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RESEARCH ARTICLE

Quantification of direct and indirect greenhouse gas emissions from rice field cultivation with different rice straw management practices – A study in the autumn - winter season in An Giang Province, Vietnam

Phát thải khí nhà kính trực tiếp và gián tiếp từ sản xuất lúa theo các biện pháp quản lý rơm rạ khác nhau – Một nghiên cứu ở vụ Thu Đông ở tỉnh An Giang, Việt Nam

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This study resulted in a comparative analysis of greenhouse gas emissions (GHGE) for rice production with different in-field rice straw management practices based on an experiment conducted in An Giang Province of Vietnam, during the autumn - winter season of 2016. Direct field GHGE was analyzed based on *in-situ* measurement and the total direct and indirect GHGE were estimated by applying the life cycle assessment using Ecoinvent3 database which is incorporated in SIMAPRO software. The experiment was conducted based on a completely random design with three treatments and three replications. The three treatments are [T1] Incorporation of straw and stubbles treated with *Trichoderma;* [T2] Incorporation of stubbles and removal of straw; and [T3] In-field burning straw. Closed chamber protocol and gas chromatography (SRI 8610C) was used to measure and analyse CH_4 and N_2O. CH_4 emission rate was not significantly different (p>0.05) among the three treatments during sampling dates except on the days 17 and 24 after sowing (DAS). N_2O emission rate was not significantly different (p>0.05) either. However, there were high variations of N_2O emission after the dates of urea applied. Direct field emissions of CH_4, N_2O and CO2 equivalent (CO_{2eq}) are not significantly different among the three treatments, but the amount of CO2eq per kg straw in T1 of incorporating rice straw treated with Trichoderma is significantly higher than in T3 of in-field burning straw. LCA based analysis resulted in total GHGE in the range of 1.93-2.46 kg CO_2-eq kg^{-1} paddy produced consisting of 53-66% from direct soil emissions. Incorporation of straw treated with *Trichoderma* did not indicate the improvement of paddy yield. However, the organic matter, N-NH_4^+, and N-NO_3^- of this treatment was higher than those of the other researched treatments. This research was just conducted in one crop season, however, the results have initial implications for the other crop seasons.

Nghiên cứu này phân tích phát thải khí nhà kính từ sản xuất lúa theo các biện pháp quản lý rơm rạ khác nhau dựa vào thí nghiệm được thực hiện ở vụ Thu Đông năm 2016 tại tỉnh An Giang, Việt Nam. Lượng phát thải khí nhà kính từ đất đã được phân tích dựa vào kết quả đo đạt tại ruộng và tổng lượng phát thải khí nhà kính trực tiếp và gián tiếp được ước tính bằng phương pháp vòng đời sử dụng cơ sở dữ liệu Ecoinvent3 gắn kết với phần mềm SIMAPRO. Thí nghiệm được bố trí hoàn toàn ngẫu nhiên gồm 3 nghiệm thức và 3 lần lặp lại. Các nghiệm thức gồm [T1] vùi rơm và rạ với Trichoderma, [T2] lấy rơm ra khỏi ruộng và vùi rạ và [T3] đốt rơm. Kỹ thuật buồng kín (closed chamber protocol) và máy sắc ký khí (SRI8610C) được sử dụng để đo đạt và phân tích khí CH_4 và N_2O. Tốc độ phát thải khí CH_4 không khác biệt giữa ba nghiệm thức, ngoại trừ kết quả ở lần lấy mẫu 17 và 24 ngày sau sạ. Tốc độ phát thải N_2O cũng không có sự khác biệt giữa các nghiệm thức. Tuy nhiên, tốc độ phát thải biến động rất lớn sau các ngày bón phân đạm. Lượng phát thải trực tiếp từ ruộng của CH_4, N_2O và CO_2 tương đương (CO_2-eq) không có sự khác biệt giữa ba nghiệm thức, nhưng lượng CO_2-eq/kg rơm ở nghiệm thức vùi rơm và rạ với Trichoderma *(T1) cao hơn nghiệm thức đốt rơm (T3). Kết quả phân tích LCA cho thấy lượng phát thải khí nhà kính dao động trong khoảng 1,93 – 2,46 kg CO_2-eq/kg lúa với 53 – 66% lượng phát thải trực tiếp từ trong đất. Vùi rơm rạ với* Trichoderma *chưa cải thiện được năng suất lúa. Tuy nhiên, phần trăm chất hữu cơ và hàm lượng đạm hữu dụng trong đất của nghiệm thức này cao hơn so với hai nghiệm thức còn lại của thí nghiệm. Nghiên cứu này chỉ mới được thực hiện một vụ, nhưng đã mang lại nhiều kết quả có thể ứng dụng cho các vụ sau.*

