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Effect of Tillage Practices and Rice Straw Management on Soil Environment and Carbon Dioxide Emission

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Abstract

Carbon (C) inputs and tillage intensity impinge on C degradation and thus CO_2 emission and soil properties get influenced. Information on CO_2 emission and soil properties under different tillage practices and straw application in rice based cropping system in Bangladesh is lacking. The effects of rice straw and tillage operations on CO_2 emission and soil properties were quantified in four consecutive seasons of transplanted Aman and Boro rice grown under two tillage operations (minimum and traditional) and three levels of rice straw (control, incorporation and mulch) during 2010 to 2012. Irrespective of tillage practices, CO_2 emission peak reached after 3-4 weeks of straw application. Carbon dioxide emission ranged from 26 to 59 kg ha^{-1} day^{-1} under minimum tillage and 25 to 96 kg ha^{-1} day^{-1} under traditional tillage. Minimum tillage accumulated more C in soil, which could be attributed to lower rates of emission and straw degradation. Carbon degradation rate constants, k were 0.000300 and 0.000394 (day^{-1}) under minimum and traditional tillage, respectively. Small increment in soil C might help reducing CO_2 in the atmosphere. Mineralization of straw increased nutrient contents and thereby improved the soil fertility and availability to the crops for nutrients' uptake. Traditional tillage significantly reduced soil bulk density and increased field capacity of the soil, whereas in addition, rice straw application furthermore increased permanent wilting point and available water content in the soil. The present study may help in identifying suitable tillage and residue management options in reducing CO_2 emission from rice fields.

Keywords: CO_2 emission; tillage; rice straw; field capacity; permanent wilting point.

1. Introduction

Global warming due to climate change appeared as a great concern, which may continue beyond decades resulting in dangerous consequences for many countries in the world. This negatively affects agriculture, living being and finally the total environment. Carbon dioxide and methane are the most important greenhouse gases releasing from paddy fields responsible for global warming (Lee *et al.,* 2006; Munoz *et al.,* 2010). World soils and terrestrial ecosystems have been a source of atmospheric CO_2. Reducing CO_2 emission from rice fields through carbon build up in soil is of prime importance (Rahman 2013a). The amount of CO_2 emitted from croplands depends on types of crops/cropping systems, crops' residue management, soil and land management and climatic conditions.

Soil is a major source of emission for atmospheric CO_2 content and reduction of its emission through C sequestration in soil is of prime importance as mitigation and adaptation strategies. Soil management practices like increasing soil OC, reduced tillage, manuring, residue incorporation, improving soil biodiversity, micro-aggregation and mulching can play an important role in accumulating carbon in the soil. It is generally assumed that after incorporation of residues to soils, it takes about one month for maximum microbial activities depending on C: N ratios of the provided organic materials. The higher is the carbon content, the longer time is needed to decompose it. The contribution of agricultural soils to CO_2 emission depends on decomposition of different types of organic residues added to soil. Carbon dioxide is released through microbial and root respiration, where microflora contributes 99% of the CO_2 arising as a result of decomposition of OM (Munoz *et al*., 2010).

Emission of CO_2 results in lower reserves of OM in soils. Soil OM stabilizes soil structure and plays a central role in soil surface-atmosphere exchange of carbon. Globally, organic C in the upper 1 m of agricultural soil is about 167 Pg, and these soil have already lost 30 to 70% of their original soil C storage in the upper 30 cm due to changing land use systems, soil and crop management practices under a wide range of climatic conditions (Eve *et al.*, 2002). Soils of Bangladesh have low reserves of carbon because of higher cropping intensity, higher decomposition rate of OM contributing to higher emission of C, use of lesser quantity of organic manure and little or practically no use of green manures coupled with warmer temperature and high humidity. The rate of soil carbon emission is strongly regulated by the complex interaction among soil physical, chemical and biological processes and environmental conditions (Agehara and Warncke, 2005; Lee *et al.*, 2006). Soil aerobic conditions produce CO_2, while anaerobic conditions produce CH_4, depending on the concentration of soil OC. Large quantities of OC added to soils through different manures and wastes to supply plant nutrients may significantly contribute to CO_2 emission. However, proper management of organic materials, conservation tillage and mulching can play an important role in reducing CO_2 emission and thus increase C build up in soil.

Carbon recycling to soils through different organic residues enhances carbon stock in soils (Rahman, 2013b), which depends upon several factors related to soil edaphic environment. Rice straws are important source for incorporation in the soils for improving soil physical, chemical and biological properties. However, it is considered to be the major source of CO_2 emission from rice fields (Rahman, 2014). Different carbon inputs and tillage options affect organic matter degradation and thereby CO_2 emission. Organic matter and nutrient deficiency appeared as major concerns in the intensively cultivated areas of Bangladesh. Because of hyperthermic temperature regime in the growing regions, organic matter mineralization is usually high, which is a concern of Bangladesh soil. Tillage is the most important practice having a major effect on C pool, either usually with ill-effects under conventional ploughing or beneficial effects when conservation tillage is practiced (IPCC, 2000). Tillage has significant effect on soil health and subsequent crops' yields, while short-term effect of conservation or reduced tillage might not be noticeable in terms of soil characters. Conservation tillage practices can minimize rapid breakdown of plant residues and found that reducing tillage significantly decreases carbon loss, which results in the improved physical, chemical and biological properties of soil and thus improved crop productivity. The present carbon status in soils of

Bangladesh is alarming and, therefore, proper and deliberate management of soil organic carbon has of great importance. Up to date information on CO_2 emission and soil carbon and fertility build up are indispensible to combat global warming and climate change and for the sustainability of agricultural production systems (Rahman, 2010). However, such information under rice based cropping system in Bangladesh is scarce. Therefore, the objectives of this research were to quantify the effect of rice straw and tillage management in rice field on CO_2 emission, carbon build up and physical and chemical properties of soils.

