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EFFECTS OF FERTILIZER AND ORGANIC MATTER MANAGEMENT ON CARBON SEQUESTRATION AND SOIL FERTILITY IN RICE SOIL

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Abstract

The experiment was conducted at the Bangladesh Rice Research Institute, Gazipur during the period of T. Aman 2010 to T. Aman 2013. Five treatment combinations, viz. T_1: Fertilizer control, T_2: Cow dung + integrated plant nutrition system (IPNS) based chemical fertilizer (CD+IPNS), T_3: Poultry manure + IPNS (PM+IPNS), T_4: Rice straw + IPNS (RS+IPNS) and T_5: Soil test based (STB) chemical fertilizer were used to quantify the changes of soil organic carbon and the rates of CO_2 emission from rice soil due to application of various organic materials. Organic materials were used @ 2.0 t C ha^{-1}. The rate of CO_2 emission was higher in PM, followed by CD and RS treated plots. The CO_2 emission was higher in the T. Aman season than Boro season. The highest amount of CO_2 emission was found in PM treated plots (4943 kg $ha^{-1}114^{-1}$ days in T. Aman and 4315 $kgha^{-1}112^{-1}$ days in Boro), and the lowest was in control. Remarkable amount of soil organic carbon (1.54%) accumulated in CD treated plot compared to control plot (1.13%).

Keywords: Cow dung, Poultry manure, Rice straw, Chemical fertilizer, CO_2 emission

1. Introduction

Carbon sequestration is essentially the process of transforming C in the air (CO_2) to stored soil C. Globally, soil organic C storage has been widely considered as a measure for mitigating global climate change through C sequestration in soils. Soil organic C plays an important role as a pool of terrestrial C, in ecosystem productivity, in the functioning of agroecosystems, and cropland fertility (Rahman, 2014; Rahman *et al.,* 2020). It plays a key role in soil quality by improving soil physicochemical and biological properties (Lal, 2013).

Therefore, developing a sustainable management of soil organic matter (SOM) is a major concern for agriculture, environmental quality, and land preservation (Paustian *et al.,* 2016). Agricultural practices may lead to an increase or depletion of SOM in agroecosystems (Edmeades, 2003). Intensive agricultural practices have depleted 25–75% of SOC in most soils of the world (Lal, 2013). But when organic-mineral fertilizations were conducted according to the C balance method, usually no substantial depletion of SOC was detected. The importance of SOC for soil quality and health highlights the need to find practices to prevent SOC depletion. Soil organic C response to soil use and management is a slow process that can only be evaluated with long-term experiments. Soil organic C content results from the balance between SOC mineralization and organic C inputs (Hasnat *et al*., 2022). As a result, management practices increasing C inputs, as farmyard manures, green manure, and crop residues incorporation, are known to restore SOC content in agricultural soils (Zhao *et al*., 2009; Bhattacharya *et al.*, 2016; Biswas *et al*., 2022). In general, the use of organic manures and compost enhances the SOC pool more than application of the same amount of nutrients as inorganic fertilizers. Changes in SOC and crop yield following application of organic amendments have received great attention.

Long-term carbon storage data in soils is important at the national level to understand the contribution of a country to global warming (Islam *et al*., 2024). In other words, it is needed to determine how much carbon is sequestrated in soils and how much is emitted through fossil fuel burning through vehicles and industries annually. To enhance soil organic C for increasing soil quality and agronomic productivity, application of crop residues, mulch, and other bio-solids, including compost and manure is necessary. In this study, what changes in soil organic C that occur due to the application of various organic materials at different fertility levels were evaluated and the rates of carbon dioxide emission from rice soils influenced by that management were quantified.

2. Materials and Methods

2.1 Experimental site, initial soil properties, and treatments

This experiment was initiated in T. Aman Season 2010 at the BRRI farm, Gazipur (AEZ-28, Modhupur Tract and Medium High Land). The soil of the experiment field was clay-loam in texture and neutral (pH 6.7). The content of soil organic C, total N, available P, exchangeable K, and available Zn (DTPA extracted) of the soil were 1.50 %, 0.18%, 7.2 mg/kg, 0.13 Cmol kg^{-1} soil, and 0.64 mg kg^{-1} soil, respectively. The following treatments were used in this experiment: T_1= Absolute control (No chemical fertilizer and organic material), T_2= Cow dung + IPNS based chemical fertilizer (CD+IPNS), T_3= Poultry manure + IPNS based chemical fertilizer (PM+IPNS), T_4= Rice straw + IPNS based chemical fertilizer (RS+IPNS) and T_5=Soil test based (STB) chemical fertilizer. The experiment was laid out in an RCB design with four replications. Organic materials were used at the rate of 2 t Cha^{-1}. Soil test-based (STB) dose was NPK @ 75, 10, and 75 $kgha^{-1}$, respectively in T. Aman season and 162, 24 and 75 $kgha^{-1}$, respectively in Boro season. BRRI dhan31 in T. Aman season and BRRI dhan29 in Boro season were used as test varieties. All intercultural operations were done as per requirements.