Keywords: GHGE, methane, nitrous oxide, straw management practices

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1. Introduction

Lowland rice cultivation is one of the important sources of greenhouse gas emissions in agriculture (Bhattacharyya et al., 2012). According to VSC (2014), Vietnam emitted approximately 46 thousand tons of CO_{2eq} from rice production, which accounted for 50.5% of total GHGE from agricultural activities. Causes of greenhouse gas emissions in rice production are irrigated rice cultivation, over-fertilization, unsustainable straw and water management, and high density of sowing (Wassmann, 2000; Trinh *et al.*, 2013; Tin et al., 2015).

Mekong Delta produces about 24 – 26 million tons of rice straw annually (GSO, 2016; Arai et al., 2015). However, the most common practice of rice straw management is open burning (54 – 98%) and incorporating fresh rice straw (7 - 26%) (Nam *et al.,* 2014; Truc *et al.,* 2012). Only 2 – 13% of rice straw is used to produce straw mushroom (*Volvariella vovaraceae*) and feed for cattle. Burning rice straw is popular due to intensification, limit of straw utilization, and lack of regulation on burning straw (Truc *et al.,* 2012 and 2013).

Open burning rice straw causes air pollution and loss of nutrients while incorporating fresh straw and stubble releases greenhouse gas emissions, as well as organic poison to the young paddy (Gadde *et al.,* 2009; Gao *et al.,* 2003; Nguyen Quoc Khang and Ngo Ngoc Hung, 2014). In order to recommend the better practice of rice straw management, an experiment on in-situ rice straw practice has been conducted to estimate direct and indirect greenhouse gas emissions. The first treatment was incorporating rice straw and stubble with *Trichoderma. Trichoderma* acts as an activator to speed up the decomposition process in 15 – 25 days, reducing organic poison when incorporated with fresh straw or stubble to the paddy field; and supplementing organic nutrients as well (Son *et al.,* 2008; Tuyen and Tan, 2001). The two other treatments are incorporating fresh stubble directly to the field, and in-field burning of rice straw which is the most practiced rice straw management in the Mekong Delta (Nam *et al.,* 2014). After quantifying in-situ greenhouse gas emission, this study also calculated the total greenhouse gas emission by life cycle assessment.

2. Materials and methodologies

2.1 Experiment set up and materials

Materials: Rice cultivation was conducted during Autumn-Winter seasons of 2016 (August to December) at Dinh Thanh Agricultural Research Center in An Giang province of Vietnam ($10^0$18'45.19"N; $105^0$18'57.87"E). The experimental design applied was the Complete Randomized Design (CRD) with 3 treatments namely [T1] Incorporation of straw and stubbles treated with *Trichoderma;* [T2] Incorporation of stubbles and removal of straw; and [T3] In-field burning straw. The experimental plot of 25m^2 and three replications were done. The quantity of straw and stubble added in the experiment is listed in Table 1.

Table 1: Quantity of straw and stubbles added in the experiment

Treatment	Straw management	Quantity (kg ha^{-1})	
		Straw	Stubble
T1	Incorporated	2,697 ± 140 ^{a}	3,852 ± 201 ^{a}
T2	Removed	2,563 ± 7.1 ^{a}	3,660 ± 10.1 ^{a}
T3	Burning	2,850 ± 86.6 ^{a}	4,071 ± 124 ^{a}

Note: Means followed by the same letter are not significantly different among sampling days at 0.05 level as determined by Duncan

Agronomic and chemical inputs for the three treatments are described in Table 2. Rice seeds were sown by drum seeder. Fertilizer was applied at 10, 20, and 50 days after sowing (DAS) (panicle initiation stage).