2. Materials and Methods

2.1 Study site

The experiment was conducted at the research farm of Bangabandhu Sheikh Mujibur Rahman Agricultural University, Gazipur, Bangladesh. The site is located at 24.09° N latitude and 90.25° E longitudes with an elevation of 8.2 m from sea level, which comes under the agro-ecological zone of Madhupur Tract. The soil belongs to Salna series and classified as Shallow Red Brown Terrace soil in Bangladesh classification and Inceptisols in USDA classification (Brammer, 1978), which is characterized by silty clay loam within 50 cm from the surface and is acidic in nature. The climate of the area is sub-tropical, wet and humid. Heavy rainfall occurs during June-July (269 to 370 mm) and scanty rains during November to February (0 to 55 mm).

Surface soil samples were collected, at the time of sowing and after harvest of the crop, air dried, grounded to pass through 2 mm sieve and subsequently used for analysis of pH, , total N, available P, S, Zn & B and exchangeable K following standard protocols (Page *et al.*, 1982). For analysis of OC, a subsample was sieved through 0.2 mm sieve. The experimental field soil had low OC (1.03%), N (0.09%), K (0.14 meq 100 g^{-1}), S (6.5 mg kg^{-1}); very low P (2.4 mg kg^{-1}) and high Zn (2.32 mg kg^{-1}) content (BARC, 2005).

2.2 Experimentation

The study was conducted during August 2010 to May 2012 in four consecutive rice seasons of Transplanting aman (BRRI dhan49) and boro (BRRI dhan29) having two tillage operations (1) minimum tillage (MT) and (2) traditional tillage (TT) and three levels of rice straw management (1) control, (2) rice straw incorporation (RSI) and (3) rice straw mulch (RSM) in a factorial RCBD with four replications. The unit plot size was 4 m × 3 m and each plot was separated by 30 cm wide well structured and polyethylene lined levee. The experimental field was prepared by country plough maintaining a depth of 15 cm. The MT treatment received two passes of country plough while the TT treatment received 4 passes. Rice straw collected from previous season that contained approximately 17.5% moisture, 0.43% total nitrogen, 41% organic carbon with a C:N ratio 95 and was applied at the rate of 5 t ha^{-1} to the selected plots 15 days before transplanting.

During the first year, the T. Aman rice was transplanted on 6 August, 2010 and Boro rice seedlings was transplanted on 15 January, 2011. In the second year of experimentation T. Aman rice was transplanted on 15 August, 2011 and Boro rice transplanted on 25 January 2012. Thirty days older seedlings were transplanted at 20 cm × 20 cm spacing. The experimental field received N, P, K and S at the rates of 110, 20, 70, and 15 kg ha^{-1}, respectively from urea, triple super phosphate (TSP), muriate of potash (MoP) and gypsum, respectively in aman, while these nutrients in boro were 180, 27, 120 and 20 kg ha^{-1}, respectively according to BARC fertilizers recommendation model (BARC, 2005). The whole amount of TSP, MoP, gypsum were applied during final land preparation and urea was applied in three equal splits at 15 days after transplanting, at maximum vegetative stage and panicle initiation stage. Inter-culture operations were carried out as and when required. Proper irrigation practices were undertaken maintaining at least 5 cm water throughout the growing season.

2.3 Carbon dynamics and carbon dioxide emission

Carbon dioxide emission was measured by NaOH absorption followed by HCl titration (Jain *et al*., 2003). Observation was taken by every 7 days interval and continued throughout the four crop growing seasons. CO_2 traps were prepared using 80 ml of 2N-NaOH into plastic bottles and placed in the plots under each treatment. Traps were covered with plastic buckets, which were inserted into soft mud to protect entrance of atmospheric CO_2. An empty bucket was used as a control without soil but of alkali of same strength. After seven days of exposure, traps were removed from plots covering with screw cap and then titrated against HCl. From 80 ml of alkali solution, 2 ml was titrated adding few drops of phenolphthalein indicator against 2N-HCl. The amount of CO_2 evolved from soil was calculated using the formula:

Milligrams of C or CO_2 = (B-V)*N*E

where, B and V are volume (ml) of acid needed to titrate trapped NaOH in the control and straw treated plots, respectively, N = normality of the acid, and E (equivalent weight) is either 6 or 12 to express data in terms of C or CO_2, respectively. Data was expressed as kg CO_2 ha^{-1} day^{-1} soil and also as kg C ha^{-1} day^{-1}. Carbon degradation rate constant, k was calculated using the exponential kinetics, $\ln(C/C_0) = -kt$, where, C and C_0 are final and initial C contents, respectively; t is time in days (Avnimelech *et al*., 1984). Carbon build up was measured by subtracting initial soil C from residual soil C (Benbi and Senapati, 2010). Carbon balance was calculated at the end of the study period by using the following equation.

Carbon balance = Input – Output

Input = Inherent soil C + added C through rice straw before the four rice seasons + Rice straw C from straw and roots (remaining in the soil after first three rice seasons)

Residue rice straw and rice roots were quantified from a sample area of 1 m^2 and then extrapolated to kg ha^{-1}. For collecting roots, a sample area was irrigated first to make soil soft and dig out from surrounding roots area and then roots were washed out, air dried and placed in an oven at 65^0C for 48-72 hours. Rice straw and roots were analyzed for carbon (Page *et al*., 1982).

Output = C emission + Residual C in the soil at the end of experiment after crop harvest

Initial and residual soil C was calculated in the 15 cm soil depth, by using the following equation.

Organic C (kg ha^{-1}) = Conc. of soil C (%) * soil bulk density (g cc^{-1}) * soil depth (cm) * 1000

2.4 Analysis of soil physical characters

Particle size distributions were done by hydrometer method (Black 1965). Bulk density and particle density of soils were determined by core sampler and Pycnometer method, respectively (Black, 1965). Soil porosity was computed from the relationship between bulk density (BD) and particle density (PD). Field capacity (FC) and permanent wilting point (PWP) were measured using pressure plate apparatus, where available water (d) was calculated using the equation given by Black (1965).

