Effect of Water Regimes and Organic Matter Strategies on Mitigating Green House Gas Emission from Rice Cultivation and Co-benefits in Agriculture in Vietnam

Thuy Nguyen Thu, Loan Bui Thi Phuong, Trinh Mai Van, and Son Nguyen Hong

Abstract—**Agriculture sector in Vietnam is not only affected by climate change but it also emits a high proportion of greenhouse gas (GHG) - especially rice, which is the main source of GHG emissions in this sector. Many GHG mitigation options have been transferred to rice cultivation in the world with biochar measure, compost measure and applying Alternative Wet and Dry (AWD) measures having high potential to reducing GHG emissions. This study assesses the co-benefits of greenhouse gas emission mitigation options above in comparison with traditional farmers' practice (applying flooding irrigation (PF) in combination with farmyard manure fertilizer (FYM)) to find a climate-smart agriculture system for Vietnam ensuring both economic benefits and maintain Global Warming Potential. Therefore, a field experiment was conducted in Hanoi city, located in Northwest Vietnam. The experiment was divided into two blocks with different water regimes: AWD and PF. Each block was designed with four different types of fertilizer: 1) NPK (i.e. irorganic fertilizer) only; 2) NPK and FYM; 3) NPK and straw compost; and 4) NPK and straw biochar. The result showed that rice yield was significantly different among mitigation treatments compared to traditional farming practise. In addition, the block with AWD irrigation method and NPK+ straw biochar fertilizer showed potential to mitigate GHG emissions significantly with 53.4% CO_2eq per grain yield reduction compared to traditional farmers' practice. Furthermore, this mitigation option also helped to save 43.24% of water irrigation, increase soil fertilit and reuse Vietnam's agricultural residue.**

***Index Terms*—Rice paddy field, biochar, compost, AWD, climate-smart agriculture system.**

I. Introduction

Agriculture has been not only damaged by climate change but also contributed a big Green House Gases (GHG) emission in total national GHG inventory [1]. According to World Bank (2007) [2], climate change affected about 1% GDP and the livelihood of residences in Vietnam.

MONRE (2012) [3] shows that if sea level rise at 1 meter up to 2100, 38.9% of natural land area and 32.16% of agricultural land areas will be lost in Mekong River Delta Region. This lead to total rice quantity in MRD will be reduced by approximately 40.52% (9.52 million ton of rice), as a result, "Vietnam will be no longer rice exportation country and threaten to domestic food security" [4]. One reason for this phenomenon is the increase of Green House Gas (GHG) emission by human activities, such as the emission of CH_4 and N_2O from agriculture, especially CH_4 from rice base systems. Vietnam has more than 7 million ha of rice cultivation with continuous flooding irrigation, the amount of CH_4 and N_2O emission are estimated very large. According to second communication on national GHG inventory [1], GHG emission from agriculture was estimated about 65.9 million ton CO_2 equivalent (CO_2e), comprised to 43.1% of total national GHG emission. Therefore, reducing emission of these gases will significantly contribute to mitigating climate change. Many researches in the world have showed that we can reduce the emission of GHG throughout agricultural activities as using dicyandiamide to limit the transforming process from ammonium to nitrate and reduce emission of N_2O [5]. Previous research also showed that in China and India, the fammers applied different farming techniques, for example, shifting from paddy rice to dry land rice; reducing flooding level in the rice field; applying ammonium sulphate fertilizer; middle season drainage; returning rice straw intercrop; applying slow release fertilizer compare with the conventional farming techniques of always flooding to reduce GHG emission [6], [7]. However, in Vietnam the study on GHG emission from rice cultivation and mitigation measures are limited. Vietnam has already signed on the Kyoto protocol on reduction of GHG emission for climate change mitigation. In order to carry out this mission, the government asked all sectors to apply the advanced technologies, implement more production procedure guidelines, especially rice cultivation sub-sector- a largest emission one. In addition, after COP16 conference in Copenhagen, Denmark, Vietnam Agriculture and Rural development minister Cao Duc Phat has promised to reduce GHG emission from agriculture up to 20% in 2020. Therefore, my objective of my research is to calculate GHG emission from different mitigation options to find out the most effective farming practice with a low cost, environmental protection and ensuring GHG emission reduction for fammers in Vietnam in order to achieve the goal of Ministry of Agricultural and rural development.