Table 2. Agronomic and chemical inputs in the experiment

Unit: kg ha^{-1}

Inputs	Trade name	Quantity
Variety	Loc Troi 1	100
Trichoderma	TRICO-DHCT-LUA VON	1*
N	Urea (46%N); DAP (18%N-46%P_2O_5)	90
P_2O_5	DAP (18%N-46%P_2O_5)	45
K_2O	KCl (46% K_2O)	45

Note: only Trichoderma was added in T1

2.2 Measurement and analysis

Gas measurement: Gas measurement and analysis were adopted from the guideline of Minamikawa *et al*., (2015). Gas samples were collected based on closed chamber method at 0, 10, 20, and 30 minutes, then stored in 30ml vacuum vials.

Figure 1. Chamber to collect a gas sample

The chamber contains two main parts namely, the gas chamber with a volume of 120 L and height 70 cm height (V1), and the base with a diameter of 50 cm and height of 30 cm (V2) (Figure 1).

Samplings of GHGE were conducted after 10 DAS. The gas samples were collected at 9 am every week until 45 DAS and every ten days until 95 DAS. CH_4 and N_2O concentration were analysed using gas chromatography (Model SRI 8610C, Haye Sept-N) with FID and ECD detectors.

Direct field-emission formula: CH_4 and N_2O rates were estimated by the following formula (Parkin et al., 2003):

$$F = \frac{dC}{dt} x \frac{MV * 60 * 24 * 10}{A * (0.08206 * T)}$$

where F: CH_4 or N_2O flux ($mg.m^{-2}.day^{-1}$); T: temperature in the chamber (°K); V: volume of chamber; M: molecular weight of CH_4 or N_2O; A: surface area of chamber (m^2); $\frac{dC}{dt}$: rate of gas concentration in the chamber ($ppm.h^{-1}$); and V: volume of chamber ($V = V_1+V_2$). Again, V_1 is the upper part of the chamber, V2 is the lower part of the chamber (V_2 = A.h); while h is the height of water level from the ground surface inside the chamber and adjusted when the water level is higher than the ground surface.

The average emission rate is calculated by:

$$\bar{F} = \frac{\sum_{1}^{n} F_i}{n}$$

where F_i: CH_4 or N_2O flux of sampling date ($mg.m^{-2}.day^{-1}$), and n: number of gas sampling (n=11). The total quantity of CH_4 or N_2O emission per season (autumn-winter season) is equal to $\bar{F}$ multiply by the number of days per season (100 days).

Indirect field-emission formula: GHGE conversion factors of all related materials were based on the database of Ecoinvent3 incorporated in SIMAPRO software. Diesel consumption for mechanized operations and seed rate were assumed 150 litres and 100 kg per ha based on the normal practices observed in the experimented areas.

Indirectly calculated emissions of the fuel consumptions and agronomic inputs used the conversion factors shown in Table 3.

For straw burning, we used the emission factors of CH_4 and N_2O reported in Romasanta et al. (2017). This indicated that burning 1 ton of straw (dry matter) caused the emissions of 4.5 and 0.069 gram of CH_4 and N_2O, respectively.

Table 3. GHGE conversion factors of fuel, agronomic inputs, and products

Parameters	GHGE		Source
	Unit	Value	
Seeds	$kgCO_2$-eq kg^{-1}	1.12	a
Diesel consumption	$kgCO_2$-eq MJ^{-1}	0.08	a
Nitrogen (N)	$kgCO_2$-eq kg^{-1}	5.68	a
P_2O_5	$kgCO_2$-eq kg^{-1}	1.09	a
K_2O	$kgCO_2$-eq kg^{-1}	0.52	a
CH_4	$kgCO_2$-eq kg^{-1}	30.5	b
N_2O	$kgCO_2$-eq kg^{-1}	265	b

(Source: a = Ecoinvent, 2016 and b= IPCC, 2013)

Soil and water measurements

Soil samples were collected before incorporating straw and stubbles, 30, 60 and 90 DAS for each plot. Soil samples were taken at 0 – 20 cm from the surface to measure N-NH_4^+/N-NO_3^- and organic content.

Redox was measured in all nine plots with three replications by SWC-201RP at the same date and time of gas sample collection (at 9 am on the gas sampling date).

Water management followed the alternate wetting and drying (AWD) technology. However, it was not followed strictly due to the rainy season. The water level was recorded at 8 am every day at the experiment plot.

Crop measurement: Actual paddy yield was estimated by harvesting yield of $5m^2$ plots in all nine treatment plots and estimated dry yield (at 14% moisture content).

