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Effects of fresh rice straw and water levels on CO_2-C gas emission, soil organic carbon content and rice production

M.B. Hossain*

Soil Science Division, Bangladesh Institute of Nuclear Agriculture (BINA), Bangladesh Agricultural University (BAU) Campus, P.O. Box 4, Mymensingh 2200, Bangladesh

Abstract

An experiment was conducted at Bangladesh Institute of Nuclear Agriculture (BINA) farm, Mymensingh, Bangladesh during 2010-2011 to find out the effect of different water and organic residue levels on rice production and soil organic carbon content. Organic carbon rates from rice straw (0.5, 1.0, 1.5 and 2.0 t C ha^{-1} including control) were evaluated under alternate wetting and drying (AWD) and continuous flooding (CF) systems. Each treatment also received the recommended dose of chemical fertilizers excluding control. Factorial experiment was laid out in a complete randomized design with three replications. Results revealed that, maximum plant height, filled grains per tiller, 1000 grains weight, grain and straw yield were also observed in continuous flooding system in combination with 2.0 t C ha^{-1} in 2010 and 2011, respectively. Combined use of chemical fertilizers, 2.0 t C ha^{-1} fresh rice straw and continuous flooding system performed better results to reduce CO_2-C gas emission, increased organic carbon and rice production with maintaining optimum soil pH level. Continuous flooding with 2.0 t C ha^{-1} as fresh rice straw is an effective way to reduce CO_2-C emission, optimize soil pH and contribute to sustainable rice production for food security.

Key words: Fresh rice straw, water levels, CO_2-C emission, soil carbon and pH, rice yield.

INTRODUCTION

Rice-rice (RR) is a major cropping system in subcontinent covering about 10.36 million ha in Bangladesh and 46.94 million ha in Bhutan, India, Nepal, Pakistan and Sri Lanka (SAARC, 2007). Soil organic carbon (SOC) is a key indicator for nutrient cycling, improving soil physical, chemical and biological properties, crop productivity and reducing green house gases (GHGs) (Bhattacharya *et al*., 2010). The burning of crop residues result in loss of soil organic matter and nutrients and causes atmospheric pollution due to emissions of toxic and greenhouse gases such as CO, CO_2 and CH_4 posing a threat to human and ecosystem health. Imbalanced nutrition is the responsible factor for the observed declines in rice yield and organic matter in soil due to erratic use of chemical fertilizer especially urea with no or little use of organic residues in Bangladesh (Ali *et al*., 1997). Hossain & Puteh (2013) reported that annual rice straw production increased from an average of 21.98×10^6 mt per year in the 1978 to 30.84×10^6 mt per year in 2008 in Bangladesh. Depletion of nutrients and organic matter contents of Bangladesh soils can be replenished by applying cost effective and easily available rice straw. Rice straw composting as a method of producing organic fertilizer has limited

* Corresponding author. E-mail: belalbina@gmail.com

popularity with farmers for two reasons. It requires extra labor and the compost normally takes 3-6 months to mature. In this regard, fresh rice straw incorporation in soil is an alternative option in place of rice straw compost but fresh rice straw enhances the immobilization of nitrogen, reduces oxygen and increases toxic carbon content in soil due to high C:N ratio and non-mobile organic carbon such as lignin which hampers rice growth. Recommended dose of nitrogen along with fresh rice straw may overcome the former problems as a result improve rice yield. Still now appropriate dose of fresh rice straw is not optimized to decrease CO_2-C emission, improve soil quality and increase rice productivity. On the other hand, water level is one of the most important factors for decomposition of organic residues in soil. Researchers have shown that soil moisture could greatly enhance organic residues decomposition and CO_2 flux (Tulina *et al.*, 2009). Intensive research works should be conducted to gain better understanding for selecting the effective dose of fresh rice straw for carbon sequestration in soil and reduce environmental pollution under different water levels. Keeping in view the situation of nominal quantity of organic matter and low fertility soils of Bangladesh, pot experiment was conducted to find out the effective dose of fresh rice straw in combination with chemical fertilizers and water regimes for carbon sequestration in soil, minimized CO2-C emission and increased rice productivity.