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II. Materials and Methods

A. Experiment Site

The research was conducted in Thanh Tri district of Hanoi

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(20°55′60″N and 105°50′54″E, elevation 3 cm – 4 cm) during summer season 2012. The climate in Thanh Tri district is humid tropical with the mean annual temperature in summer season is 33 °C. The soil had the same characteristic to the Red River Alluvial soil with slightly acidic (pH_{KCK} = 5.07), and containing 2.62% of orangic *C* and a high 0.25% total of *N* according Table I.

TABLE I: SOIL PROPERTITIES BEFORE EXPERIMENT

Soil horizon thickness *(cm)*	Bulk Density *(g/cm^3)*	Particle Density *(g/cm^3)*	Porosity *(%)*	Particle size (%)		
				Sand	Limon	Clay
0 - 15	1.37	2.60	49	22.0	50.2	26.8

B. Experiment Design

For the summer rice crop in this experiment, the rice variety is *Oryza sativa* L. indica, and experimental activities of field experiment are summarized in Table II.

TABLE II: EXPERIMENTAL ACTIVITIES

Ord	Activities	*Date*
1	*Farming activities*	
	Rice variety preparation	19 July
	- Sowing	22 July
	- Transplanting:	5 August
	- Havesting:	30 October
2	Fertilizer	
	- Base application	5 August
	- First top dressing	20 August
	- Second top dressing	5 September
3	*Measurement*	
	Plant height, Soil and water environment dynamic: water depth, air, water and soil temperature, soil and water pH, soil and water EC, soil and water Eh.	Every week
4	*Sampling*	
	-Gas sampling	Every week
	- Plant sampling	When haverting
	- Soil sampling	Before cultivation, in the time of taking air sampling and after haverting
5	*Gas sampling analysis*	10-12/2012

Rice was transplanted in paddy field with 2–3 seedlings per hill and with 20cm × 20cm spacing between hills. The experiment was designed with 8 treatments using a block Randomized Complete Block (RCB) with triplicates on a plot size 4m × 5m each. There were two water regimes including permanent flooding (PF) and Alternative Wetting and Drying (AWD) with four types of feritilizer being mineral fertilizer (NPK) was applied equally for all treatment, farmyard manure fertilizer (FYM), straw biochar fertilizer (BC) and straw compost fertilizer (COM). Only NPK was used as fertilizer in control treatments. These treatments are described in Table III.

The water regimes were controlled differently in each block. In PF block, water level was kept at 3-5cm above soil surface starting from one week before transplanting until 15 days before harvest. In AWD block, water level was maintained according water saving techniques from Wassman in IRRI [8].

TABLE III: TREATMENTS IN EXPERIMENTAL SITE

	Treatments	
Water regimes	a. PF irrigation	b. AWD irrigation
Fertilizers	PF control	AWD control
	PF- FYM	AWD- FYM
	PF-COM	AWD-COM
	PF-BC	AWD-BC

There were three times for fertilizer. The first time was base application with FYM/Biochar/compost, 30% nitrogen and 100% phosphorus. The next time was first split application (10 days after transplating) with 50% *N* + 50% K_2O and the last time was second split application (Particle Initiation): 20% *N* + 50% K_2O. The equal amount of C input (1000 kg ha^{-1}) was used for each treatment with organic fertilizer in Table IV. In addition, the amount of mineral fertilizer for all treatments was used as similarly as that for fammer's farming practise with 80 (kg ha^{-1})*N* + 60 (kg ha^{-1})P_2O_5 + 40 (kg ha^{-1})K_2O.