2.2 CO_2 measurement

Carbon dioxide (CO_2) emission was measured by the following standard method (Jain *et. al.*, 2003) in both T. Aman and Boro seasons. Reading was taken every 7-day interval, and it was continued throughout the crop growing season. A CO_2 trap was prepared using 80 ml of 2

N NaOH in a plastic bottle and placed in the plots under different treatments. Each trap was covered with a plastic bucket, which was inserted into soft mud to protect the entrance from air and CO_2 into the bucket. After 7 days of exposure, the alkali bottle was removed from the plot, covered with a screw cap, and then it was titrated against 0.5 N hydrochloric acid. An empty bucket was used as a control for this experiment without soil, but the alkali of the same strength. The alkali solutions from the control and those exposed to soil were titrated to determine the quantity of alkali that had not reacted with CO_2. For this purpose, 2 ml saturated $BaCl_2$ was added to the NaOH solution to precipitate the carbonate as insoluble $BaCO_3$. From an 80 ml alkali solution, exactly 10 ml was titrated, adding 2 ml of saturated $BaCl_2$ and a few drops of 1% phenolphthalein indicator against 0.5 N HCl. The acid was added slowly to avoid contact with possible dissolution of the precipitated $BaCO_3$. The volume of acid needed to titrate the alkali was noted. The amount of CO_2 evolved from the soil during exposure to alkali was calculated using the formula: Milligrams of CO_2 = (B-V) N E. Where B = volume (ml) of acid needed to titrate NaOH in the jars from the control cylinders, V = volume (ml) of acid needed to titrate the NaOH in the beakers exposed to the soil atmosphere, N = normality of the acid, and E = equivalent weight. To express the data in terms of carbon, E = 6d; to express it as CO_2, E = 22. Data were expressed as CO_2 $kgha^{-1}day^{-1}$ per crop growing. After the harvesting of the 5th crop, the soil samples were collected for the determination of organic C, total N, available P, exchangeable K, and available Zn (DTPA extracted) following the standard procedure.

2.3 Calculation of C balances

Carbon balance = Input – Output

Input = Inherent soil carbon+ added carbon using residues and manures

Output = Carbon (emission) + residual carbon in soil

Statistical analysis was done following the Crop Stat version 7.0 software.

3. Results and Discussion

3.1 Cumulative CO_2 emission from rice field under organic residue/manure management

In T. Aman 2011, cumulative CO_2 emission was measured after eight weeks of transplanting and continued up to 16 weeks after transplanting. Results are presented in Table 1. From the table, it is shown that there was no significant effect on cumulative CO_2 emission from rice soils among the treatments. In T. Aman 2012, cumulative CO_2 emission was measured after 1st week of transplanting and continued up to the 17th week after transplanting. Results are presented in Table 2. From the table, it is shown that there was a significant effect on the cumulative CO_2 emission from rice soils among the treatments. Among the treatments, the rate of cumulative CO_2 emission from rice soils was higher in organic manures/residues treated plots followed by control and STB fertilizer application treatment during the crop growing period. In T. Aman 2013, cumulative CO_2 emission was measured after

1st week of transplanting and continued up to the 15th week after transplanting. Results are presented in Table 3. From the table, it is shown that there was a significant effect on cumulative CO_2 emission from rice soils among the treatments at the 1st to 4th and 6th week after transplanting. Among the treatments, the rate of cumulative CO_2 emission was higher in organic manures/residues treated plots, followed by control and STB fertilizer application treatment during the crop growing period. A similar trend of CO_2 emission was observed by Rahman *et al*. (2016). They also reported that CO_2 emission was higher in organic manures/residues-treated plots than only STB-treated plots.