MATERIALS AND METHODS

An experiment was conducted two rice growing seasons-one in wet season (2010) and another in dry season (2010-11 ~ 2011) at the experimental farm of Bangladesh Institute of Nuclear Agriculture (BINA), Mymensingh, Bangladesh ($24^0$43'43" N and $90^0$25'77" E located around with 82.296 m above mean sea level). The area receives an average of 2666 mm of annual rainfall, about 76% of which occurs from July to September. The mean minimum and maximum temperatures during the rice growing wet season (July – October) was 26 and 32^0C, whereas during the dry season (November-April), was 17 and 26^0C, respectively. Fresh rice straw was collected from rice field after grain harvest. Then it was washed with distilled water and dried at 70 ^{o}C in laboratory before carbon analysis. Rice straw (RS) with four levels of carbon (0.5, 1.0, 1.5 and 2.0 t ha^{-1}) including control with no use of fresh rice straw were tested in alternate wetting and drying (AWD) and continuous flooding (CF) systems. Each treatment also received the recommended dose of chemical fertilizers excluding control. Factorial experiment was laid out in a complete randomized design with three replications. About 30-d-old rice seedlings (Binadhan-7 and BRRIdhan 29) were transplanted in July, 2010 and October, 2010, respectively. Irrigation was applied to maintain a 5-cm depth of standing water during entire growth period of rice for continuous flooding (CF) system. The wetting and drying cycle consisted of flooding the pot then allowing it to dry out; the pot was then re-flooded to 5 cm above the soil surface until the next drying cycle. Each drying & wetting cycle was taken about 7 days. Nitrogen at the rate of 105 and 164 kg ha^{-1} was applied in Binadhan-7 and BRRIdhan 29 respectively as half dose at 15 days after transplanting and the remaining half at maximum tillering stage, respectively. Different doses of nitrogen were applied treated pots due to seasonal variation. A recommended basal dose of 15, 24 and 11 kg P, K and S ha^{-1} for Binadhan-7 and 30, 96, 12 and 1 kg P, K, S and Zn ha^{-1} for BRRIdhan

29, respectively was applied through triple super phosphate, muriate of potash, gypsum and zinc oxide. Fresh rice straw was applied to the soils as per treatments and mixed thoroughly. Decomposition of fresh rice straw as carbon dioxide was measured by standard method (Stotzky, 1956). The CO_2-C evolved was measured at 15 d interval from 0 to 360 d during experimentation but the emission trend of CO_2-C is indicated 30, 60, 90, 120, 180 and 360th day of crop production period. The amount of CO_2-C was calculated by using the formula.

$$\text{mg evolved } CO_2\text{-C/day} = \frac{(T_2 - T_1)\ M \times 22}{t}$$

where, T_1=amount of HCl used to neutralize NaOH, T_2=T_1 + amount of HCl used to dissolve precipitated $BaCO_3$, M=molarity of HCl, 22=22 mg CO_2-C/1 ml 1M HCL, t=time in days.

The CO_2-C in control treatment was subtracted from the calculated value for CO_2-C release. Carbon dioxide emission was calculated up to 360 DAT (two crop seasons) of rice. Quantitative information related to yield and yield contributing characters, grain and straw yield of two varieties (Binadhan-7 and BRRIdhan 29) were analyzed to obtain the effect of different levels of water and rice straw doses on paddy. Two hills were selected from each pot for recording different data. Plant height (cm), tiller per hill (no.), panicle length cm), filled grain (no.), unfilled grain (no.) and 1000 seed weight (gm) were recorded at harvesting stage. Crop was harvested at ripening stage and oven-dried at 65 ± 2^0C to record dry matter yield of grain and straw of rice. Soil samples were air dried and ground to pass a 2 mm sieve before analyzed for total organic carbon and soil reaction. Soil pH was analyzed by standard method. Total organic carbon was determined by potassium dichromate ($K_2Cr_2O_7$) method (Ryan *et al.*, 2001). Data were subjected to analysis of variance (ANOVA) to assess the effect of water management levels, carbon doses and their interaction on the measured values. Significance of treatment means was tested using Duncan’s Multiple Range Test (DMRT) at 5% probability level. The statistical analysis was performed using MSTAT-C computer package.