2.3. Statistical analysis

Means among treatments of CH_4, N_2O and $_{CO2\text{-}eq}$ and related parameters were tested by analysis of variance with Duncan test of 95% confidence. Besides, correlation analysis of water level and redox was also used by Pearson tests.

3. Results and discussions

3.1 Water level and redox potential

Water levels in the paddy field varied from –13 cm to 5 cm during experimental 95-day-period (Fig. 1a). Water management in this experiment tried to follow the alternate wetting and drying (AWD) technology even it was in rainy season. According to Bharati *et al*. (2001), the water level in the paddy field may affect the oxidation process in the soil, and thus may affect the emissions of CH_4 and N_2O. However, there are no significant correlations between water level and redox among three treatments.

In the first 45 DAS, the redox potential was low ranging from -120 to -160mV in all treatments (period of 10-46 days in Fig. 2b). It is indicated that the reduction process in the soil was the main process which happened during this period. The reason for this trend was caused by the fast degradation of the straw biomass in the first 45 DAS. Then the redox increased gradually until 95 DAS due to the low water level and slow straw degradation at the end of the season.

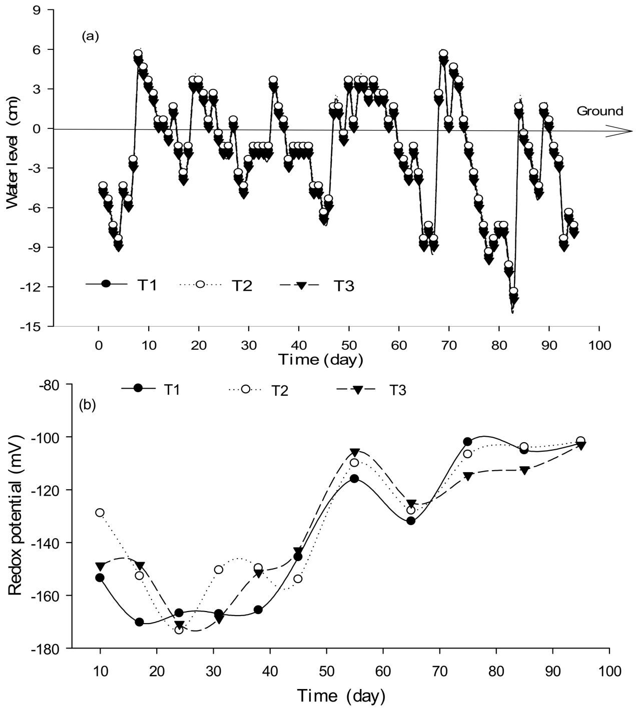

Figure 2. Water level (a) and redox potential (b)

3.2 Emissions of CH_4 and N_2O

3.2.1 Directly emission rate of CH_4

The average CH_4 emission rates of T1, T2 and T3 treatments fluctuated from 139.7 – 222.6 mg.m^{-2}.day^{-1} (Fig. 3). The emission rate of CH_4 in T1 was not significantly different from T2 and T3 treatments (p>0.05) in most of the sampling dates, except in 17 and 24 DAS. The strong decomposition process of T1 during this period may be the reason for the high CH_4 emission in comparison with T2 and T3. According to Du *et al* (2014), *Trichoderma* can decompose up to 40% of the straw within 20 days. Another report from Hoi (2008) concluded that the decomposition rate of rice straw was highest in the first 15 days, then the decomposition rate slows down causing the straw weight to decrease slowly.

There are high variations in CH4 emission rates among previous researches. For example, Neue and Sass (1998) reported that the average CH_4 emission rate in a rice field ranged from 240 to 520 mg.m^{-2} days^{-1}. Meanwhile, the study conducted by Bhattacharyya *et al.* (2012) showed that CH_4 emission rates ranged from 45.6 - 137 mg.m^{-2}.days^{-1}. The lowest emission rate was 85 DAS at 5.87 mg.m^{-2}.days^{-1} in which water level was -1 cm and redox was -112 mV in all treatments (Fig 3).