Porosity (%) = (1 – BD/PD) x 100

d = (FC-PWP)/100 *BD (g cc^{-1}) *soil depth (cm)

2.5 Statistical analysis

SPSS version 12.0 statistical software (SPSS Inc., Chicago IL) was used to analyze the data. ANOVA and univariate analysis were performed and means were separated by LSD.

3. Results and Discussion

3.1 Carbon dioxide emissions (kg CO_2 ha^{-1} day^{-1})

Tillage operation did not show significant effect on CO_2 emission from soil in T. Aman 2010 and Boro 2011, while TT released significantly higher amount of CO_2 over MT in T. Aman 2011 and Boro 2012 (Table 1). CO_2 emission under MT were about 26, 34, 59 and 34 kg ha^{-1} day^{-1} in T. Aman 2010, Boro 2011, T. Aman 2011 and Boro 2012, respectively, while under TT, the respective values were 25, 33, 96 and 65 kg ha^{-1} day^{-1}. Rice straw management significantly affected CO_2 emission from soil ($p<0.05$) in all four rice growing seasons (Table 1). In case of T. Aman 2010, amount of CO_2 released was significantly higher (36.61 kg CO_2 ha^{-1} day^{-1}) in RSI over the RSM (27.33 kg CO_2 ha^{-1} day^{-1}). On the other hand, in case of Boro 2011, T. Aman 2011 and Boro 2012 straw application released significantly higher amount of CO_2 over the control i.e. where no residues were added, but the amount of CO_2 released from RSI and RSM were statistically similar. The interaction effect of tillage and rice straw was significant in CO_2 emission under T. Aman 2010 (Table 2), while the interaction was non-significant in Boro 2011, T. Aman 2011 and Boro 2012 (Table 2 and 3). In case of T. Aman 2010, RSI in both tillage practices released significantly higher amount of CO_2 from soil over other treatment combinations while RSI along with TT released the higher amounts of 37.4 kg CO_2 ha^{-1} day^{-1}. It was found that in the entire four crop growing seasons the interactions of RSI and TT were contributed in higher CO_2 emission from soil (Tables 2 and 3).

It was also noticed that in all the treatments of tillage verses rice straw management, emission of CO_2 increased with the progress of crop growing period. At the beginning when carbon stock in soil was low, consequently carbon emission was also low. However, application of rice straw in each season and moreover residual amounts of carbon in soils accelerated microbial respiration and thus contributed to higher emission of CO_2 in the latter stage of experiment. The higher amount of CO_2 emission during T. Aman 2011 (August to December) over Boro 2012 (January to May) might be attributed by faster microbial respiration because of higher air and soil temperatures in T. Aman season. The average air and soil temperatures during August to December were 23-30 and 27-31 ^{0}C, respectively, while these values during January to May were 15-30 and 20-28 ^{0}C, respectively. Positive effect of air and soil temperatures on microbial decomposition and subsequent CO_2 emission has been reported by other researchers (Grote and Al-Kaisi, 2007).

Table 1. Carbon dioxide emission (kg CO_2 ha^{-1} day^{-1}) under different tillage operations and rice straw management practices

Carbon dioxide emissions (kg CO_2 ha^{-1} day^{-1})				
Tillage operation	T. Aman 10	Boro 11	T. Aman 11	Boro 12
Minimum	25.76	33.49	58.66b	33.92b
Traditional	25.28	33.46	95.75a	64.77a
S.E.(±)	*0.40*	*0.99*	*0.97*	*0.95*
Rice straw management (5 t/ha)				
No rice straw	12.63c	14.54b	64.45b	37.12b
Rice straw incorporation	36.61a	43.77a	86.37a	57.97a
Rice straw mulch	27.33b	42.11a	80.81a	51.97a
S.E.(±)	*0.48*	*1.22*	*1.19*	*1.17*
CV (%)	*5.36*	*10.23*	*4.36*	*6.69*
Tillage practices x rice straw	*	NS	NS	NS

Table 2. Interaction effects of tillage operations and rice straw management on CO_2 emission (kg CO_2 ha^{-1} day^{-1}) in Aman 2010 and Boro 2011

Rice straw	Carbon dioxide emissions (kg CO_2 ha^{-1} day^{-1})					
	Aman 2010			Boro 2011		
	MT	TT	Difference (TT-MT)	MT	TT	Difference (TT-MT)
Control	12.64c	12.62c	-0.02	15.34	13.75	-1.59
RSI	35.81a	37.41a	1.60	42.30	45.25	2.95
RSM	28.85b	25.80b	-3.05	42.83	41.40	-1.43
CV (%)	5.36			10.23		

MT = minimum tillage, TT = traditional tillage, RSI = rice straw incorporation, RSM = rice straw mulch

Table 3. Interaction effects of tillage operations and rice straw management on CO_2 emission (kg CO_2 ha^{-1} day^{-1}) in Aman 2011 and Boro 2012

Rice straw	Carbon dioxide emissions (kg CO_2 ha^{-1} day^{-1})					
	Aman 2011			Boro 2012		
	MT	TT	Difference (TT-MT)	MT	TT	Difference (TT-MT)
Control	64.13	64.75	0.62	38.03	38.21	0.18
RSI	83.72	89.01	5.29	56.22	59.71	3.49
RSM	81.71	79.90	-1.81	52.19	51.75	-0.44
CV (%)	4.36			6.69		

MT = minimum tillage, TT = traditional tillage, RSI = rice straw incorporation, RSM = rice straw mulch

There are some uncertainties associated with emission determination. Carbon dioxide emission in the rice field soils mainly depends on soil respiration and organic matter decomposition where soil temperature and moisture regimes amplify the process (Agehara and Warncke, 2005; Lee *et al.,* 2006; IPCC, 2014). Temperature from plot to plot may vary and water depth in all plots could not be maintained at equal depths as flood irrigation was provided to rice fields. Because of the method used in the present study it was also not possible in partitioning total CO_2 emission into microbial emission and root respiration. The diurnal variation also may cause as an uncertainty in measuring CO_2. In the present study, CO_2 was measured weekly from field at 10.0 am in the morning. Therefore, the uncertainties remained in our experiment and need to be addressed in future studies.