RESULTS AND DISCUSSION

Effect of different water levels on yield and growth of rice, CO_2-C, organic carbon content and pH of soils are presented (Table 1, Figs. 1a, c, e). Yield attributing characters are the most important components for the performance of rice yield. Data indicated that different water levels had a significant effect on yield contributing characters of rice. Maximum plant height, tillers per hill, panicle length, filled and unfilled grains per panicle, 1000 seed weight, grain yield and straw yield were observed in CF system in 2010 and 2011, respectively (Table 1). Minimum yield contributing characters were found in AWD system. Mean increase of tillers per hill (4 and 9%), filled grains per panicle (9 and 11%), 1000 grain weight (2.79 and 13.16%) were obtained from CF system in 2010 and 2011, respectively. Regarding water levels, CF had a significant effect on grain yield of rice. Minimum grain yield was observed in AWD system which increased to the maximum for CF during both years. Mean increase in grain yield was 28 and 32% in case of CF in 2010 and 2011, respectively. AWD system produced more CO_2-C than CF system at each interval except 30 DAT of rice (Fig. 1a). Maximum organic carbon content was found in CF condition at different durations except 30 DAT of rice. Among the soil sampling durations, highest organic carbon content (0.61%) was obtained at 60 DAT. Organic carbon content was higher in CF than AWD condition due to inhibition of oxidation process of organic residues (Fig. 1c). Continuous flooding condition showed lower pH in soil than AWD system and it was the maximum at different durations except 60 DAT. Higher pH was observed from 90 to 360 DAT. CF system significantly reduced pH in post harvest soil (Fig. 1e). Highest organic carbon content was obtained under CF condition. As a result, carbon accumulation in flooded soils was higher than AWD condition. It may be concluded that CF was the suitable water management practice for the improvement of soil quality and minimized environmental pollution.

Different levels of fresh rice straw in combination with recommended doses of chemical fertilizers had also significant effect on yield and growth of rice, carbon emission, organic carbon content and pH of soils. Maximum plant height, tillers per hill, panicle length, filled and unfilled grains per panicle, 1000 grain weight, grain yield and straw yield were found in 2.0 t C ha^{-1} in 2010 and 2011, respectively. Minimum yield contributing characters were obtained from control pots where no rice straw and chemical fertilizers were applied. Mean increase in plant height was 16.51, 22.46, 25.14, 25.21% in 2010 and 40.41, 45.79, 47.25 and 47.35% in 2011 in case of 0.5, 1.0, 1.5 and 2.0 t C ha^{-1} respectively as compared to control. Similar trends were observed for no. of tillers per hill, panicle length, filled grains per panicle, 1000 grain weight except unfilled grains per panicle. Data indicated that application of different doses of fresh rice straw had pronounced impact on grain yield of rice. Highest rice yield was obtained in 2.0 t C ha^{-1} (20.28 g $plant^{-1}$) treatment followed by 1.5, 1.0, and 0.5 t C ha^{-1} treatments in 2010. Carbon doses of rice straw performed statistically significant difference in 2010 and the lowest grain yield was found in control. Increase in straw level from 0.5 t C ha^{-1} to 1.0 and 1.5 t C ha^{-1} did not satisfy significant superiority in case of grain yield of rice compared to 2.0 t C ha^{-1}. Mean increase in grain yield was 500, 605, 636 and 674% and 134, 167, 174 and 339% in case of 0.5, 1.0, 1.5 and 2.0 t C ha^{-1} in 2010 and 2011, respectively compared to control. The positive response of grain yield to fresh rice straw incorporation could be ascribed to the improvement of rice growth. Similar trends were found in straw yield of rice in both the years (Table 1). Maximum CO_2-C emission was obtained at 60 and 120 DAT. Among the carbon rates from fresh rice straw, 2.0 t C ha^{-1} produced the maximum CO_2-C emission in 180 and 360 DAT (Fig. 1b). Organic carbon content results were statistically significant except 30 days after transplanting of rice. 2.0 t C ha^{-1} produced the highest organic carbon content (0.62%) found at 360 DAT (Fig. 1d). Organic carbon content increased with the increase of time. Lowest organic carbon content was obtained from control treatment. Effect of carbon doses on pH was not statistically significant in all the estimated dates (Fig. 1f). Among the organic residue levels, 2.0 t C ha^{-1} produced the suitable soil pH for plant nutrition.