TABLE IV: PROPERTIES OF ORGANIC FERTILIZER APPLIED

Organic amendments	*Humidity (%)*	*% C content*	*N (%)*	*P (%)*	*K (%)*	*C input (kg ha^-1)*
Farmyard manure	72.3	31.34	0.65	0.91	0.6	1000
Biochar from rice straw	78.07	35.32	1.21	0.12	1.81	1000
Compost	37.89	20.95	0.19	0.38	0.72	1000

C. Gas Sampling Analytical Methods

The closed chamber technique as described by Zhang *et al.* (2010) [7] was used to take gas sampling. The chamber includes two main parts. The first part is a chamber fixing foot made from a stainless steel 36 cm wide, 40 cm long and 35 cm high. The second is a closed-top chamber made by transparent Plexiglas with dimession 36 cm wide, 40 cm long and 95 cm high. A thermometer to measure temperature and two small electric fans to homogenize air during gases sampling were fixed inside the top chamber. The fans were connected with disposable batteries placed on the top of the chamber within a case to supply power. The top chamber also contained a 3 mm hole on the top. An open ended plastic tube with 3 mm diameter and 1 m length was inserted into the chamber through the hole with one end hanging 50 cm inside and the other end protruding 50 cm outside the top chamber. The hole was sealed from periphery after the tube insertion so as to prevent air leakage. A check valve was provided on the protruding part of the tube to control the gases flow during gases sampling.

The calculation of emission was based on the change in gas concentrations within the chamber's enclosed in a period from 0 minute to 30 minute for each sampling. Equation by Pihlatie, 2013 [9] was used to calculate the amount of CH_4 and N_2O emission per hour (F= mg/m^2/h):

$$F = \frac{S\frac{M}{Vm}\times\frac{V}{A}\times\frac{273.16}{T+273.16}\times 3600}{1000} \quad (1)$$

where S is the slope of the linear at chamber closure (ppm/s), M is the mocule weight of the gas of interest in which CH_4 and N_2O being 16,042g/mol and 44,0128g/mol respectively, V is the chamber volume (m^3), Vm is the volume of the ideal gas (0.0024m^3/mol) and T is the temperature inside the chamber (^{0}C). The cumulative emission of CH_4 and N_2O from transplanting to before harvesting 15 days was calculated from the area under curve each mesurement time point as Fig. 1 below and equation 2.

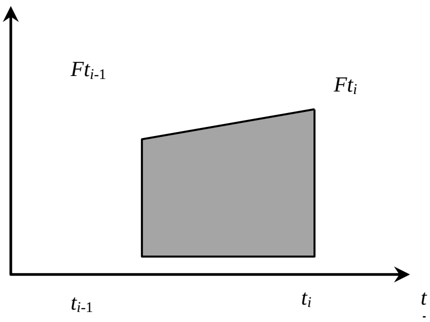

Fig. 1. The area of two adjacent intervals.

$$At\left(_{i-1,i}\right) = \left(t_{i-1} - t_i\right)\times\left(Ft_{i-i} + Ft_i\right)\div 2 \quad (2)$$

where $At(_{i\text{-}1,\,i})$ is the area of two adjacent intervals (between t_{i-1} and t_i), t_{i-1} and t_i are two dates of measurements corespondently. Ft_{i-1} v àFt_i are the fluxes of CH_4 or N_2O at the two measurement date above.