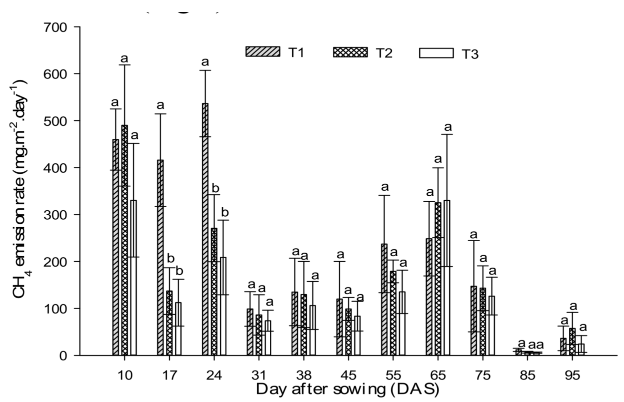

Figure 3. Direct emission rate of CH_4

Note: Means followed by the same letter are not significantly different among sampling days at 0.05 level as determined by Duncan

3.2.2. Directly emission rate of N_2O

The emission of N_2O in three treatments varied from 0 – 6.57 mg.m^{-2}.day^{-1} and there were no N_2O emissions in most of the sampling dates (Fig. 4). The data showed that just after applying chemical fertilizers, the N_2O emission was increased later. When fertilizers were applied on 8, 20, and 55 DAS, the N_2O emissions on 10, 24, and 65 DAS were dramatically increased (Fig. 4). Snyder *et al.* (2007) also reported that N_2O emissions are closely related to the amount of nitrogen applied in the field. However, there was no significant difference among the three treatments in terms of N_2O emission (p>0.05). It seemed that N_2O emission is more closely related to fertilizer application than straw management practices.

The knowledge and research on N_2O emission from the paddy field were quite limited compared to CH_4 (Jiang *et al.,* 2003). However, according to Lou *et al.,* (2007), incorporating rice straw increases N_2O emission, in comparison with removing the straw from the field. The emission of N_2O is increased when the soil is fertilized by organic matter, due to the increased nitrate reduction and nitrification of NH_4^+ in partly or full aerobic condition (Khuong and Hung, 2014).

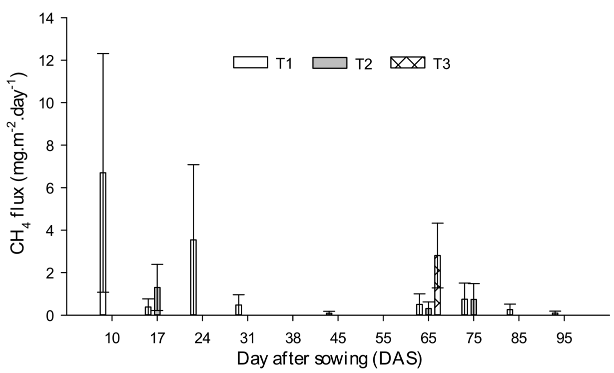

Figure 4. Direct emission rate of N_2O

3.2.3 Total directly emission of CH_4, N_2O and CO_{2eq}

a. Total CH_4 and N_2O of direct emissions

Fig. 5 illustrates that the average total emission of CH_4 is 179.1 ± 24.0 kg.ha^{-1}.season^{-1} (T1, T2 and T3 are 222.6, 174.9, and 139.7 kg.ha^{-1}.season^{-1}, approximately). The statistical analysis showed that there was no significant difference in CH_4 emissions among the three treatments (p>0.05). This value is higher than the value reported by Linquist et al. (2012) at 100 kg CH_4.ha^{-1}.season^{-1}.

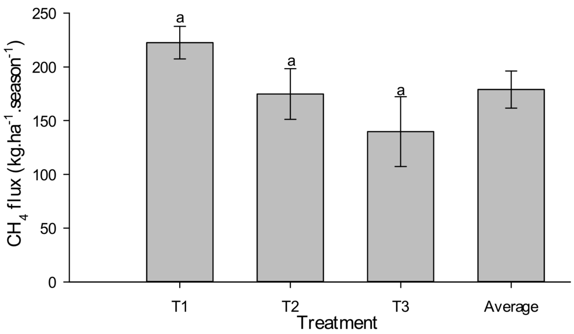

Figure 5. Total emission of CH_4

Note: Means followed by the same letter are not significantly different at 0.05 level as determined by Duncan

Similarly, there was no significant difference in N_2O emissions among three treatments, and it highly fluctuated from 0.21 – 1.16 kg.ha^{-1}.season^{-1} (Fig. 6). The N_2O emission also varied in all treatments (Fig. 6). Studying paddy fields, Pittelkow et al. (2013) stated that the total emissions were 0.2 to 0.4 kg N_2O.ha^{-1}, which was lower than the N_2O emission found in this study. The result of N_2O needs to be confirmed by repeating this experiment in both dry and wet seasons.