Table 1. Effect of rice straw doses and water levels on yield and yield attributing characters of rice

Treatment	Plant height (cm)		Tillers/hill (no.)		Panicle length (cm)		Filled grains/panicle (no.)		Unfilled grains/panicle (no.)		1000 seed weight (g)		Grain yield (g $plant^{-1}$)		Straw yield (g $plant^{-1}$)	
	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011
Water management (W)																
AWD	48.43 b	64.30 b	6.53	7.51 b	18.42 b	22.06 b	70.20 b	75.23 b	24.64 b	17.93 b	18.08 b	22.23 b	10.85 b	15.80 b	13.09 b	23.44
CF	51.92 a	69.81 a	6.80	8.20 a	20.05 a	23.55 a	76.53 a	83.22 a	30.48 a	24.53 a	20.46 a	22.85 a	12.73 a	20.26 a	17.31 a	23.93
Carbon in rice straw (RS)																
$RS_{0.0}$	42.57 b	49.25 c	3.50 c	2.78 c	16.02 b	17.98 b	34.00 d	43.40 b	11.70 c	11.67 d	17.91 c	20.51 b	2.05 c	6.86 d	2.72 b	5.90 c
$RS_{0.5}$	49.60 a	69.15 b	7.00 ab	8.61 b	19.67 a	23.70 a	75.50 c	83.45 a	23.35 b	24.00 b	18.19 bc	22.26 a	12.31 b	16.03 c	16.90 a	25.66 b
$RS_{1.0}$	52.13 a	71.80 a	7.33 b	8.72 b	19.84 a	23.90 a	82.33 b	84.67 a	33.85 a	26.00 a	19.44 a	22.16 a	14.47 ab	18.33 b	17.34 a	27.04 b
$RS_{1.5}$	53.27 a	72.52 a	7.34 ab	8.78 b	20.10 a	24.10 a	87.34 a	90.83 a	33.45 a	25.00 ab	19.05 bc	22.46 a	15.10 a	18.81 b	18.77 a	27.05 b
$RS_{2.0}$	53.30 a	72.57 a	8.17 a	10.38 a	20.57 a	24.33 a	87.67 a	93.77 a	35.45 a	19.50 c	21.76 a	23.31 a	15.88 a	30.13 a	20.28 a	32.80 a
Interaction (W×RS)																
AWD× $RS_{0.0}$	40.33 c	43.63 f	3.00 d	2.44 c	13.90 e	17.70 d	37.00 g	42.47 b	11.50 d	5.33 e	17.93 de	19.86 c	2.30 d	5.19 g	2.67 c	5.16 f
AWD× $RS_{0.5}$	49.13 ab	66.00 d	6.67 c	7.78 b	19.13 cd	22.80 c	68.67 f	79.27 a	20.10 cd	19.67 c	16.13 e	23.78 ab	12.45 c	14.18 e	14.88 b	23.52 e
AWD× $RS_{1.0}$	50.00 ab	69.30 c	6.67 c	8.44 b	19.47 bcd	23.60 abc	73.33 e	82.67 a	33.50 ab	27.33 a	18.78 cd	21.18 bc	12.92 bc	15.96 de	14.79 b	25.05 e
AWD× $RS_{1.5}$	51.27 ab	70.40 bc	7.33 bc	9.33 ab	19.53 abc	23.33 bc	85.67 c	83.20 a	27.50 bc	23.00 b	17.22 de	22.67 abc	13.15 bc	16.99 d	14.79 b	30.36 bc
AWD× $RS_{2.0}$	51.40 ab	72.17 abc	9.00 a	9.55 ab	20.07 bcd	23.33 bc	86.33 c	88.53 a	30.60 abc	14.33 d	20.35 bc	23.62 ab	13.41 bc	26.67 b	18.33 ab	33.13 a
CF× $RS_{0.0}$	44.80 bc	54.87 e	4.00 d	3.11 c	18.13 d	18.27 d	31.00 h	44.33 b	11.90 d	18.00 c	17.89 de	21.13 bc	1.81 d	8.53 f	2.78 c	6.63 f
CF× $RS_{0.5}$	49.20 ab	72.30 abc	7.33 bc	8.22 b	20.20 abc	24.07 abc	82.33 d	83.70 a	26.60 bc	28.33 a	20.25 bc	22.25 abc	12.17 c	15.06 de	22.22 a	23.72 e
CF× $RS_{1.0}$	55.13 a	72.87 ab	7.33 bc	9.00 b	20.67 ab	25.40 ab	89.00 b	90.07 a	34.20 ab	24.67 b	20.10 bc	23.14 abc	16.00 ab	21.67 c	19.01 ab	27.79 d
CF× $RS_{1.5}$	55.20 a	74.73 a	7.33 bc	9.44 ab	21.07 a	25.60 a	89.00 b	99.00 a	39.40 a	27.00 a	20.88 b	23.00 abc	16.79 a	22.47 c	19.89 ab	29.05 cd
CF× $RS_{2.0}$	55.27 a	74.73 a	8.00 ab	11.20 a	22.20 a	25.80 a	91.33 a	99.00 a	40.30 a	24.67 b	23.16 a	24.75 a	16.88 a	33.58 a	22.67 a	32.46 ab
CV(%)	9.96	2.85	10.49	16.51	4.55	5.73	1.85	17.74	22.23	6.20	5.61	6.48	15.74	8.45	26.10	5.43

