American Journal of Climate Change, 2018, 7, 40-53
http://www.scirp.org/journal/ajcc
ISSN Online: 2167-9509
ISSN Print: 2167-9495

Effect of Biochar Application on Soil Carbon Fluxes from Sequential Dry and Wet Cultivation Systems

Mahmudul Islam Piash[1], Md. Faruque Hossain[2*], Ihuoma N. Anyanwu[3], Shamim Al Mamun[4], Zakia Parveen[1]

[1]Department of Soil, Water & Environment, University of Dhaka, Dhaka, Bangladesh
[2]American International University-Bangladesh, Dhaka, Bangladesh
[3]Department of Biology/Microbiology/Biotechnology, Federal University Ndufu-Alike Ikwo, Ikwo, Nigeria
[4]Department of Environmental Science and Resource Management, Mawlana Bhashani Science and Technology University, Tangail, Bangladesh
Email: *hossainfaruque@hotmail.com, *mfhossain@aiub.edu

How to cite this paper: Piash, M.I., Hossain, Md.F., Anyanwu, I.N., Al Mamun, S. and Parveen, Z. (2018) Effect of Biochar Application on Soil Carbon Fluxes from Sequential Dry and Wet Cultivation Systems. *American Journal of Climate Change*, **7**, 40-53.
https://doi.org/10.4236/ajcc.2018.71005

Received: November 15, 2017
Accepted: March 2, 2018
Published: March 5, 2018

Abstract

Application of biochar has been highly credited for its potential to sequester carbon and GHG mitigation from tropical agro-ecosystems. However, experiments show inconsistent results depending on soil and biochar type, cultivation system, climatic condition and the type of evolved GHGs. This study emphasized on the effect of biochar on carbon emission trends from a sequential dry and wet cultivation system of Bangladesh. An incubation study was conducted with two contrasting soils and eight different treatments viz. control, only fertilizer, three different biochars (10 $t \cdot ha^{-1}$) with and without recommended fertilizer dose. Results revealed the fact that, emission of carbon was substantially higher from Sara soil than Kalma soil. Biochar treatments did not have any easing effect on CO_2 emission at field condition; rather, increased in most of the cases. However, emission was significantly ($P < 0.05$) suppressed at submerged condition by biochar application. Non-fertilized water hyacinth biochar was most effective in this regard. In general, fertilizer application caused higher emission of CO_2. Biochar application was ineffective to control CH_4 and CO release to atmosphere and submergence further intensified their emission significantly. The overall results indicate that applied biochars have negligible effect on carbon emission except for reducing CO_2 from submerged soils.

Keywords

Greenhouse Gases, Carbon Emission, CO_2, CH_4, CO, Emission from Submergence

1. Introduction

The global climate is changing rapidly due to simultaneous emission of anthropogenic greenhouse gases (GHG) into the atmosphere since the pre-industrial era [1]. During the past few decades, total concentrations of CO_2, CH_4 and N_2O in the atmosphere increased at rates of 0.5%, 0.8% and 0.3%, respectively [2]. Therefore, surface temperature has increased about 0.78˚C ± 0.06˚C since the last 19th century [3]. Agricultural activities are one of the major reasons of elevated GHG concentrations in the atmosphere. Total GHG emission from agriculture is estimated to be 1.4 - 1.6 Gt (Gigaton) CO_2-C equivalent (CO_2-C_e) year^{-1} which is approximately 12% - 14% of total human-induced warming effect [4]. Therefore, it is high time to take serious steps to reduce the agricultural emission of GHGs to mitigate climate change.

Application of biochar has been vastly credited for its potential role to sequester carbon while applied to soil [5] [6] [7] [8]. It is the solid by-product of pyrolysis process which converts biomass physio-chemically in an oxygen limited condition, which is, resistant to microbial decomposition and can also reduce the agricultural emission of carbonaceous gases [9]. Biochar can seize about 50% of the carbon in biomass. When biochar is applied to soil, the carbon is sequestered for centuries. Thus, biochar reduces the overall atmospheric CO_2 by removing C from the active cycle and sequestering it that also enhances plant growth, which takes more CO_2 out of the atmosphere. It can also reduce the emission of N_2O and other gases significantly. Moreover, many studies have proved biochars capability to enhance soil fertility, moisture retention and intern increased plant growth [10] [11]. Biochar can efficiently work as a soil amendment particularly in highly weathered tropical soils.

However, the GHG mitigation potential of biochar is highly variable depending on soil and feedstock type, biochar production temperature, climatic condition, farmland management (dry or wet), crop species etc. [12]. Some laboratory and field trials have showed increased GHG fluxes after biochar incorporation while others showed no significant effect [13]. For instance, application of wheat straw biochar on maize field caused a 12% increase of CO_2 flux while reduced 41.8% of N_2O and 9.8% of methane emission [14]. A meta-data analysis of Song *et al.* (2016) reveals the fact that biochar application significantly decreases CO_2 emissions by 5% in paddy fields but increases CO_2 emissions by 12% in upland fields [15]. Low biochar application rates (≤10 t·ha^{-1}) decreased CO_2 emissions. Biochar derived from wood (including soft and hard woods) significantly increased CO_2 emissions by an average of 21%, whereas biochar derived from husk significantly decreased CO_2 emissions. Slow-pyrolysis Biochar (≤500˚C) significantly increases CO_2 emissions [15]. Moreover, application of urea fertilizer results higher emission of nitrous oxide and CO_2 from soils [16].