Table 1. Cumulative CO_2 emission from the rice field with different organic residue management (T. Aman 2011)

Treatment	**Weeks after transplanting**															
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th	13th	14^{th}	15th	16th
Abs. ctrl	nd	nd	nd	nd	nd	nd	nd	nd	283	597	964	1456	1675	2020	2389	2792
CD+IPNS	nd	nd	nd	nd	nd	nd	nd	nd	404	759	1071	1410	1662	2108	2533	2964
PM+IPNS	nd	nd	nd	nd	nd	nd	nd	nd	368	666	1010	1326	1628	2029	2503	2980
RS+IPNS	nd	nd	nd	nd	nd	nd	nd	nd	337	581	906	1213	1466	1829	2233	2644
STB	nd	nd	nd	nd	nd	nd	nd	nd	317	594	955	1227	1442	1786	2085	2380
F-test	nd	nd	nd	nd	nd	nd	nd	nd	NS	NS	NS	NS	NS	NS	NS	NS
CV%	nd	nd	nd	nd	nd	nd	nd	nd	15.8	14.3	12.6	11.2	7.8	9.2	8.4	8.9

*nd: not detected

Table 2. Cumulative CO_2 ($kgha^{-1}$) emission from the rice field with different organic residue management (T. Aman 2012)

Treatment	**Weeks after transplanting**																
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th	13th	14^{th}	15th	16th	17th
Abs ctrl	214b	454b	622b	770b	916b	1136b	1381b	1572b	1931	2135b	2308b	2498b	2758b	3055b	3413b	3499b	3737b
CD+IPNS	370a	794a	1147a	1379a	1609a	1924a	2257a	2525a	2965a	3297a	3498a	3725a	4044a	4377a	4774a	4925a	5228a
PM+IPNS	351a	767a	1105a	1337a	1567a	1898a	2226a	2476a	2935a	3288a	3547a	3832a	4132a	4513a	4919a	5082a	5378a
RS+IPNS	313a	702a	1033a	1271a	1507a	1811a	2124a	2358a	2801a	3118a	3337a	3584a	3904a	4221a	4623a	4768a	5002a
STB	194b	471b	653b	813b	970b	1204b	1454b	1665b	2035b	2285b	2467b	2664b	3003b	3300b	3662b	3761b	3978b
F-test	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**
CV%	14.9	6.4	4.4	4.1	4.7	5.5	6.1	7	5.2	6	6.9	7.5	7.2	7.4	7.5	8.2	8.6

Table 3. Cumulative CO_2 (kg ha^{-1}) emission from the rice field with different organic residue management (T. Aman 2013)

Treatment	Weeks after transplanting														
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th	13th	14th	15th
Abs. ctrl	247b	465b	703c	922c	1131	1352b	1592	1835	2053	2358	2607	2883	2995	3169	3472
CD+IPNS	327a	615a	940ab	1258ab	1580	1924a	2250	2473	2764	3133	3444	3761	3942	4184	4530
PM+IPNS	328a	669a	1089a	1363a	1604	1987a	2313	2602	2849	3169	3434	3747	3900	4138	4508
RS+IPNS	338a	660a	928ab	1229ab	1511	1847ab	2143	2449	2744	3083	3366	3656	3813	4045	4333
STB	224c	486b	770bc	999bc	1235	1489ab	1750	1999	2240	2596	2895	3228	3346	3540	3834
F-test	**	**	*	*	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV%	2.4	8.2	13	13	14.1	14.6	14.9	15	14.8	14.4	14.7	13.9	14.3	14.1	13.4

Table 4. Cumulative CO_2 (kgha^{-1}) emission from the rice field with different organic residues management (Boro 2011-12)

Treatment	Weeks after transplanting															
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th	13th	14th	15th	16th
Abs ctrl	11b	76b	148b	246b	426c	595b	859b	1050b	1285b	1480b	1650b	1897b	2115b	2350c	2706b	2955b
CD+IPNS	40a	116b	193b	328b	586b	855b	1160b	1471a	1846a	2173a	2426a	2735a	2990a	3272b	3665a	3966a
PM+IPNS	56a	176a	308a	512a	803a	1091a	1323a	1670a	2066a	2410a	2688a	3017a	3309a	3626a	4016a	4315a
RS+IPNS	44a	158a	299a	512a	799a	1238a	1526a	1793a	2131a	2420a	2673a	2978a	3235a	3528a	3911a	4191a
STB	13b	89b	159b	267b	503b	719b	969b	1202b	1504b	1787b	2004b	2235b	2433b	2656c	2979b	3208b
F-test	*	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**
CV%	47.2	18.2	19.1	18.9	12.7	18.6	14.0	12.5	10.7	9.3	8.6	8.8	8.7	8.4	7.6	7.1