3.2 Weekly released patterns of CO_2 from soil

In case of T. Aman 2010, during the first week CO_2 emission rates showed a little difference among the tested treatments, being the lowest in MTC and the highest in MTRSM (Figure 1). The CO_2 emission tended to increase in second week compared to the first week, but the magnitude of increase in case of MTRSM appeared noticeable. The trend of CO_2 emission in the third week demonstrated a significant treatment interaction. The CO_2 emission in TTRSM showed a consistent increasing trend up to third week, while it decreased in case of MTRSM and

MTRSI compared to that of second week. Irrespective of the tillage treatment, the straw treated plots emitted the highest amount of CO_2 in the fourth week but showed no difference among the method of straw incorporation and tillage operations. Contrast to the straw applied plots, CO_2 evolution in the control treatment showed declining trend in fourth week and continued up to seventh week. The fifth week's evolution of CO_2 declined in all the treatment negligible difference among them. CO_2 evolution in the sixth week produced a second peak with the highest in TTRSI followed by MTRSM and MTRSI and the least in TTRSM. Receiving the straw mulching treatment both in TT and MT had lower CO_2 emission than the rice straw incorporated one consistently during seventh to eleventh week. During twelfth to sixteenth weak of measurement, rice straw incorporation treatment emitted more CO_2 compared to other treatment, but the treatment difference was not significant.

T. Aman 2010 was transplanted during the first week of August 2010 and the air temperature as well as soil temperatures were high at that time, which favored rapid microbial decomposition of added rice straw and therefore, CO_2 emission was higher at that time. In the fifth week of rice growing period it was the first week of September 2010 when the air temperature decreased and also there was rainfall of about 8 mm (BSMRAU weather Office), which resulted in slower decomposition of organic residues and hence CO_2 emission was low. However, though not measured under this study, methane emission under this flooded situation might have been higher. The maximum rates of CO_2 emission were over 600 kg CO_2 ha^{-1} wk^{-1} found in all the treatments, except control (Figure 1). After twelve weeks of rice growing period, emission of CO_2 decreased to 33 to 130 kg CO_2 ha^{-1} wk^{-1}, which continued till the end of growing period.

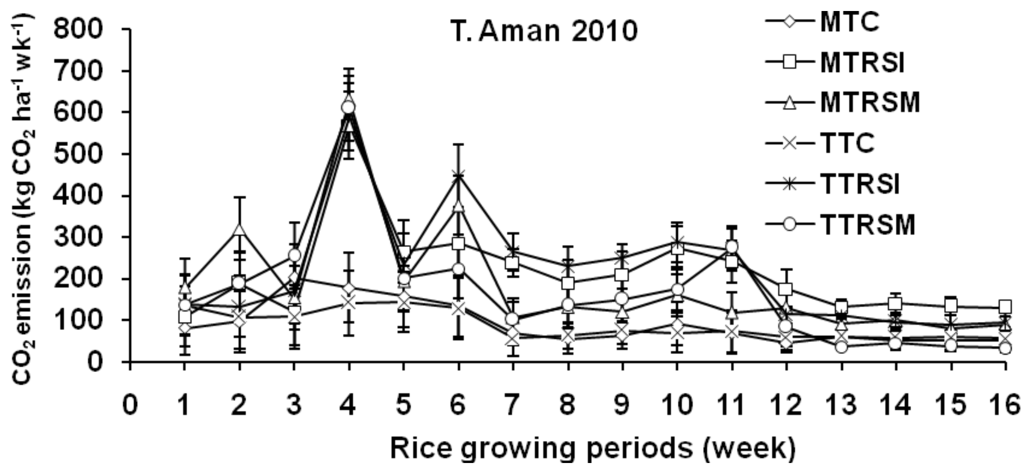

Figure 1. Carbon dioxide emissions (kg CO_2/ha/week) under different tillage operations and rice straw management practices during T. aman 2010. MTC: minimum tillage control, MTRSI: minimum tillage rice straw incorporation, MTRSM: minimum tillage rice straw mulch, TTC: traditional tillage control, TTRSI: traditional tillage rice straw incorporation, TTRSM: traditional tillage rice straw mulch.