In contrast, very little is known regarding the effects of biochar on total CH_4 emission though its global warming potential is 28 times higher than CO_2. Moreover, rice fields are a potential source of CH_4, emitting approximately

31,112 Tg (Teragram) globally [17]. Approximately 57% of rice is grown in irrigated or continuous flooded fields under extremely anaerobic conditions globally, which ultimately encourages methane emission. Single studies of CH_4 emission have frequently reporting ambiguous results. A study of Jeffery *et al.* (2016) reveals that biochar can substantially mitigate CH_4 emissions from soils, particularly from flooded (*i.e.* rice) fields and/or acidic soils [18].

Carbon monoxide is not considered as a direct GHG but it has indirect effects on increasing other greenhouse gases. It reacts with hydroxyl radicals reducing their concentration in the atmosphere which in turn helps to reduce the lifetime of strong GHGs like CH_4. Scientists have already proposed that CO should have a GWP because of their stimulating effects on other greenhouse gases [19]. Potter *et al.* (1996) demonstrate a model where they estimated gross production of CO from surface soils is about 9.4 ± 2.5 Tg CO yr^{-1} [20]. Model results support the assumption that temperate dry zones are the major global sinks for soil CO, whilst tropical wet zones are the major sources for soil CO production.

Biochar could be a promising option for carbon sequestration and soil amendment for tropical countries like Bangladesh as it has very low organic carbon content in it's soils (approximately 1%) and her economy largely depends on agriculture. According to a report on GHG Footprint of Nations, per capita carbon footprint of Bangladesh was only 1.1 tons·$year^{-1}$ in 2001 but 55% of it comes from the food sector [21]. Besides, FAO Rice Market Monitor (2017) predicted Bangladesh will remain the fourth largest rice producing country in the world and rice fields are one of the major sources of methane emission [22]. Model-based estimation says Bangladesh will emit nearly 653 Gg (Gigagram) of CH_4 in 2030 and approximately 906 Gg in 2050 from paddy fields if the water management practice remains the same [23]. However, very limited laboratory or field-based experiments have been conducted to quantify the actual carbon emission trends from rice-dominated and sequential dry-wet cultivation practices of Bangladeshi agro-ecosystem. Considering the cropping system and different soil types of Bangladesh, the main objective of this study is to investigate the carbonaceous GHG's emission behaviors in both winter crops and submerged rice production, effect of fertilizer application and biochar type etc. This analysis is expected to improve our understanding of GHG emission patterns from Bangladeshi agro-ecosystems and the probable impact of biochar on carbon fluxes to mitigate national contribution towards climate change.

2. Materials and Methods

The experiment was conducted with two benchmark soils of Bangladesh with contrasting characteristics. The first one was the Sara series collected from Rarikhal village, Shreenagar Upozilla, under Munshigonj district, Bangladesh. The geo-location of the sampling site was between 23˚32'N to 23˚39'N and 90˚13'E to 90˚23'E. The Sara is a calcareous fluvisol which belongs to Ganges river floodplain covering 249,798 hectares of land. The soil is poorly to moderately well drained, silty loam, slightly alkaline, pH ranges from 7.1 to 8.2 and used as an agricultural land. The Kalma soil was collected from Shreenpur Upozilla, Gazipur, Bangladesh. The geo-location of the sampling site located between 24˚01'N to 24˚21'N Latitude and 90˚21'E to 90˚33'E. Kalma soil series belongs to Modhupur tract physiology, medium highland and well drained and pH ranges from 4.8 to 6.1, acidic in nature, belongs to silty clay textural class. Vegetables are usually grown; tree plantation is common. Both soil samples were collected from surface to a depth of 0 - 15 cm by composite soil sampling method as described in Soil Survey Staff of USDA [24].

Feedstocks for biochar production were selected on their availability throughout Bangladesh and considering the best use of municipal organic wastes. Farmyard manure (FM) and water hyacinth (WH) were collected from the farmyards of Sreenagar Upozilla of Munshigonj District (adjacent to Padma River). The domestic organic waste (DW) was collected from a typical apartment building's daily waste generated at Uttara, Dhaka. The collected feedstocks were appropriately treated before biochar production (slow pyrolysis) at about 380˚C ± 20˚C. Produced biochars were analyzed for their physicochemical properties and nutrient content [25] before applying into the soils.

2.1. Experimental Setup

The incubation experiment consisted of eight different treatments for both the soils with 3 replicates each. The treatments include control, only fertilizer, three different biochars (10 t·ha^{-1}) with and without recommended fertilizers (**Table 1**). Similar fertilizer doses were applied in both the soils as recommended in online fertilizer recommendation system of Soil Resources Development Institute (SRDI) [26].