Therefore, the cumulative gas emission was calculated by equation as followed:

Cumulative emission:

$$CH_4 \text{ or } N_2O = \sum At(i\text{-}1,\, i) \quad (3)$$

The following equation was used to calculate total amount of CH_4 or N_2O emission during all season (where $\triangle d$ is the total days from transplanting to havesting):

$$N_2O(\text{mgN/m}^2\text{/season}) = \sum N_2O\ (\text{mgN/m}^2\text{/hr}) \times 24\text{hours} \times \triangle d \quad (4)$$

D. Statistic Method

Statistical analyses of data were conducted by SAS 9.1 model. The impact of different rice cultivation option on CH_4, N2O emission and CO_2 equivalent per rice grain were investigated by one-way ANOVA. Using Duncan (alpha= 0 05) post-hoc test for multiple comparisons if appearing the significance of the treatment effect.

III. Results and Discussion

A. Soil Properties Improvement

The result showed that some of soil properties were improved in Table V.

In table below, pHKCl after treatment increased from 0.38 to 0.85 compared to before treatment. Organic matter in soil of treatments after experiment rose compared to that before experiment fluctuating from 24.5% to 65% depending on each treatment. The lowest increase was in mineral fertilizer treatments and the highest was in biochar treatments followed by FYM treatments. Carbon exchange capacity (CEC) is proportional to the organic carbon in the soil. There were no significantly difference in organic carbon in soil between PF irrigation and AWD irrigation block.

TABLE V: Soil Properties before and after Experiment

Treatments	pH_{KCl}	N (%)	OC (%)	CEC (cmolc/kg)
Before experiment	5.07	0.103	1.255	19.20
After experiment				
a. PF irrigation				
PF control	5.92	0.113	1.564	19.32
PF- FYM	5.61	0.179	1.823	19.86
PF-COM	5.65	0.157	1.679	19.59
PF-BC	5.72	0.180	2.074	20.25
b. AWD irrigation				
AWD control	5.90	0.135	1.562	19.19
AWD- FYM	5.45	0.192	2.070	19.92
AWD-COM	5.86	0.176	1.754	19.50
AWD-BC	5.84	0.192	1. 945	19.90

B. Reusing Agricultural Residue

After haverting, the fammers have burnt agricultural residue directly in farming site [10]. This leads to CO_2 emission, air pollution and even affect seriously to residence's health.

According the inversitgation from Institute for Agricultural Environment [10] in Fig. 2, about more than haft of fammers said that they burnt rice residue directly after haverting. So, if the famers reuse agricultural residue for farming activities by using them to making biochar and compost fertilizer. As a result, the community can avoid adverse impacts from burning agricultural residue and obtain economic values from this activity.

Experiment showed that the treatments applying straw biochar, the amount of rice straw residue was used for one ha accounted for 21.6 tons. And the treatments applying straw compost, the amount of rice straw using was 19.5 tons per ha. Therefore, if applying biochar and compost method, the situation of burning agriculture residue especially rice residue will be limited.

C. Water Saving

The total of irrigation level of one season is determined by

the equation [5]: $M = M_1 + M_2$
where:
M_1 is irrigation level of tillage period;
M_2 is adding irrigation level for land;
The amount of water usage for irrigation tillage period:

$$M_1 = W_1 + W_2 + W_3 + W_4 - 10CP \text{ (m}^3\text{/ha)}.$$

The amount of water to saturating the soil cultivation:

$$W_1 = 10 \times A \times H \times (1-\beta_o) = 10 \times 0.4 \times 300 \times (1-0.6) = 480 \text{ (m}^3\text{/ha)}.$$

The amount of water needed to form water layers in field surface: $W_2 = 10\ a = 300$ (m³/ha).

Average water layers in field surface in caculation period (a = 30mm);

The amount of water stabilization soaked in Tillage a:

$$W_3 = 10K \times \frac{H+a}{H} \times (Ta - Tb) \text{ (m}^3\text{/ha)} \quad (5)$$

where H is The depth of soil cultivation layer (H = 300mm), Ta is Time to prepare soil (Ta = 10 day), Tb is time to saturate the soil cultivation layer (Tb = 2 day)

$$W_3 = 10 \times 2 \times (300+30)/300 \times (10-2) = 176 \text{ (m}^3\text{/ha)}$$

The amount of water evaporation during Tillage:

$$W_4 = 10.ET_o.t = 10 \times 4.42 \times 10 = 442 \text{ (m}^3\text{/ha)}.$$

$$M_1 = W_1 + W_2 + W_3 + W_4 - 10CP = 480 + 400 + 176 + 442 - 10 \times 0.6 \times 7.3 = 1454 \text{ (m}^3\text{/ha)}.$$

To determine the amount of evaporation water in field surface(Etc), we applied Penman–Monteith equation [11].