Boro season

In Boro 2011-12, cumulative CO_2 emission was measured after 1st week of transplanting and continued up to the 16th week after transplanting. Results are presented in Table 4. It is shown that there was a significant effect on cumulative CO_2 emission from rice soils among the treatments from the 1st to 16th week after transplanting. Among the treatments, the rate of cumulative CO_2 emission was the highest in PM applied plots, which were statistically identical to CD and RS applied plots (Table 4). But the cumulative CO_2 emission was lower in CD applied plots than in PM and RS applied plots from the 2nd to 7th and 14th week after transplanting. Haque *et al.* (2021) also reported that the emission of CO_2 was higher in the application of organic manure than chemical fertilizer.

3.2 CO_2 emissions from rice field as influenced by organic amendments

The total CO_2 emissions from rice soils under different organic residues/manures in T. Aman 2012, 2013 & Boro 2011-12 are presented in Table 5. In T. Aman 2012 & Boro 2011-12, there was a positive effect of different organic residues/manures on the total CO_2 emissions from rice soils, while in T. Aman 2013, it was non-significant (Table 5). In T. Aman 2012, among the treatments, the total CO_2 emissions from rice soils were the highest in PM applied plots, which were statistically identical to CD and RS applied plots (Table 5). But the lowest was in the STB and control plots. A similar trend was found in Boro 2011-12. From Table 5, it is shown that the total amount of released CO_2 was higher in the T. Aman season than in the Boro season. Results might be due to the comparatively higher temperature in the T. Aman season than the Boro season.

Table 5. Total CO_2 emissions from rice fields under different organic residues/manures management, T. Aman 2012, 2013 & Boro 2011-12

Treatment	T. Aman			Boro
	2012	2013		2011-12
	Total CO_2 emission (kg ha^{-1} 119^{-1} days)	Total CO_2 emission (kg ha^{-1} 112^{-1} days)	Average Total CO_2 emission (kg ha^{-1} 114^{-1} days)	Total CO_2 emission (kg ha^{-1} 112^{-1} days)
Abs ctrl	3737b	3472	3605	2955b
CD+IPNS	5228a	4530	4879	3966a
PM+IPNS	5378a	4508	4943	4315a
RS+IPNS	5002a	4333	4668	4191a
STB	3978b	3834	3906	3208b
F-test	**	NS	---	**
CV%	8.6	13.4	---	7.1

3.3 Organic materials on soil nutrients after harvesting of the 5th crop

The effect of different organic materials on nutrient contents in soil after harvesting of the 5th crop (T. Aman 2012) found significant effects on SOC (%), available P, and available Zn, but the effects were significant on soil pH, total N, and exchangeable K (Table 6). The highest SOC% (1.54) was observed in CD+IPNS treatment, and the lowest was found in the control plot, which was statistically identical to RS+IPNS treatment. The highest available P (53.05 mgkg^{-1}) was observed in PM+IPNS treatment, followed by CD+IPNS (16.95 mgkg^{-1}), and the lowest was found in RS+IPNS treatment, which was statistically identical to control and STB treatments. The highest available Zn (1.27 mgkg^{-1}) was observed in CD+IPNS and PM+IPNS treatments, and the lowest was found in STB treatment, which was statistically identical to control and RS+IPNS treatment. Application of CD, PM, and RS contributed to a positive soil nutrient balance, which indicates the improvement of soil fertility as reported by Rahman *et. al.* (2016).

Table 6. Effect of different organic materials on soil nutrients after harvest of the 5th crop

Treatments	pH (1:2.5)	OC%	Total N (%)	Available P (mg kg^{-1})	Exchangeable K (Cmol kg^{-1} soil)	Available Zn (mg kg^{-1})
Control	6.4	1.13d	0.13	6.58c	0.22	0.71b
CD+IPNS	6.5	1.54a	0.15	16.95b	0.21	1.27a
PM+IPNS	6.6	1.47b	0.13	53.05a	0.26	1.27a
RS+IPNS	6.4	1.15d	0.13	3.63c	0.22	0.74b
STB	6.4	1.22c	0.13	5.75c	0.22	0.67b
F-TEST	NS	**	NS	**	NS	**
CV%	1.1	3.00	13.2	19.7	13	8.6