2.2. The Design of the Gas Trapping Container

To trap and measure the evolved gases from incubated soils, specially designed plastic containers of 5 L volume were used. Those containers were procured from the local market. At first, all the containers were washed properly with

Table 1. Treatment combination for the conducted experiment.

Treatment No.	Arrangement of experiments	Symbol/Designation
1	Control soil	C
2	Soil + Fertilizer	F
3	Soil + Farmyard manure Biochar	FM
4	Soil + Water Hyacinth Biochar	WH
5	Soil + Domestic Organic waste Biochar	DW
6	Soil + Farmyard manure Biochar + Fertilizer	FM + F
7	Soil + Water Hyacinth Biochar + Fertilizer	WH + F
8	Soil + Domestic Organic waste Biochar + Fertilizer	DW + F

distilled water, dried in sunlight and labeled. Two holes were made in each container to serve two different purposes; one is to insert adequate water when necessary and another one for the measurement of the evolved gases. The first hole was made on the sides of each container and was sealed with a rubber stopper that facilitates one-way entry of a syringe needle for watering the incubated soil. The second hole was made on the top of the lid with the exact size of the suction tube of Gas-analyzer. Plastic syringes were used to insert water where necessary. Each hole was sealed with cotton, sellotape, rubber band and foil paper. The foil paper and sellotape were only removed when it was time for gas measurement and watering the soils.

Each container received 3 kg of air-dried soils and adequate biochar & fertilizer treatments. The soils in the containers were kept in 50% saturated water condition, up to 60 days, representing the Rabi crops cultivated at field condition. Thereafter, those were waterlogged under 2 cm of standing water for next 60 days representing subsequent rice cultivation of the Kharif season. Each container had 3200 mL of free space above the soil.

Emission of both direct and indirect Greenhouse gases (CO_2, CH_4 and CO) was analyzed in every 15 days interval. Two machines were used to measure the gases (**Figure 1**): For the measurement of CO_2 and CH_4, a portable 800-5 CO_2/CH_4 Gas Meter was used which is manufactured by the Columbus Instruments. This machine gives the results on a percentage basis. Apart from this, Indoor Air Quality Monitor Kit manufactured by Graywolf sensing solutions was used to measure CO emission. This machine gave the reading in $ug \cdot m^{-3}$ unit.

Calculation: CO emission was first converted to % gas in the container from $ug \cdot m^{-3}$ unit.

Occupied gas in the container: 3200 cm^3.

Volume occupied by only CO_2/CH_4/CO in the container): (% gas*3200)/100.

Equivalent CO_2/CH_4/CO release from 1 hectare (in cm^3): (vol. of gas * 2,000,000)/3.

Now, according to the gas law: $V_1T_1 = V_2T_2$.

Here,

V_1 = volume of CO_2/CH_4/CO released from 1 hectare.

T_1 = temperature of that day (temperature ranged from 22.5˚C to 34.6˚C during the incubation period).

Figure 1. Portable CO_2/CH_4 meter and Indoor air qualities monitor kit.

V_2 = volume of gas at STP.

T_2 = 298 K.

Therefore, $V_1 = V_2T_2/T_1$.

Again, we know, $\rho = m/v$.

where, ρ = density.

M = mass.

V = volume of gas.

Now, amount of emitted gas, $m = \rho * v$ ($kg \cdot ha^{-1}$).

Emission of evolved CO_2 and CH_4 were represented by $kg \cdot ha^{-1}$ and emitted CO was $g \cdot ha^{-1}$ unit. Equivalent CO_2 (CO_2e) emission was calculated by multiplying the mass of CH_4 with 28 (GWP) for 100 years of lifetime.

Statistical analyses were done using Stata version 14.0. Analysis of variance was done to investigate significant variations among the treatments.

3. Results and Discussions

3.1. Effect on CO_2 Emission

From Sara soil, the CO_2 emission at first sampling date (15th day) reveals that all the biochar applied treatments expelled more CO_2 than the other two treatments (control and only fertilized) (**Figure 2**). This curve of emission remained static for next three sampling dates *i.e.* up to 60th day of incubation. Which means that, at field condition, the emission of CO_2 was considerably higher in biochar treated soils than the control and the sole-fertilized-one. These high emission rates of CO_2 after biochar incorporation might be due to the sudden increase in soil organic matter content. At 30th day of incubation, the emission of CO_2 dramatically increased for all the treatments; ranged from nearly doubled to as much as six times (for fertilized farmyard manure biochar treatment) than the first recording date. This may be attributed to increase decomposition of organic matter by a maximum number of microorganisms between 15th to 30th day. On average, the highest emission of CO_2 (950 $kg \cdot ha^{-1}$) after 15 days of incubation was due to the application of fertilized domestic waste biochar (DW + F); which is nearly double than the average emission of control soil of Sara. The overall