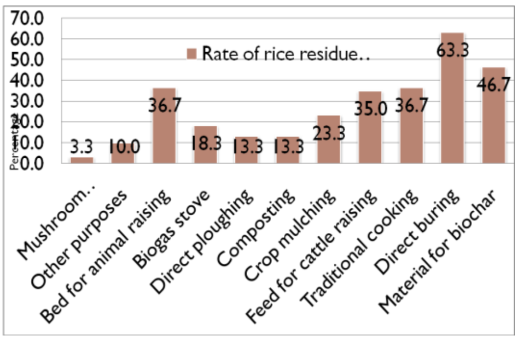

Fig. 2. Multi- purpose of rice residue use in Red River Delta [10].

1) Caculating the amount of water caring irrigarion for rice in summer season 2012 (Permanent floofing irrigation)

Caculation result shown that:
The total amount of water consumption in season:

$$\Sigma(ETc + Kc) = 756.77 \text{ mm} = 7567.7 \text{(m}^3\text{/ha)}$$

The total amount of rainwater in season:

$$\Sigma P = 330{,}08 \text{ mm} = 3300.8 \text{ (m}^3\text{/ha)}$$

The total amount of irrigated water in season:

$$M_2 = \Sigma(ETc + Kc) - \Sigma P = 7767.7-3300.8 = 4266.9 \text{ (m}^3\text{/ha)}$$

The amount of needed water for tillage and caring soil irrigarion:

$$M_1 + M_2 = 1454 + 4266.9 = 5720.9 \text{ (m}^3\text{/ha)}$$

2) Caculating the amount of water for AWD irrigarion for rice in summer season 2012

The total amount of water consumption in season:

$$\Sigma(ETc + Kc) = 654.72 \text{ mm} = 6547.72 \text{ (m}^3\text{/ha)}$$

The total amount of rainwater in season:

$$\Sigma P = 330{,}08 \text{ mm} = 3300.8 \text{ (m}^3\text{/ha)}.$$

The total amount of irrigated water in season:

$$M_2 = \Sigma(ETc + Kc) - \Sigma P = 6547.72 - 3300.8 = 3246.92 \text{ (m}^3\text{/ha)}.$$

The amount of needed water for tillage and caring soil irrigarion:

$$M = M_1 + M_2 = 1454 + 3200 = 4654 \text{ (m}^3\text{/ha)}.$$

TABLE VI: WATER USAGE IN AWD AND PF IRRIGATION

	Amount water usage (m³/ha)		
Season	PF	AWD	Water saving (%)
Summer season 2012	5720.9	3246.92	43.24

Because experiment was conducted from July to October, this period was rainny season. Both PF and AWD irrigation block, the amount of irrigated water was very small. Even though, some period of drying to AWD block the water in the field was quite high about 5cm and have to bump off water to outside. As Table VI, with AWD treatments, the amount of water saving was about 14.67% compared to PF treatments.

D. The Effect of Mitigation Option on Rice Yield

The result showed the rice yield in summer season 2012 in experimental site as described in Table VII.