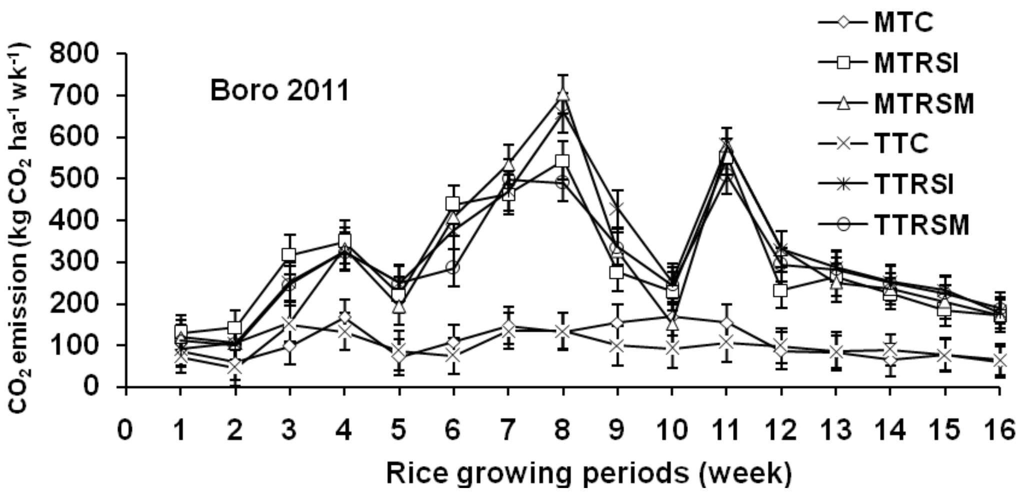

Figure 2. Carbon dioxide emission (kg CO_2 ha^{-1} wk^{-1}) measured under different tillage and rice straw management practices during boro 2011. MTC: minimum tillage control, MTRSI: minimum tillage rice straw incorporation, MTRSM: minimum tillage rice straw mulch, TTC: traditional tillage control, TTRSI: traditional tillage rice straw incorporation, TTRSM: traditional tillage rice straw mulch.

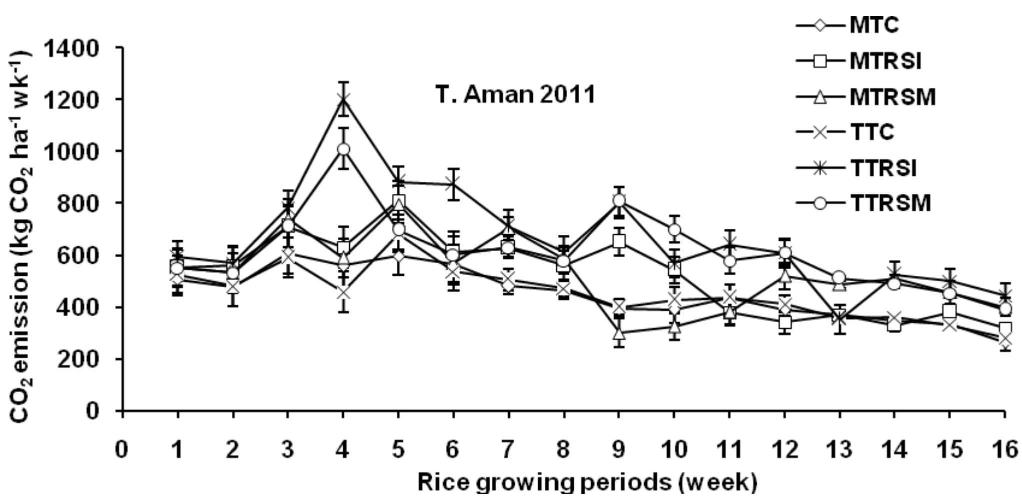

Figure 3. Carbon dioxide emission (kg CO_2 ha^{-1} wk^{-1}) measured under different tillage and rice straw management practices during T. aman 2012. MTC: minimum tillage control, MTRSI: minimum tillage rice straw incorporation, MTRSM: minimum tillage rice straw mulch, TTC: traditional tillage control, TTRSI: traditional tillage rice straw incorporation, TTRSM: traditional tillage rice straw mulch.

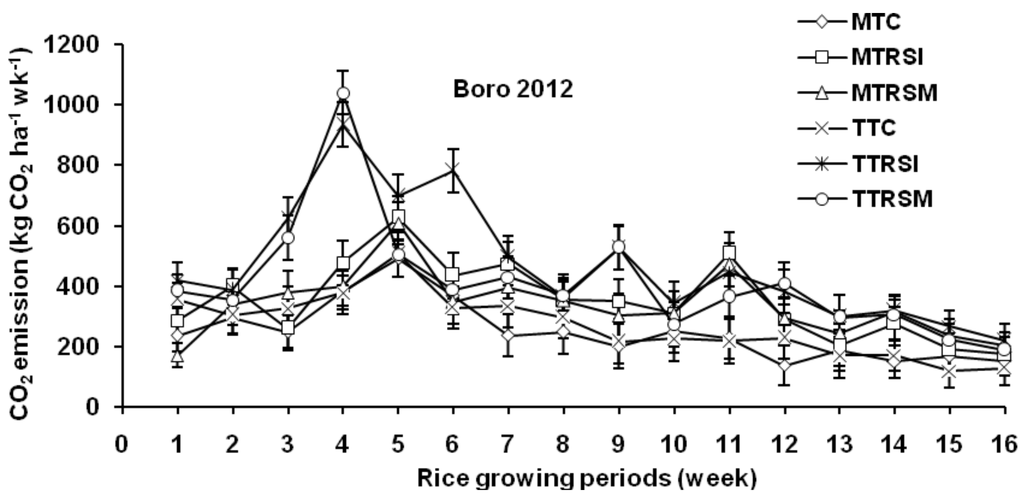

Figure 4. Carbon dioxide emission (kg CO_2 ha^{-1} wk^{-1}) measured under different tillage and rice straw management practices during boro 2012; MTC: minimum tillage control MTRSI: minimum tillage rice straw incorporation, MTRSM: minimum tillage rice straw mulch, TTC: traditional tillage control, TTRSI: traditional tillage rice straw incorporation, TTRSM: traditional tillage rice straw mulch.

In Boro 2011 (Figure 2), weekly released patterns of CO_2 were different from that of T. Aman 2010. During first two weeks CO_2 emission rates showed a little difference among the tested treatments and remain almost same, while start increasing in the 3rd week and drop down in the 5th week then further increased and reached to a peak at the 8th week of rice growing periods. Rice seedlings of Boro 2011 were transplanted on January 15, 2011 when temperatures were low, resulting in lower microbial activites. Emission of CO_2 reached its peak at eight week of transplanting, when air temperature increased. The highest amount of CO_2 released from straw mulched plot under MT were 703 kg CO_2 ha^{-1} wk^{-1}. A second peak was observed at 11th week of rice growing periods were MTRSM and TTRSI released the highest amount of CO_2 which was 578 kg CO_2 ha^{-1} wk^{-1}. After twelve weeks of rice growing periods emission of CO_2 decreased to a range of 65–188 kg CO_2 ha^{-1} wk^{-1}, which continued till the end of growing period. The release pattern of CO_2 infers that degradation of carbon in soils is responding to increased soil and air temperatures. Under normal situation, the peak of CO_2 emission reaches after 3-4 weeks of rice straw application in soil. In T. Aman 2011, CO_2 emission slightly decreased in the 2nd week, while start increasing in 3rd week (Figure 3).