Figures sharing the same letter do not differ statistically at 5% level of significance, AWD-alternately wetting and drying and CF-continuous flooding and carbon rate in rice straw (RS) @ 0.0, 0.5, 1.0, 1.5 & 2.0 t ha^{-1}.

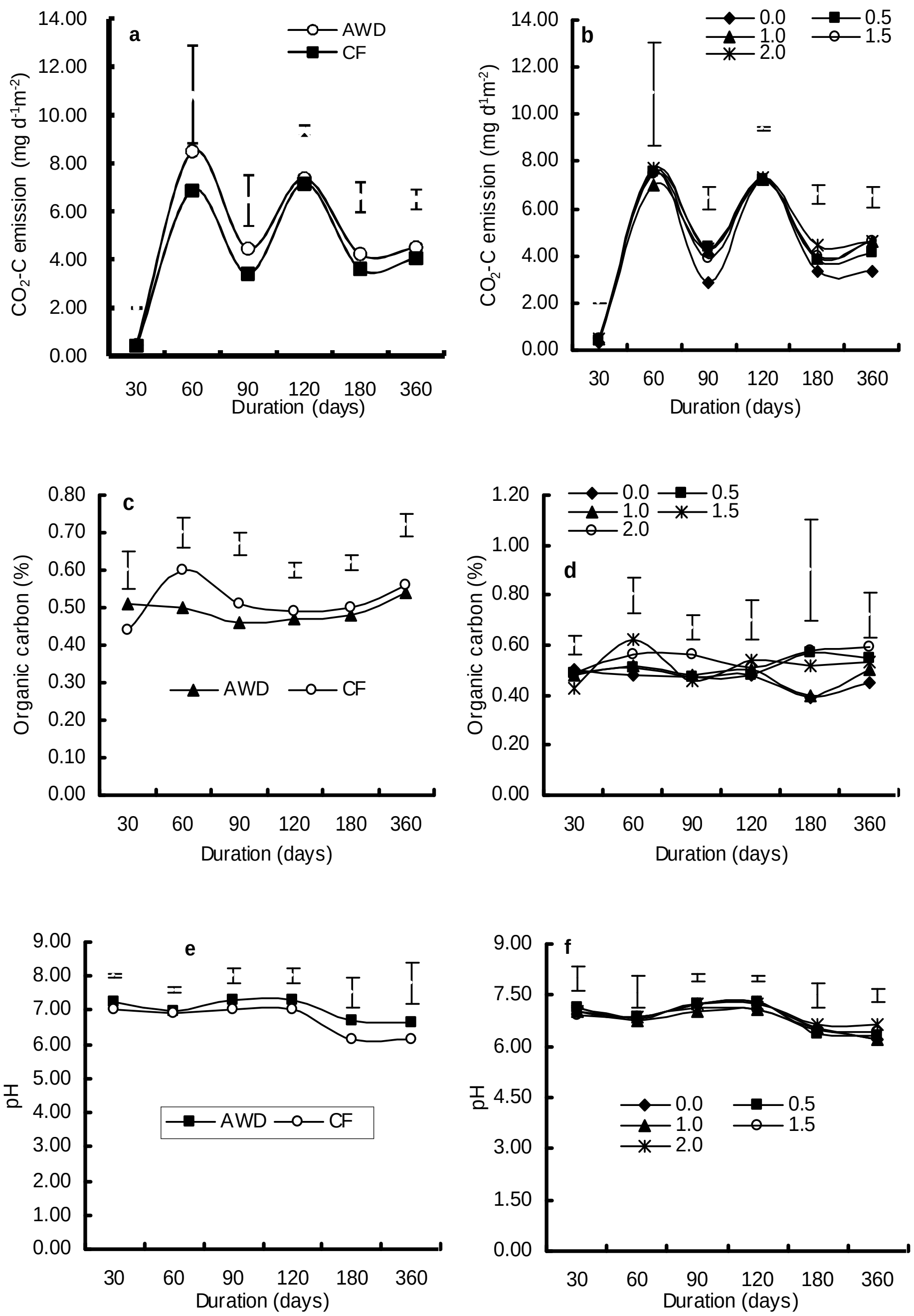

Fig. 1. Effect of water levels and rice straw on soil. a & b : carbon dioxide carbon emission c & d : organic carbon (%) and e & f : soil pH

The interactive effect of water management and carbon levels showed also significant differences on yield and yield attributing characters of rice (Table 1). In 2010 and 2011, maximum plant height was found in 1.0, 1.5 and 2.0 t C ha^{-1} in combination with CF system. Mean increase in plant height was 37 and 71% in $W_2 \times RS_{2.0}$ treatment compared to $W_1 \times RS_{0.0}$ treatment in 2010 and 2011, respectively. The highest total tillers per hill were obtained from $W_2 \times RS_{2.0}$ followed by 9.55, 9.45 and 9.33 from the treatments of $W_1 \times RS_{2.0}$, $W_2 \times RS_{1.5}$ and $W_1 \times RS_{1.5}$, respectively in 2010. In 2011, maximum tillers per hill were found in $W_1 \times RS_{2.0}$ followed by $W_2 \times RS_{2.0}$ treatment. In both the years, $W_2 \times RS_{2.0}$ produced the highest panicle length of rice and the lowest panicle length was found in $W_1 \times RS_{0.0}$ treatment. The second highest panicle length was observed in $W_2 \times RS_{1.5}$ in 2010 and 2011. Number of filled grains was statistically similar in all the interactive treatments except $W_1 \times