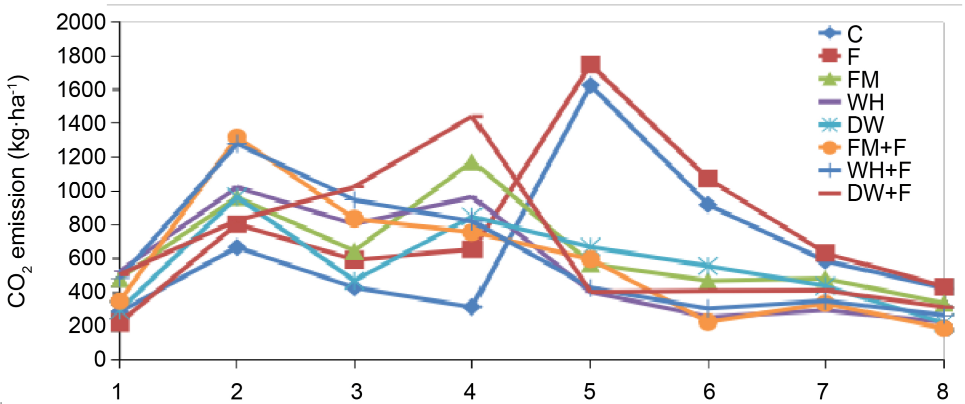

Figure 2. Change in CO_2 emission behaviors from Sara soil.

behavior of CO_2 emission in field condition illustrated an alternating increase and decrease pattern from 15th to 60th day which is highly significant ($p < 0.001$). However, no significant variations were recorded among the biochar treatments or by the application of fertilizer on CO_2 emission.

Fifteen days after introduction of the submerged condition, suddenly the lowest CO_2 emitting treatments of Sara soil became the highest emitter. The only fertilized treatment became the principal emitter with 1748 kg·ha^{-1} followed by the control (1625 kg·ha^{-1}). Similar trends of increased soil CO_2 fluxed immediately after flooding were seen by a group of scientist, exceeded pre-flooding values by two-thirds [13] [27]. This increase is unexpected and pulse like. Water hyacinth biochar, which was among the highest emitting treatments, became the least emitter (WH + F and WH, respectively) at this stage. In next 45 days, overall CO_2 emission reduced and the difference in emission from the treatments became gradually smaller. Overall, only fertilized treatments emitted 972 kg·ha^{-1} per 15 days which is approximately 3 times higher than water hyacinth biochar treatment (293 kg·ha^{-1}). The effect of biochar treatments in reducing CO_2 emission from submerged condition was significant at 5% level. All the biochar treatments were significantly effective in reducing CO_2 emission; especially non-fertilized water hyacinth biochar (WH). Increasing incubation period also significantly ($p < 0.05$) reduced emission from Sara soil.

The overall CO_2 emission from Kalma soil (**Figure 3**) was comparatively lower than that of Sara. This may be due to the low inherent organic C content of the soil along with initial acidic pH. At first sampling date, the highest emitter was the domestic waste biochar treated soil with 506 kg·ha^{-1} followed by the WH + F treatment (501 kg·ha^{-1}). The lowest emission was from the FM treatment; only 133 kg·ha^{-1}. After next 15 days of incubation, five of the eight treatments showed increased emission. For next two recording dates (45th and 60th days) CO_2 emission lessened down. At both the stages, farmyard manure biochar applied soils emitted the highest CO_2. Throughout the field condition, neither the treatments nor the fertilizer application caused any significant variation.

Resembling Sara, control and only fertilized treatment of Kalma soil saw an increase in CO_2 emission after the introduction of the submerged condition. At

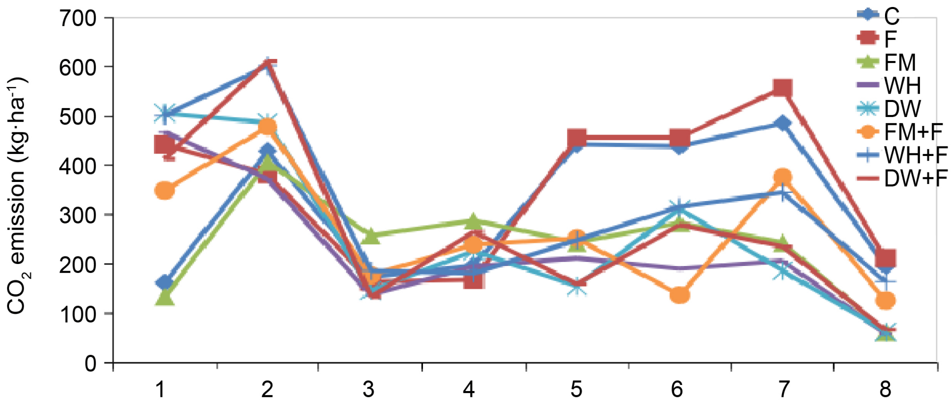

Figure 3. Change in CO_2 emission trends from Kalma soil.

75th days of incubation, the maximum emission is from the only fertilized soil followed by control. During the next three recording date of submerged condition, either the control soil or the only fertilized one was the main emitter. The peak emission (557 kg·ha^{-1}) of Kalma soil was observed at 105th day of incubation from the fertilized soil. At the end of the incubation period, emission of CO_2 became very low like 58 kg·ha^{-1} per 15 days for WH. In this submerged condition, biochars effect on suppressing the emission of CO_2 was significant ($p < 0.05$) and water hyacinth biochar (without fertilizer) come out to be the best treatment for this.