During 4th week of rice growing periods emission increased and reached to the highest amount in TTRSI (1201 kg CO_2 ha^{-1} wk^{-1}) and TTRM (1011 kg CO_2 ha^{-1} wk^{-1}), while in all other treatment combinations CO_2 emission decreased from the 3rd week. Almost similar fashions in CO_2 emission under different tested treatments were observed at 9th week of growing season. At the end of 16th week it reduced to 280 to 443 kg CO_2 ha^{-1} wk^{-1}. During Boro 2012 the emission of CO_2 dropped down compared to both Boro and T. Aman 2011. The highest amount of CO_2 released during Boro 2012 at 4th week in TTRSM, which was 1039 kg CO_2 ha^{-1} wk^{-1} and in TTRSI, which was 932 kg CO_2 ha^{-1} wk^{-1}, while in all other treatments emission decreased (Figure 4). At the end of 16th week, it reduced to

127 to 219 kg CO_2 ha^{-1} wk^{-1}. It was found that trend of CO_2 emission among four rice seasons of T. Aman and Boro varied widely. The probable reasons of seasonal variations of CO_2 emission from soil treated with different organic materials are many where weather conditions, soil oxidation states and attributes of materials added are leading. The emission of CO_2 from soil is an index of the activity of microorganisms which in most cases ranged from 25 to 40 kg ha^{-1} day^{-1} with a peak of about 100 kg ha^{-1} day^{-1} (Boyd 1995). Therefore, emission of CO_2 in the present study is assumed to be somewhat higher which is attributed by subtropical climatic condition favoring faster microbial decomposition of soil organic matter. Emission of CO_2 was reported higher in warmer weather which vary with soil pH, moisture content, O_2 supply and N availability as all these factors have profound effect on soil microbial dynamics and activity (Zebarth *et al.*, 2009).

3.3. Rice yield

Tillage operations showed poor effect on grain yields of rice during four cropping seasons (Table 4). It needs longer time to get positive effect of MT in crop production and soil health improvement. However, the non-significant yield difference between tillage practices indicates the superiority of MT over TT. The effect of RSI and RSM on rice yield was found insignificant (Table 4). The maximum grain yields were observed 5.25 and 6.34 t ha^{-1} in T. Aman 2011 and Boro 2012, respectively.

However, the grain yields of rice in the present study were found satisfactory considering the national yield goals of BRRI dhan49 and BRRI dhan29, which are 5.0 and 7.5 t ha^{-1}, respectively set by BARC (2005). Incorporation of the crop stubble and straw into soil replenish nutrients and helps to conserve soil nutrient reserves in the long-term (Tuyen and Tan, 2001). Among different types of crop residues, rice straw is readily available in the wetland rice field, which can easily be incorporated into soil. It was observed that short-term effects of residue incorporation in soils on grain yield are often small, but in the long run it obviously would benefit significantly. Incorporation of rice straw improves soil health and fertility and thereby increases crop yields about 0.4 t ha^{-1} per season (Tuyen and Tan, 2001).

Table 4. Effect of tillage and rice straw on grain yields of T. Aman and Boro rice

Yield of rice grain at harvesting (t/ha)				
Tillage operation:	T. Aman	Boro	T. Aman	Boro
Minimum	4.54	5.66	4.68	5.83
Traditional	4.50	5.74	4.92	6.05
S.E.(±)	*0.25*	*0.34*	*0.45*	*0.19*
Rice straw management 5 t/ha):				
No rice straw	3.90	4.90b	4.10b	5.21b
Rice straw incorporation	4.78	6.06a	5.15a	6.27a
Rice straw mulch	4.89	6.13a	5.25a	6.34a
S.E.(±)	*0.53*	*0.42*	*0.46*	*0.23*
CV (%)	*21.30*	*31.07*	*23.45*	*11.25*
Tillage practices x rice straw	NS	NS	NS	NS

In the present study, seasonal and year to year variations in grain yields of T. Aman and Boro rice were also observed. Because of better soil, water and crop management practices grain yields of both Aman and Boro rice increased positively from the year 2010 to 2012. Yield of Boro rice was higher than that of Aman rice owing to higher yield potential and more photosynthetically active radiation in the Boro season. The average yield of modern rice varieties is 1.0 to 1.5 t ha^{-1} higher in the Boro season compared to the Aman season due to favorable growing environment such as high sun shine hour and low pest pressure (Hossain *et al.,* 2013).

3.4 Soil chemical properties

Tillage operation significantly influenced soil available S and exchangeable K, while its effect was non-significant in case of pH, OC, total N, available P, available Zn and B (Table 5). The significantly higher amounts of K and S were found in soils under MT having the values 0.17 cmol kg^{-1} and 7.22 mg kg^{-1}, respectively, while under TT the values were 0.16 cmol kg^{-1} and 5.81mg kg^{-1}, respectively. Soil chemical properties were significantly influenced by rice straw application over the control (Table 5). However, non-significant differences in soil nutrients including pH, were noticed between rice straw incorporation and mulch treatments.