TABLE VII: RICE YIELD FROM TREATMENTS

Treatment	**Summer rice season 2012**	
	Yield (kg/ha)	**% increase to control**
a. PF irrigation		
PF control	3530 (b)*	
PF- FYM	4740 (a)	34.39
PF-COM	3850 (b)	9.05
PF-BC	3810 (b)	7.91
b. AWD irrigation		
AWD control	3520 (b)	
AWD- FYM	4490 (a)	27.36
AWD-COM	3730 (b)	5.83
AWD-BC	3570(b)	1.28

*Small letters indicate significance on grain yield among treatments ($p < 0.05$)

Grain yield was slightly higher in PF irrigation than AWD irrigation with same fertilizer method. In addition, it was also higher in organic fertilizer treatments than mineral fertilizer treatment. However, in both two kinds of irrigation, farmyard manure was illustrated by the highest yield in compared to other fertilizers. Among organic fertilizers, the lowest yield under BC- amended treatment can be explained by the low bioavailability of N in BC in comparision with N in FYM in the first season BC applied. The increase of bioavailability of N in second season will be stronger and grain yield can improved.

E. Green House Gas Emission

1) GWP of each treatment

Based on IPCC 2007, global warming potential (GWP) over a hundred-year period was calculated by converting all to CO_2 equivalent and CH_4 was converted to CO_{2e} by a coefficient of 25 and the coefficient of N_2O being 298 [12]. Total green house gas emission was calculated as followed equation:

$$GWP\ CO_2e = CH_4\ (CO_2\ e) + N_2O\ (CO_2\ e) = CH_4 \times 25 + N_2O \times 298.$$

According Fig. 3, traditional farming practices (PF-FYM) illustrated the biggest amount of CO_2eq emission in summer season 2012, whereas, biochar application in both water regimes had a low of CO_2 emission in same time.

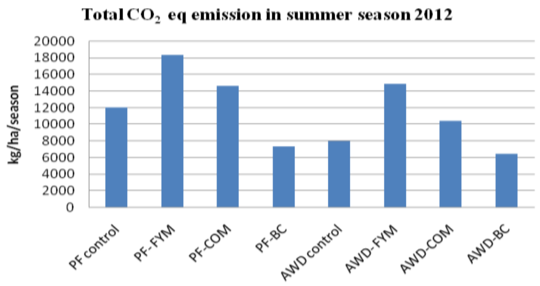

Fig. 3. Total CO_2eq emission as affected by mitigation options.

The CO_2eq emission per kg grain yield was calculated from dividing GWP CO_2e by grain yield produced.

The Table VIII presented that FYM fertilizer in both PF water regimes and AWD water regimes had the highest of CO_2e/kg grain yield with 3.88 kgCO_2e/kg grain yield and 3.80 kgCO_2e/kg grain yield, corespondently in summer season 2012. In contrast, the AWD-BC showed the lowest CO_2eq emission per grain yield only 1.81 CO_2e/ kg grain yield reducing 53.4% and 20.2% the amount of CO_2eq emission compared to traditional farming practice of farmers (PF-FYM treatment) and AWD control only applying mineral fertilizer, respectively.

TABLE VIII: CUMULATIVE EMISSION OF CH_4 AND N_2O, GWP CO_2EQ AND CO_2EQ PER KG GRAIN RICE FOR TREATMENTS

Treatment	Summer season 2012			
	Total acummulated CH_4 (kg ha^{-1} $season^{-1}$)	**Total acummulated N_2O (kg ha^{-1} $season^{-1}$)**	**GWP CO_2e (kg ha^{-1} $season^{-1}$)**	**CO_2e/ kg grain yield**
a. PF irrigation				
PF control	459.83bc	1.872cd	12053.6bc	3.41ab
PF- FYM	693.66a	3.499b	18384.2a	3.88a
PF-COM	546.07b	3.258b	14622.6b	3.80a
PF-BC	272.11d	1.704d	7310.5d	1.92d
b. AWD irrigation				
AWD control	288.46cd	2.530c	7965.4a	2.26cd
AWD- FYM	545.16b	4.123a	14857.7b	3.31b
AWD-COM	369.79c	3.830ab	10386.1c	2.78c
AWD-BC	237.32d	1.730d	6448.5d	1.81d