Results show that the average of each 15 days CO_2 emission from both the soils in field condition and submerged condition is 525 kg·ha^{-1} and 388 kg·ha^{-1}, respectively. At field condition, biochar did not have the appreciable CO_2 reducing effect; it even increased for most of the treatment. However, the effect of biochar on suppressing the emission of CO_2 was significant in submerged conditions for both the soils. A similar trend was observed in the laboratory after biochar application in waterlogged paddy soil [28] and they attributed such results to the restriction in methanogen activity, limitation on microbial biomass carbon and the rise in pH value. In general, fertilized biochar treatments expelled an elevated amount of CO_2 compared to their non-fertilized counterparts; however, the effect was not significantly proved. This study supports the findings of several scientists in terms of CO_2 emission from upland and paddy fields [13] [15]. They also revealed the fact that, lower biochar application rates (≤10 t·ha^{-1}) decrease CO_2 emissions which comply with this experiment at the submerged condition. Therefore, a range of factors like soil and biochar type, soil moisture level and fertilizer application determined the emission of CO_2 from this experiment.

3.2. Effect on CH_4 Emission

At first recording date of Sara soil, the Control (C) and fertilized domestic waste biochar (DW + F) treatment both caused the lowest emission of CH_4 (3.22 kg·ha^{-1}), whereas, the FM + F observed highest emitting treatment (9.65 kg·ha^{-1}) (**Figure 4**). At second sampling date, methane emission was undetectable by the

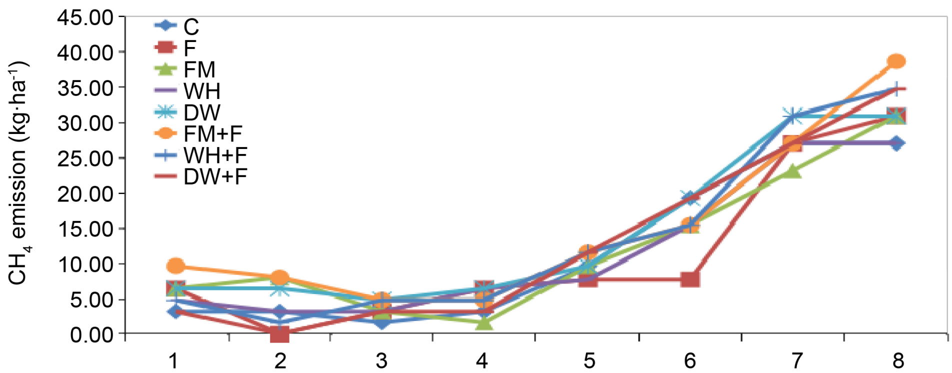

Figure 4. Change in CH_4 emission from Sara soil.

machine from both F and DW + F treatments. Emission declined slightly for treatments in 3rd sampling period and the overall emission increased a little at the 4th date of recording for fertilized biochar treatments. The CH_4 emission was comparatively lower than CO_2 from incubated soils which might be due to the prevalence of aerobic microbes.

However, after the introduction of the submerged condition, the changed moisture regime caused predicted increase in CH_4 emissions from almost all the treatments. Overall emission increased gradually until the end of the experimental period. During the submerged condition, biochar treatments with fertilizer emitted a higher amount of CH_4 than that of non-fertilized or control soils.

Biochar treatments increased considerable amount of CH_4 emission from both field and submerged condition in Sara soil, though it was not significantly proven. Average emission in submerged condition was significantly ($p < 0.001$) higher than field condition (nearly 4 times). The effect of fertilizer on CH_4 emissions was not significantly proved in Sara soil.

The CH_4 emission was a bit higher in field condition from Kalma soil (**Figure 5**) than that of Sara. Very little variations were noticed among the emission behavior treatments revealing the fact that biochar treatments did not affect the pattern of emissions. In submerged condition, CH_4 emissions fall slightly from 75th to 90th day. However, by the end of the experiment, a minor rise in CH_4 emission including a sharp increase from 90th to 105th days was seen. Fertilized biochar treatments were seen to be the highest emitter here as well. By the end of the incubation period, fertilized water hyacinth biochar treatment became the highest emitter from submerged Kalma soil with 28.96 $kg \cdot ha^{-1}$.

Results reveal that biochar treatments did not have any significant effect on CH_4 emission either in field or in submerged condition. Like the Sara soil, emission from Kalma soil was not significantly affected by fertilizer application.