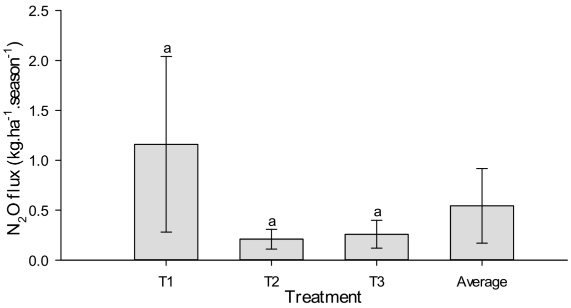

Figure 6. Total emission of N_2O

Note: Means followed by the same letter are not significantly different at 0.05 level as determined by Duncan

b. Total direct emissions of CO_{2eq}

The emission of CO_{2eq} was 4,330 – 7,097 kg CO_{2eq}.ha^{-1} and it was not significantly different among the three treatments (Table 4). However, the emission of CO_{2eq} per kg of rice straw incorporated to the rice field with *Trichoderma* in T1 (2.63±0.24 kg CO_{2eq}.ha^{-1}.kg rice straw^{-1}) was significantly higher than that of T3 treatment (1.52 ± 0.35 kg CO_{2eq}.ha^{-1}.kg rice straw^{-1}). The result of this study is in agreement with that reported in 2006 IPCC guidelines and other studies for the similar studies of straw incorporation with *Trichoderma* or compost (Truc, 2011; Wassmann *et al*, 2000).

Table 4. CO_2 equivalent emission

Treatment	Yields (kg.ha^{-1})	Rice straw (kg.ha^{-1})	CO_{2eq} (kgCO_2.ha^{-1}.season^{-1})	CO_{2eq} (kgCO_{2eq}.kg paddy^{-1}.season^{-1})	CO_{2eq} (kgCO_2.kg straw^{-1}.season^{-1})
T1	4,360 ± 112 ^{a}	2,697 ± 140 ^{a}	7,097 ± 639 ^{a}	1.62 ± 0.15 ^{a}	2.63 ± 0.24 ^{a}
T2	4,400 ± 97.0 ^{a}	2,563 ± 7.10 ^{a}	5,390 ± 743 ^{a}	1.22 ± 0.17 ^{a}	2,10 ± 0.29 ^{ab}
T3	4,250 ± 85.0 ^{a}	2,850 ± 86.6 ^{a}	4,330 ± 991 ^{a}	1,02 ± 0.23 ^{a}	1.52 ± 0.35 ^{b}
Average	**4,337 ± 98.0**	**2,703 ± 77.9**	**5,605 ± 806**	**1.29 ± 0.18**	**2.08 ± 0.19**

Note: Mean ± Standard Error; Means followed by the same letter are not significantly different at 0.05 level as determined by Duncan

3.3 Yields and nutrients in the soil

Rice yields of T1, T2 and T3 treatments were from 4.25 to 4.40 ton.ha^{-1} and there was no significant difference between three treatments (p>0,05) (Table 4). It needs at least two or even longer time to see the difference in yield among different rice straw management (Surekha *et al.* 2003; Son *et al*, 2008; Khuong and Hung, 2014; Du *et al*, 2014). Besides, the yield is better improved in Spring - Winter Season rather than in Autumn Winter season as in this experiment. The results in Fig. 7 and Fig. 8 show that organic carbon content and nitrogen available (N-NH_4^+ and N-NO_3^-) in the soil in treatment T1 was significantly higher than in T2 and T3 at the end of the season. Mil *et al. (2012)* reported that straw incorporation in soil returns 40% of N, 30% of P and 80% of K (which is absorbed by rice); straw incorporation also increases organic matter in soil as well. On the other hand straw burning results in losing 70 - 80% of C and N in straw (Hill *et al.,* 1999). The improvement of carbon and nitrogen contents available in soil was one of the evidence that soil and paddy yield can be improved in the long term.