Plants can alter soil pH by releasing root exudates, such as organic acids and anions, to enhance mineral nutrient solubility as well as liberation of OH^- or HCO_3^- resulting from OH^- carbonation in order to counter balance cations entering the roots (Hinsinger, 2003). Decomposition of organic acid anions can also increase soil pH due to proton consumption in the decarboxylation process. Organic matter from residues improved soil pH status by increasing buffering capacity (Ogbodo, 2011). Mineralization of rice straw might contribute to soil total N, available P, S, Zn, B and exchangeable K. Rice straw applied to soils acted as a harbor of microbes as well OM contents in soil is increased, which enriches the labile pool of nutrients. Improvement of soil pH led to solubilzation of inorganic P (Ogbodo, 2011). Rice straw contains higher amount of potassium, therefore, K concentration was expectedly higher under straw treatment. The hydrogen ions released from organic materials are exchanged with K on exchange site or set free from the fixed site of the clay micelle. Thus, the overall status of soil regarding availability of potassium is improved (Singh *et al.,* 2002).

3.5 Carbon balance

The effect of tillage practices and rice straw incorporation were found significant on cumulative emission of carbon in all the four rice growing seasons (Table 6). Traditional tillage and rice straw application (either mulch or incorporation) released higher amount of carbon compared to MT and control, respectively. It is worthy to note that total carbon input under TT was higher by about 1000 kg ha^{-1} over MT, which might have significant positive effect on higher emission of carbon from soil. Residual carbon in soils revealed the opposite trends to carbon emission i.e. carbon accumulation in soil was found higher under MT. Rice straw mulch and RSI did not show significant difference in carbon accumulation in soils.

Carbon balance was significantly affected by rice straw application. Carbon balance may be positive, negative or even zero depending on the nature and types of carbon source applied in soil, presence of microbial communities, soil physical and chemical properties and agronomic management practices. The positive carbon balance (input>output) indicates some amount of inputs could not be traced out in soil system, while negative balance (input<output) indicates addition of carbon over the applied amount due to higher microbial activities. Carbon cycling is the continuous transformation of organic and inorganic carbon compounds by plants and micro- and macro-organisms between soil, plants and atmosphere. In cultivated organic soils, about 450- 4500 kg bacteria are present in the furrow slice, while fungi ranges in 1120-11200 kg/ha and actinomycetes ranges in 450- 4500

kg/ha (Brady, 2001). Bacteria, fungi and actinomycetes are 50% carbon (Boyd, 1995). Thus a significant amount of carbon might be added to soils.

Carbon degradation rate constant, k was found significantly higher under TT than MT, while carbon build up was higher in MT (Table 6). Rice straw mulching or incorporation did not show significant difference on C emission, degradation and build up. The k value in the present study under the MT was 0.000300 d^{-1}, while it was 0.000394 d^{-1} under TT. Rahman (2013b) reported from a laboratory study that carbon degradation rate constants (k) of rice straw varied from 0.002834 to 0.005104 d^{-1}. Jorgensen (1979) found k value of 0.00001 to 0.0008 d^{-1} for mineral soil. Significantly lower C emission and degradation rate, k in soils attributed higher C build up under MT than TT. Under MT and TT carbon build up were 3813 and 1980 kg ha^{-1}, respectively. Variation in carbon build up in soil from different manures and crop residues depends on their application rates and carbon contents. During ten years of rice cropping Bhattaacharyya *et al.* (2012) found that application of rice straw at the rate of 7.12 t ha^{-1} yr^{-1} carbon content in soil was increased by 1230 kg C ha^{-1}, while rice straw applied at the rate of 4.8 t ha^{-1} yr^{-1} along with inorganic fertilizes contributed to 1390 kg C ha^{-1}. Rahman *et al.* (2016) applied rice straw at the rate of 2 t C ha^{-1} $season^{-1}$ in five consecutive rice growing season and found that carbon content increased by 1040 kg C ha^{-1}. In the present study, initial carbon concentration in soil under MT was 1.18%, while in residual soil it was increased to 1.37% i.e. the carbon increment was only 0.19% after four consecutive rice growing season taking all carbon inputs viz. initial soil carbon, carbon applied as rice straw, residual rice straw and rice roots. On the other hand, carbon increment under TT practice was only 0.09%. Though the carbon increment in soil was found small, however, it has immense positive effect in reducing CO_2 concentration in the atmosphere over the longer term, which would help in mitigating global warming and climate change.

Table 5. Effect of tillage practices and rice straw management on soil fertility statuses after harvest fourth crop (Boro 2012)

Treatment	Soil chemical properties							
	pH	Carbon (%)	Total N (%)	Available P (mg kg^{-1})	Exchangeable K (cmol kg^{-1})	Available S (mg kg^{-1})	Available Zn (mg kg^{-1})	Available B (mg kg^{-1})
Tillage								
Minimum	5.7	1.37	0.10	2.10	0.17a	7.22a	2.46	0.25
Traditional	5.6	1.32	0.10	1.94	0.16b	5.81b	2.40	0.26
SE(±)	*0.094*	*0.05*	*0.010*	*0.232*	*0.002*	*0.438*	*0.107*	*0.014*
Rice straw (5t/ha)								
No rice straw	5.4b	1.17b	0.07b	1.57b	0.15b	5.31b	2.31	0.22b
Rice straw incorporation	5.8a	1.36a	0.13a	2.43a	0.18a	7.73a	2.58	0.28a
Rice straw mulch	5.7a	1.37a	0.11a	2.06ab	0.17a	6.50a	2.41	0.27a
SE(±)	*0.116*	*0.45*	*0.012*	*0.284*	*0.003*	*0.537*	*0.131*	*0.017*
CV (%)	*4.14*	*13.47*	*24.95*	*28.15*	*5.87*	*16.49*	*10.82*	*13.91*
Tillage x Rice straw	NS	NS	NS	NS	NS	NS	NS	NS

Table 6. Carbon input-output balance, degradation rate constant and carbon build up