Many studies have found reduced emission of CH_4 from biochar incorporated soils [18] [27] [28]. The CH_4 emissions reduced are credited mainly to the effects of biochar on soil physicochemical factors and changes in the activity of methanogens that generate CH_4 and increases in the abundance and activity of the

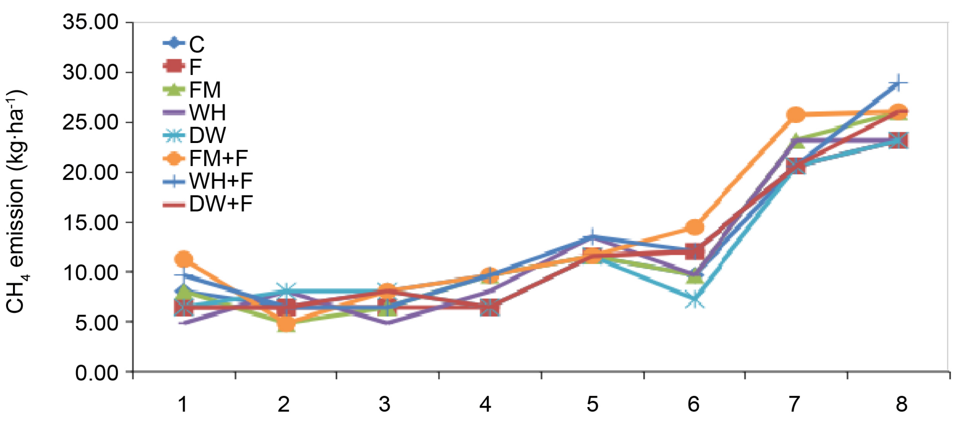

Figure 5. Change in CH_4 emission from Kalma soil.

methanotrophs that oxidize it [13] [27] [29] [30]. It also attributed this to the decreased activity of methanogens along with the increased CH_4 oxidation activity and *pmoA* gene abundance of methanotrophs [31]. A meta-analysis conducted by several scientist shows that addition of biochar to non-flooded soils, particularly when neutral or alkaline, may decrease the CH_4 reduction potential of those soils [18].

The average CH_4 emission for each 15 day from both the soils in field condition is 6.02 kg·ha^{-1} and 19.45 kg·ha^{-1} in submerged condition. Therefore, the equivalent CO_2 emission for a 100 years lifetime would be 168.5 and 544.5 kg·ha^{-1}. Results in this study do not support the overwhelmed prediction of biochar's potential to suppress CH_4 emission. Reviews even found 19% increase in methane emission from paddy fields after biochar application and high uncertainty in upland soils [13] [15].

3.3. Effect on CO Emission

The amount of CO evolved from the incubated soils was extremely low compared to evolved CO_2 and CH_4. The **Figure 6** and **Figure 7** demonstrates the emission trends of CO from two agricultural soils of Bangladesh at varying incubation days. The results are expressed as gram per hectare. The carbon monoxide emission from biochar treated Sara soils were higher than the control or only fertilized ones. Especially the non-fertilized biochar treatments emitted higher degrees of CO than other treatments at the first sampling date, but this trend inverted from the second sampling date to the end of the field condition. At the last recording date of the aerobic treatment, overall emission increased significantly ranging from 5.50 to 15.87 g·ha^{-1} except for the FM treatment (0.46 g·ha^{-1}). From the beginning of the submerged condition, CO emission increased a couple of folds ($p < 0.001$) than field condition specially for the C and F treatment which became the greatest emitter (32.50 and 33.25 g·ha^{-1}, respectively) in submerged condition. In this phase, only biochar application caused greater emission than that of their fertilized counterparts and this trend continued to the end of the incubation period. The CO emission was recorded the minimum at 105th day in this anaerobic stage of incubation. Water hyacinth biochar set up to be the mean highest emitting biochar treatment. Biochar treatments had a

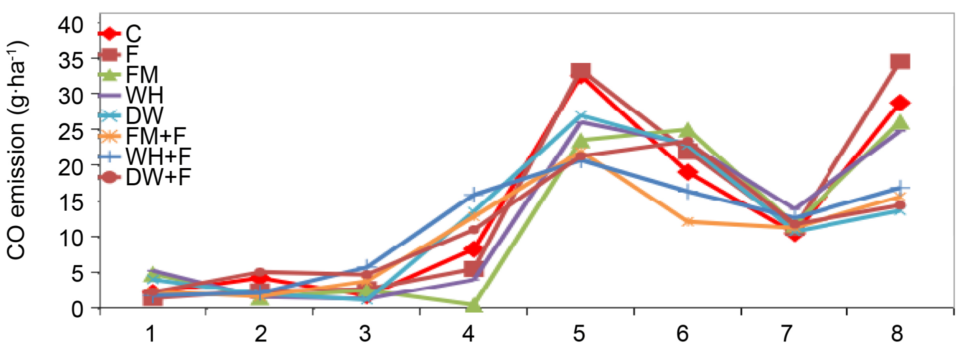

Figure 6. Change in CO emission from Sara soil.

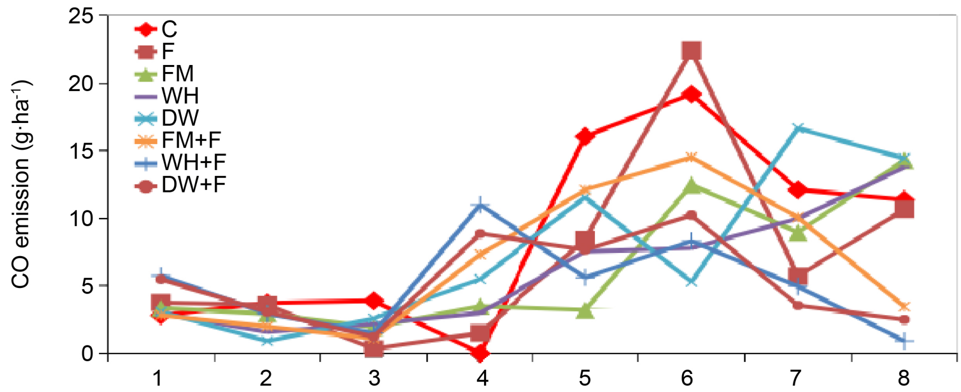

Figure 7. Change in CO emission from Kalma soil.

non-significant effect on CO emission from Sara soil.