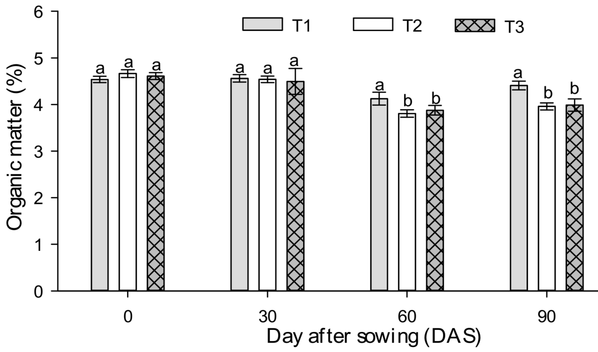

Figure 7. Organic matter in the soil (%)

Note: Mean ± Standard Error; Means followed by the same letter are not significantly different at 0.05 level as determined by Duncan

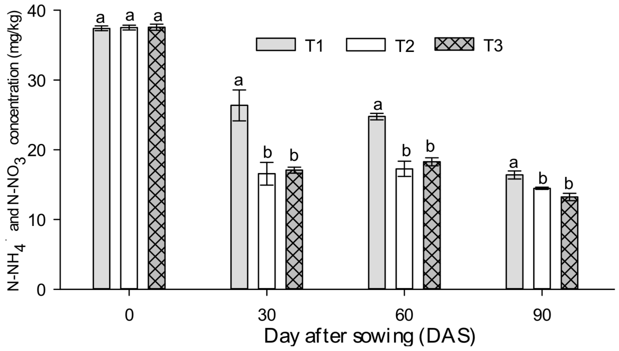

Figure 8. N-NH_4^+ and N-NO_3^- concentration in soil

Note: Mean ± Standard Error; Means followed by the same letter are not significantly different at 0.05 level as determined by Duncan

3.4 Total greenhouse gas emissions (GHGE)

Figure 9 shows GHGE (kg CO_2eq.ha^{-1}) of the components constituting to the total emissions for three treatments (i.e. T1, T2, and T3). Total GHGE was in the range of 8,187-10,739 kg CO_2eq ha^{-1}, equaling to 1.93-2.46 kg CO_2-eq kg^{-1} paddy produced (moisture content of paddy was at 14% in wet basis). The results showed that incorporation of all straw (T1) had the highest GHGE at 10,739 kg CO_2-eq ha^{-1} season^{-1}. Contribution to the overall GHGE, the highest was from direct field-emission during rice cultivation ranging 53-66% of the total GHGE. Mechanized operations consuming fuel also contributed a range of 26-34%, while the agronomic inputs contribute about 7% of the total emissions.

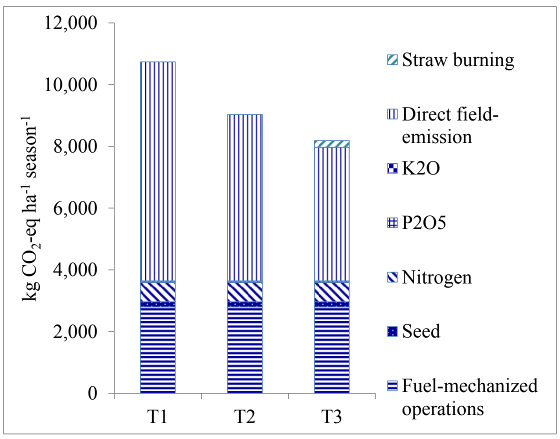

Figure 9. Total greenhouse gas emissions from three treatments

4. Conclusions

CH_4 and N_2O emission rates were not significantly different among the treatments; however, there were high variations of N_2O emission after the dates when urea was applied. Direct field emissions of CH_4, N_2O and CO_2 equivalent (CO_{2eq}) are not significantly different among the three treatments, but the amount of CO_{2eq} per kg straw in T1 of incorporating rice straw treated *Trichoderma* is significantly higher than in T3 of in-field burning straw. LCA based analysis resulted in total GHGE in the range of 1.93-2.46 kg CO_2-eq kg^{-1} paddy produced consisting of 53-66% from direct soil emissions. Incorporation of straw treated with *Trichoderma* did not indicate the improvement of paddy yield. However, the organic matter and N-NH_4^+ and N-NO_3^- of this treatment were higher than those from other researches. This research was just conducted in one crop season, however, the results have initial implications for the other crop seasons. To verify these results, we recommend to conduct further experiments with replications of crop seasons and extending to other seasons and cropping systems.

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