Treatment factors	C input (kg ha^{-1})					C output (kg ha^{-1})			Balance	k (d^{-1})	C build up (kg ha^{-1})
	ICS	RS1	RS2	RR	Total	Emission	Residual	Total			
Tillage:											
Minimum	23563	4800	1361	1983	31706	4638b	27376a	32015	-309	0.000300b	3813a
Traditiona	24340	4800	1378	2130	32647	6697a	26320 b	33017	-370	0.000394a	1980b
SE (±)	*498*	*00*	*19*	*55*	*479*	*67*	*539*	*48*	*332*	-	*320*
RS (5 t/ha):											
Control	22367	00	909	1541	24816	3963b	23723b	27686	-2869c	0.000241b	1356b
RS	24880	7200	1600	2431	36112	6864a	28816a	35679	433b	0.000404a	3935a
RS mulch	24605	7200	1600	2196	35601	6177a	28005a	34182	1419a	0.000372a	3400a
SE (±)	*610*	*00*	*24*	*67*	*586.9*	*83*	*660*	*671*	*406*	-	*392*

ICS = initial carbon in soil, RS1 = rice straw added carbon, RS2 = residue rice straw carbon, RS = rice straw, RR = rice root carbon, C = carbon, k = degradation rate constant

3.6. Soil physical properties

Tillage practices showed significant effect on soil bulk density and field capacity, whereas insignificant effect was observed in soil particle density, porosity, permanent wilting point and available water content (Table 7). On the other hand, rice straw application showed significant effects on soil bulk density, field capacity, permanent wilting point and available water content, while insignificant effect was noticed in case of soil particle density and porosity (Table 7). Soil bulk density was higher under MT (1.35g cm^{-3}) than that of TT (1.33g cm^{-3}), field capacity was higher in TT (27.12%) compared to MT (24.5%). These findings are in agreement with the studies of Husnjak *et al.* (2002). It is fact that the particle density not altered easily by normal physical manipulation of soil.

The soil porosity ranged from 45.88 to 47.88%. The lowest soil porosity 45.88% was recorded where no rice straw was added. Comparatively lower porosity was also found in MT than that of TT. Soil porosity is very much influenced by the soil bulk density as particle density is not greatly altered by the agricultural manipulation. Rice straw application and intensive ploughing made the soil more aggregated and porous. The bulk density of initial soil was 1.38 g cm^{-3}, which decreased to 1.33 g cm^{-3} where rice straw was incorporated and 1.31 g cm^{-3} where more tillage was done, which indicated that addition of rice straw and TT made surface soil loose and porous, thus enhanced the capacity of soil to store and retain more moisture. Therefore, the field capacity of surface soil was increased in such condition. The lowest field capacity (23.10%) was recorded in soils where rice straw was not applied. The highest field capacity of 27% was recorded under TT and also rice straw applied treatment.

The permanent wilting point and available water contents were found significantly higher under rice straw applied soils over the control treatment (Table 7). In rice-rice cropping systems repeated adoption of traditional tillage increases micropores that can hold more water. On the other hand, organic matter contents under rice straw applied plots were found significantly higher compared to the control (Table 5), which might be the reason of increased moisture holding at permanent wilting point. Organic matter addition improves soil structure and increase water holding capacity of soil. Torkashvand and Shadparvar (2013) reported that application of rice straw and municipal waste significantly increased field capacity, permanent wilting point and plant available water content in soil.

Table 7. Effect of tillage practices and rice straw management on soil physical properties at 0-15 cm soil depth of post experimental soil after four rice crop

Treatments	Soil physical properties					
	Bulk density (g cm^{-3})	Particle density (g cm^{-3})	Porosity (%)	Field capacity (%)	Permanent wilting point (%)	Available water content (cm of water in the upper layer)
Tillage:						
Minimum tillage	1.35a	2.53	46.64	24.50b	10.44	2.85
Traditional tillage	1.31b	2.51	47.80	27.12a	12.12	2.95
SE(±)	*0.014*	*0.007*	*0.512*	*1.012*	*0.753*	*0.101*
Rice straw (5 t/ha):						
No rice straw	1.38a	2.55	45.88	23.10b	10.10b	2.69b
Rice straw incorporation	1.33b	2.54	47.64	27.53a	11.53ab	3.19a
Rice straw mulch	1.36a	2.54	46.46	27.22a	12.10a	3.08a
SE(±)	*0.011*	*0.004*	*0.322*	*0.534*	*0.321*	*0.178*
CV (%)	*2.73*	*2.22*	*4.81*	*7.34*	*5.24*	*7.53*

Therefore, from our study it can be accentuated that manipulation of soil moisture dynamics through tillage and rice straw management could be one of the feasible ways of higher moisture retention and increased crop production.

4. Conclusions

Minimum tillage was found positive in soil carbon enrichment and CO_2 emission reduction. Emission of CO_2 under minimum tillage were 26, 34, 59 and 34 kg ha^{-1} day^{-1} in T. Aman 2010, Boro 2011, T. Aman 2011 and Boro 2012, respectively, while under traditional tillage respective values were 25, 33, 96 and 65 kg ha^{-1} day$^{-1.}$ During the entire four rice growing seasons the interactions of RSI and TT were contributed in higher CO_2 emission from soil. In most of the cases the peak values of CO_2 emission reached after 3-4 weeks of straw application, irrespective of tillage practices. Rice straw mulching or incorporation did not show significant difference on C emission, degradation and build up in soil. Carbon degradation rate constant (k) and C build up under minimum tillage were 0.0003 (day^{-1}) and 3.8 t ha^{-1}, respectively, while in traditional tillage respective values were 0.000394 (day^{-1}) and 1.9 t ha^{-1}. Slow degradation of rice straw ensures an uninterrupted supply of soil nutrients and thereby improves soil fertility. After four consecutive rice seasons, the increment in soil C was found small, however, which may exert immense positive effect in reducing CO_2 emission in the atmosphere on the long term basis and thus helping in mitigating global warming and climate change.

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