The CO emission trends from the Kalma soil followed the behavior of Sara soil. At the first recording date, fertilized biochar treatments emitted a higher amount of CO than other treatments. This happened at the 4th recording date as well. The overall emission was negligible and saw a lot of ups and downs throughout the aerobic incubation period. However, at the end of the 60 days, the overall emission increased with the only exception of the non-detectable level of CO emission from the control treatment. The control treatment became the highest emitter at the beginning of the submerged incubation period followed by the FM + F treatment (16.05 and 12.10 $g \cdot ha^{-1}$, respectively). By the end of the incubation period, fertilized biochar treatments became the lowest emitter of CO from Kalma soil. Biochar treatments did not have any significant effect in reducing CO emission as well. Submergence caused significantly higher emission.

The overall trend reveals the fact that carbon monoxide emission increased with submergence significantly ($p < 0.05$). This study suggests that biochar incubation could not reduce the CO emission ($p > 0.05$) from soils and fertilized biochar application caused higher reduction of emission. This complies with the findings of a laboratory study conducted by a group of scientist in a Bangladeshi soil with biochar application rate of 5 $t \cdot ha^{-1}$ [32] and results are comparable with other study as well [13] [27].

4. Conclusion

In Bangladesh, being a very insignificant contributor of global atmospheric carbon and a developing country, there is a huge knowledge gap on national carbon budget and sector based GHG emission inventory. This makes the planning and implementing carbon mitigation measures difficult. The Energy-intensive production process and low feedstock availability of Bangladesh would make biochar an onerous tool for carbon sequestration. Although this study doesn't support the overwhelmed carbon emission reducing potential of biochar, adequate field studies with diverse biochar sources and soils are needed before drawing any conclusion. It would be most effective if methane and nitrous oxide could be reduced from the rice dominated wet cultivation practice of Bangladesh. However, biochar's potential to improve soil fertility, organic matter content and to amend problem soils would be the key factors to be considered before deciding its prospects in Bangladesh.

References

[1] Pachauri, R.K., Meyer, L., Plattner, G.K. and Stocker, T. (2015) IPCC, 2014: Climate Change 2014: Synthesis Report. *Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, IPCC, 151.

[2] Wang, Y.Y., Hu, C.S., Ming, H., Zhang, Y.M., Li, X.X., Dong, W.X. and Oenema, O. (2013) Concentration Profiles of CH_4, CO_2 and N_2O in Soils of a Wheat-Maize Rotation Ecosystem in North China Plain, Measured Weekly over a Whole Year. *Agriculture, Ecosystems & Environment*, **164**, 260-272. https://doi.org/10.1016/j.agee.2012.10.004

[3] Stocker, T., Ed. (2014) *Climate Change* 2013: *The Physical Science Basis*: *Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, UK.

[4] Change, I.C. (2014) *Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge and New York.

[5] Smith, P., Martino, D., Cai, Z., Gwary, D., Janzen, H., Kumar, P., McCarl, B., Ogle, S., O'Mara, F., Rice, C. and Scholes, B. (2008) Greenhouse Gas Mitigation in Agriculture. *Philosophical Transactions of the Royal Society B*: *Biological Sciences*, **363**. https://doi.org/10.1098/rstb.2007.2184

[6] Lehmann, J., Czimczik, C., Laird, D. and Sohi, S. (2009) Stability of Biochar in Soil. *Biochar for Environmental Management*: *Science and Technology*, 183-206.

[7] Sohi, S.P., Krull, E., Lopez-Capel, E. and Bol, R. (2010) A Review of Biochar and Its Use and Function in Soil. *Advances in Agronomy*, **105**, 47-82. https://doi.org/10.1016/S0065-2113(10)05002-9

[8] Lehmann, J. and Joseph, S. (2015) Biochar for Environmental Management: Science, Technology and Implementation. Routledge, New York.

[9] Laird, D.A., Brown, R.C., Amonette, J.E. and Lehmann, J. (2009) Review of the Pyrolysis Platform for Coproducing Bio-Oil and Biochar. *Biofuels*, *Bioproducts and Biorefining*, **3**, 547-562. https://doi.org/10.1002/bbb.169

[10] DeLuca, T.H., Gundale, M.J., MacKenzie, M.D. and Jones, D.L. (2015) Biochar Effects on Soil Nutrient Transformations. *Biochar for Environmental Management*: *Science*, *Technology and Implementation*, **2**, 421-454.