3.4 Apparent carbon balance because of organic amendments after harvesting of 5th T. Aman

The emission of CO_2-C was significantly influenced by sources i.e., residues and manures (Table 7). Though the carbon contents in the rice straw and even in the roots were high, however, the emission of CO_2-C was higher in the PM with IPNS-based chemical fertilizer treatment. During the crop growing period (2.5 years) the highest total amount of CO_2-C released from the PM+IPNS containing plot was 6.40 tha^{-1}2.5^{-1} year where whereas in the control plot (without organic manures) it was 4.56 tha^{-1}2.5^{-1} year, and in the STB plot it was 4.95 tha^{-1}2.5^{-1} year (Table 7). The sources of carbon, i.e., the residues, significantly affected carbon balance (Table 7). The finding was directly alien to the findings of Rahman *et al*. (2016), who reported that Poultry manure was found to be efficient at increasing carbon and other nutrients in soils. When plant residues and manures are applied to the soil, various organic compounds undergo decomposition. The addition of residues and manures to the soil surface contributes to the biological activity and the carbon cycling process in the soil. Application of organic manure to the rice crop field not only increased the crop productivity but also enhanced the carbon sequestration in soil.

Among the treatments, the highest output carbon was found in the treatments PM+IPNS and CD+IPNS, and the lowest in the RS+IPNS treatment. Although Smith *et al*. (1997) reported that use of organic manures, sewage sludge or crop residues has less potential for carbon sequestration in soil than afforestation of surplus arable land in Europe. The lowest amount of output carbon in RS+IPNS treatment might be due to the activity of several generations of different microbes. Several generations of different microbes in this process die and add carbon to the soil. Carbon cycling is the continuous transformation of organic and inorganic carbon compounds by plants and soil organisms between the soil, plants, and the atmosphere. In cultivated organic soils, about 450-4500 kg bacteria per hectare- furrow slice, while fungi present 1120-11200 kg and actinomycetes 450-4500 kg, bacteria, fungi, and actinomycetes are 50% of carbon (Ray *et. al.,* 2017). Therefore, a significant amount of carbon might be added to soils. Maintaining a satisfactory soil organic C content is particularly important for soil quality and sustaining the productivity of agro-ecosystems because it plays a decisive role in the cycle and transformation of nutrients by affecting soil physical, chemical, and biological properties. Previous studies have shown that the accumulation rate of organic C in soils is strongly linked with the location of organic C within the soil matrix.

Table 7. Apparent carbon balance under different organic materials/residues

Treatment	C input (t ha^{-1} 2.5^{-1} year)			C output (t ha^{-1} 2.5^{-1} year)			C balances (t $ha^{-1}$$2.5^{-1}$yr)
	Soil C	Added C (OM applied & rice root)	Total	Emission*	Residual	Total	
Abs ctrl	39	1	40	4.56	29b	34	6
CD+IPNS	39	12	51	6.15	35a	41	10
PM+IPNS	39	12	51	6.40	35a	41	10
RS+IPNS	39	12	51	6.10	27c	33	18
STB	39	2	41	4.95	29b	34	7
F-test	--	--	--		**	--	--
CV%	--	--	--		2.5	--	--

*Note: It is the sum of Boro and T. Aman seasons

4. Conclusions

The total amount of released CO_2 was higher in the T. Aman season than in the Boro season. The highest SOC% (1.54) was built in the CD (2.0 t C ha^{-1}) + IPNS treated plot, followed by PM + IPNS treated plot (1.47%), and the lowest was in the control plot (1.13%). The highest available P (53.05 $mgkg^{-1}$) was observed in PM+IPNS treatment followed by CD+IPNS treatment (16.95 $mgkg^{-1}$). Carbon dioxide emission was higher in the CD and PM applied plots compared to the RS applied plot. The total CO_2 emission was highest in PM applied plots (4943 kgha^{-1}114^{-1} days in T. Aman & 4315 kgha^{-1}112^{-1} days in Boro) and the lowest was in control (3605 kg ha^{-1}114^{-1} days in T. Aman & 2955 kg ha^{-1}112^{-1} days in Boro). It is challenging to increase carbon sequestration in soils of sub-tropical climatic conditions, but regular use of carbon-rich materials through the application of different organic manure and crop residues to soil may maintain and increase the soil carbon status.

Conflicts of Interest

The authors declare no conflicts of interest regarding publication of this paper.

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