RS_{0.0}$ and $W_2 \times RS_{0.0}$ treatments in 2010. Maximum filled grains were obtained from $W_2 \times RS_{2.0}$ treatment. In 2011, maximum filled grain number was found in $W_2 \times RS_{2.0}$ which was not statistically significant with other interactive treatments. The lowest grain number was observed in no residue treated plots irrespective of different water management levels. Maximum unfilled grains were found in $W_2 \times RS_{2.0}$ and $W_2 \times RS_{0.5}$ treatments in 2010 and 2011, respectively. The lowest unfilled grains were observed due to lowest number of total grain per panicle in no residue application irrespective of different water management levels. In 2010 and 2011, the highest 1000 grains weight was observed in plots where continuous flooding system was followed at the level of 2.0 t C ha^{-1}. Treatment $W_2 \times RS_{2.0}$ was not statistically similar with other treatments in 2010 in respect of 1000 seed weight. The interactive effect of water management and carbon levels, the maximum mean value of rice yield was observed in case of CF system along with 2.0 t C ha^{-1}. The second highest grain yield was found in $W_2 \times RS_{1.5}$ followed by $W_2 \times RS_{1.0}$ treatment in 2010. Treatment $W_2 \times RS_{2.0}$ was statistically significant with other treatments in 2011. The lowest grain yield was found in $W_1 \times RS_{0.0}$ and $W_2 \times RS_{0.0}$ treatments in both years. However, maximum straw yield was found in $W_2 \times RS_{2.0}$ treatment in both years.

