:Incorporation of stubble; IHP: Incorporation of Stubble, Harrowing and Puddling; RSNT:Rice Straw and No Tillage; RSI: Rice Straw and Incorporating; RSIHP:Rice Straw, Incorporating, Harrowing and Puddling

After sowing, the effect of rice straw on MER was obvious. The MER during the second period (maximum tillering stage at 61-67 days after sowing) reached 1,992 mg m^{-2}d^{-1} which was the highest rate in the soil with rice straw, incorporation of rice stubble, harrowing and puddling (RSIHP) due to the addition of rice straw and puddling resulting in higher density of rice plant per area. (Junthakosin et al., 2009). This also accelerated the decomposition of organic substances creating the substrate of methane gas. This process also releases nutrients to rice plants yielding the good rice growth and tillering. Consequently, rice plants provides transport channel for methane from submerged soil to atmosphere resulting in higher amount of seasonal methane emission.

The third period of MER exhibited at the heading stage (89 days after sowing), plotted soil with rice straw, incorporation of rice stubble, harrowing and puddling (RSIHP) released the highest MER at 1,478 mg m^{-2}d^{-1}. Because the rice roots secreted root exudates, slough off and dead of old roots, becoming the source of substrate for methanogens (Wassmann et al., 2000). The experiment found that addition of rice straw and soil preparation with puddling enhanced methane emission as rice plant grew relatively well. Additionally, soil tillage and puddling promoted decomposition of rice straw as well as plant nutrient released for rice growth and simultaneously allowed a better transport of methane. (Nouchi et al., 1990).

3. Influence of rice straw addition and soil tillage on total emission emission (TME) and global warming potential (GWP)

The total methane emission (TME) during the rice cropping season ranged from 20.6-102.3 gCH_4 m^{-2} with global warming potential (GWP) of 129-642 gC_{eq} m^{-2} (Table 1) The treatment with incorporation of stubble, harrowing and puddling (IHP) resulted in higher TME during the cropping season and increased GWP by 53% compared with no tillage (NT). The mentioned paddy field soil with rice stubble incorporation (I) originally was incorporated 18 days before sowing. During that time, soil was moist and aerobic causing the organic substances in the soil to decompose to a certain extent, therefore TME declined and reduced the global warming by 32% compared with the no-tillage soil. It was clear that reduced tillage by preparing soil just only incorporation of rice stubble under field-capacity moisture condition could reduce TME and GWP down by 32 %.

Table 1. The effect of rice straw addition and soil tillage on total methane emission rate during the cropping season (TME) and global warming potential

Treatment	TME	GWP	Impact on GWP (%)	
	(g CH_4 m^{-2})	(g C_{eq} m^{-2})	Tillage	Rice Straw Addition
NT	30.2 bc	190	-	-
I	20.6 c	129	-32	-
IHP	46.2 bc	290	53	-
RSNT	62.2 b	390	-	105
RSI	45.0 bc	282	-28	119
RSIHP	102.3 a	642	65	121
F-test	**	-	-	-
CV %	22.9	-	-	-

The average data (n = 3) with the same letter in the same column was statistically indifferent at the confidence level of 95 % (*)and 99 % (**). The treatments were compared by DMRT, TME: total methane emission, GWP: global warming potential (CO_2 : CH_4 = 1 : 23); GWP = TME x 23 x 12/44 g C_{eq} m^2; NT:No tillage; I:Incorporation of stubble; IHP: Incorporation of Stubble, Harrowing and Puddling; RSNT:Rice Straw No Tillage; RSI: Rice Straw and Tillage; RSIHP:Rice Straw, Incorporating, Harrowing and Puddling

For the treatments with rice straw and soil tillage, the effect of soil tillage on TME was similar to that without the rice straw. The plot with rice straw followed by soil tillage (RSI) had TME of 45.0 $gCH_4\ m^{-2}$ while the plot with rice straw, incorporation of stubble, harrowing and puddling (RSIHP) had the highest TME at 102.3 $gCH_4\ m^{-2}$. Consequently, when the soil tillage reduced, the TME and GWP dropped by 28%. The plot with RSIHP had the highest TME at 102.3 $gCH_4\ m^{-2}$ pushing GWP up by 65% when comparing with no soil tillage. On the contrary, the rice straw addition resulted in TME and GWP to increase by 105-121 % compared with without rice straw. Nevertheless, we would like to mentioned rice production from such treatment (no data shown) that the treatment RSIHP could increase the rice production by 45 % when compared with rice straw and no tillage (RSNT) treatment. Similarly, the plot with RSIHP caused the rice production to increase by 28% when compared with no rice straw addition with incorporation of stubble, harrowing and then puddling (IHP) (Junthakosin et al., 2009). Rice straw addition and soil tillage increased the rice production while considerably increased the TME and GWP.

The above experiment might imply that reduction of soil tillage could reduce TME by 28-32%. However, there was another option to reduce methane gas such as effective use of water by allowing rice to consume up the water till the paddy soil become dry for sometimes. This could reduce methane by 44-70% (Saenjan et al., 2004). Sowing rice cultivation could reduce methane by 18-69% when compared with transplanting rice. Other than that, rice varieties also had influence on methane emission. Chainat1 released methane 67% of Sakol Nakon (data has not been published). The application of fertilizer into the paddy soil also had influence directly on the methane emission. As such, organic fertilizer would release methane more than chemical fertilizer did because the organic fertilizer worked as primary food source for methanogens. Top dressing of ammonium sulfate would reduce methane by 27% when compared with no application (Asami and Takai, 1970; Minami and Yagi, 1998). The cultivation of organic rice would release methane more than inorganic rice. Soil management to mitigate methane emission may cause an increase in carbon dioxide emission. However, the GWP of carbon dioxide was lower than methane.

Conclusion

Puddling the soil reduced the density of rice root (RR), particulate organic residue (POR), soil organic carbon (SOC), and total organic carbon (TOC) during growing season and at harvest regardless of rice straw addition. Additionally, the frequency of soil tillage inversely correlated to the density of organic carbon.

Puddling caused total methane emission (TME) and global warming potential (GWP) to increase by 53-65% while rice straw addition caused TME and GWP to increase by 105-121% when compared with the treatment without rice straw. However, the reduction of soil tillage through incorporation of stubble in moist-soil condition alone rendered TME and GWP to decline by 32% when compared with no tillage. Besides the impact of soil tillage and rice straw on methane emission and global warming potential, it is highly recommended that further comprehensive researches on the production of rice should be performed.

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