TABLE IX: TOTAL CO_2EQ SAVING IN SUMMER SEASON 2012

Treatment	Summer season 2012			
	GWP CO_2e (kg ha^{-1} $season^{-1}$)	**CO_2eq saving to PF-FYM (kg ha^{-1} $season^{-1}$)**	**CO_2eq saving from avoiding agricultural residue burnt (kg ha^{-1} $season^{-1}$)**	**Total CO_2eq saving (kg ha^{-1} $season^{-1}$)**
a. PF irrigation				
PF control	12053.6bc	6330.6	0	6330.6
PF- FYM	18384.2a	0	0	0
PF-COM	14622.6b	3761.6	11092	14853.6
PF-BC	7310.5d	11073.7	12283.9	23357.6
b. AWD irrigation				
AWD control	7965.4a	10418.8	0	10418.8
AWD- FYM	14857.7b	3526.5	0	3526.5
AWD-COM	10386.1c	7998.1	11092	19090.1
AWD-BC	6448.5d	11935.7	12283.9	24219.6

Total emission saving = Emission saving from rice cultivation + emission saving from avoiding agricultural residue burnt.

Therefore, we can calculate the total GHG emission saving when applying mitigation option as following Table IX. We assumed that one ton rice straw burning emitted 1.21ton CO_2eq and 47% of rice straw residue be burnt without biochar and compost application [11].

The AWD treatments had a potential in mitigating GHG emission remarkably compared to PF treatment. Especially, the AWD-BC treatment had big amount of CO_2eq saving with 24219.6 kg CO_2eq saving /ha/season compared to traditional practice of famers.

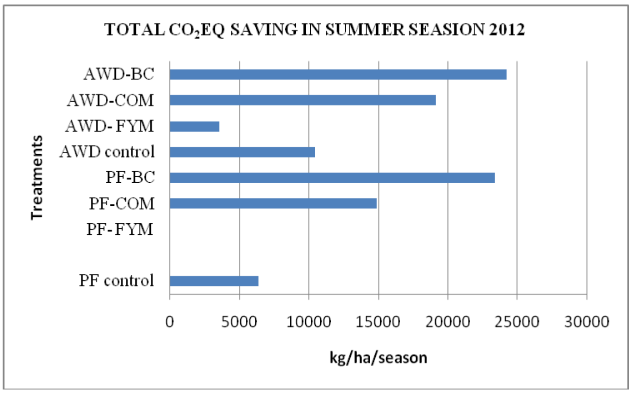

Fig. 4. Total CO_2eq saving when applying mitigation options.

Fig. 4 showed that in same water regimes, the biggesst amount of CO_2 eq saving in summer season 2012 was resulted from applying biochar fertilizer, followed by compost fertilizer.

IV. Conclusion

The AWD water regime and organic matter fertilizer such as biochar and compost had potential in reducing CH_4 and N_2O emission compared to traditional practice of famers. Applying AWD water regimes can help save the amount of water irrigated per season by about 43.24% compared to permanent flooding. Oganic matter fertilizers can help the famer recycled residue and increae soil quality including organic carbon contening and CEC in soil improvement. Suprisingly, the AWD-BC treatment with 1.81 CO_2e/ kg grain yield reduced by 53.4% and 20.2% the amount of CO_2eq emission compared to traditional farming practice of farmers (PF-FYM treatment) and AWD control only using mineral fertilizer, respectively. Besides, the amount of CO_2eq saving when apply AWD-BC practice was very high nearly 2.4 ton/ha/season. From the result of experiment, it can be seen that the most effective mitigation practice for rice cultivation is the AWD in combination with biochar option. This mitigation ensures bringing co-benefits for agriculture sector not only reducing significantly of Green House Gas emission but also improving soil quality and saving irrigation water. However, it takes more time to examine the long-term impact of AWD-BC practice on yield, soil quality and GHG emission.

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