Alternate wetting and drying increased 16% more CO_2-C emission than CF system. Good aeration is an important factor for the proper activity of microorganisms involved in the decomposition of organic matter. As a result, AWD condition enhanced the oxidation process of organic residues after transplanting of rice. Soil moisture could greatly enhance organic residue decomposition and CO_2 flux (Tulina *et al.*, 2009) or reduces it (Iqbal *et al.*, 2009). On the other hand, under anaerobic condition such as CF system, fungi and actinomycetes are almost suppressed and only a few bacteria occur in anaerobic decomposition (Hossain & Puteh, 2013). The low microbial activities at higher C:N ratio with non-labile C content slowed down the decomposition of rice straw in flooded condition resulting in higher stability of organic carbon in soil. Continuous flooding system increased yield and yield contributing characters of rice. Nitrogen is one of the most yield limiting in rice production in Bangladesh. In AWD condition, nitrogen use efficiency is lower than CF system due to enhanced nitrifying activities of soil microorganisms. Dong *et al.* (2012) reported that major loss of fertilizer N occurred through ammonia volatilization amounting to 21% and 13% of the applied N in the AWD and CF treatments, respectively. They also reported that loss of fertilizer through nitrification-denitrification was 6 fold higher under AWD than CF. Plant height, tillers per hill, panicle length, filled grains per panicle, 1000 grain weight, grain and straw yield of rice were decreased with the increase of water stress (Oliver *et al*., 2008). Flooded soil increased organic carbon and improved soil reaction are reported (Snyder, 2002). Rice straw in combination with NPK increased rice yield (Xionghui *et al*., 2012). Incorporation of widely available rice straw and chemical nitrogen into soil can be a strong means for controlling soil nitrogen dynamics and reducing leaching of fertilizer nitrogen, because fresh rice straw used applied nitrogen instead of soil nitrogen as well as adsorbed applied nitrogen by their great surface areas (Wopereis *et al*., 2009). As a result, rice straw incorporation performed better due to effective synchronization of nutrient release with crop demand. Organic residues decreased pH in post harvest soil due to the production of organic acid, phenolic and carboxylic compounds and secretion of growing biomass (Rezig *et al*., 2013). It may be concluded that higher dose of organic material in combination with chemical fertilizers especially nitrogen supplied significant amount of plant nutrients during crop production and increased organic carbon content in soil. Ruensuk *et al.* (2010) reported that rice straw incorporation into the soil at rates of 0-5 t ha^{-1} did not affect early rice growth stage or rice yield.

From this experiment it may be concluded that combined use of chemical fertilizers with 2.0 t C ha^{-1} fresh rice straw in continuous flooding system performed better to reduce CO_2-C gas emission, increased organic carbon, optimized soil pH and increased rice production. Reduced plant height, no. of effective tillers per hill, grain yield, straw yield and increased CO_2-C emission were found with the increasing water stress as AWD system. Thus on overall basis continuous flooding with 2.0 t C ha^{-1} as fresh rice straw is an effective way to reduce CO_2-C emission, optimize soil pH and contribute to sustainable rice production.

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