[11] Darby, I., Xu, C.Y., Wallace, H.M., Joseph, S., Pace, B. and Bai, S.H. (2016) Short-Term Dynamics of Carbon and Nitrogen Using Compost, Compost-Biochar Mixture and Organo-Mineral Biochar. *Environmental Science and Pollution Research*, **23**, 11267-11278. https://doi.org/10.1007/s11356-016-6336-7

[12] Van Zwieten, L., Kammann, C., Cayuela, M., Singh, B.P., Joseph, S., Kimber, S., Donne, S., Clough, T. and Spokas, K. (2015) Biochar Effects on Nitrous Oxide and Methane Emissions from Soil. *Biochar for Environmental Management*: *Science*, *Technology and Implementation*, Routledge.

[13] He, Y., Zhou, X., Jiang, L., Li, M., Du, Z., Zhou, G., Shao, J., Wang, X., Xu, Z., HosseiniBai, S. and Wallace, H. (2017) Effects of Biochar Application on Soil Green-

house Gas Fluxes: A Meta-Analysis. *GCB Bioenergy*, **9**, 743-755. https://doi.org/10.1111/gcbb.12376

[14] Zhang, A., Liu, Y., Pan, G., Hussain, Q., Li, L., Zheng, J. and Zhang, X. (2012) Effect of Biochar Amendment on Maize Yield and Greenhouse Gas Emissions from a Soil Organic Carbon Poor Calcareous Loamy Soil from Central China Plain. *Plant and Soil*, **351**, 263-275. https://doi.org/10.1007/s11104-011-0957-x

[15] Song, X., Pan, G., Zhang, C., Zhang, L. and Wang, H. (2016) Effects of Biochar Application on Fluxes of Three Biogenic Greenhouse Gases: A Meta-Analysis. *Ecosystem Health and Sustainability*, **2**, e01202.

[16] Tongwane, M., Mdlambuzi, T., Moeletsi, M., Tsubo, M., Mliswa, V. and Grootboom, L. (2016) Greenhouse Gas Emissions from Different Crop Production and Management Practices in South Africa. *Environmental Development*, **19**, 23-35.

[17] Denman, K.L., Brasseur, G.P., Chidthaisong, A., Ciais, P., Cox, P.M., Dickinson, R.E., Hauglustaine, D.A., Heinze, C., Holland, E.A., Jacob, D.J. and Lohmann, U. (2007) Couplings between Changes in the Climate System and Biogeochemistry. In: Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M. and Miller, H.L., Eds., *Climate Change* 2007: *The Physical Science Basis*, Cambridge University Press, Cambridge, Chapter 7.

[18] Jeffery, S., Verheijen, F.G., Kammann, C. and Abalos, D. (2016) Biochar Effects on Methane Emissions from Soils: A Meta-Analysis. *Soil Biology and Biochemistry*, **101**, 251-258. https://doi.org/10.1016/j.soilbio.2016.07.021

[19] Prather, M.J. (1996) Time Scales in Atmospheric Chemistry: Theory, GWPs for CH4 and CO, and Runaway Growth. *Geophysical Research Letters*, **23**, 2597-2600. https://doi.org/10.1029/96GL02371

[20] Potter, C.S., Klooster, S.A. and Chatfield, R.B. (1996) Consumption and Production of Carbon Monoxide in Soils: A Global Model Analysis of Spatial and Seasonal Variation. *Chemosphere*, **33**, 1175-1193.

[21] Hertwich, E.G. and Peters, G.P. (2009) Carbon Footprint of Nations: A Global, Trade-Linked Analysis. *Environmental Science & Technology*, **43**, 6414-6420. https://doi.org/10.1021/es803496a

[22] FAO (2017) Rice Market Monitor. Trades and Market Division. Food and Agriculture Organization of the United Nations, Vol. 20, 1-38.

[23] Khan, R.U. and Saleh, A.F.M. (2015) Model-Based Estimation of Methane Emission from Rice Fields in Bangladesh. *Journal of Agricultural Engineering and Biotechnology*, **3**, 125-137.

[24] USDA (United States Department of Agriculture) (1951) Soil Survey Manual. Soil Survey Staff, Bureau of Plant Industry, Soil and Agricultural Engineering, United States Department of Agriculture, Washington DC, 18, 205.

[25] Piash, M.I., Hossain, M.F. and Parveen, Z. (2017) Physico-Chemical Properties and Nutrient Content of Some Slow Pyrolysis Biochars Produced from Different Feedstocks. *Bangladesh Journal of Scientific Research*, **29**, 111-122. https://doi.org/10.3329/bjsr.v29i2.32327

[26] Web 1: Online Fertilizer Recommendation System. http://frs-bd.com/

[27] Liu, Y., Wan, K.Y., Tao, Y., Li, Z.G., Zhang, G.S., Li, S.L. and Chen, F. (2013) Carbon Dioxide Flux from Rice Paddy Soils in Central China: Effects of Intermittent Flooding and Draining Cycles. *PLoS ONE*, **8**, e56562. https://doi.org/10.1371/journal.pone.0056562

[28] Liu, Y., Yang, M., Wu, Y., Wang, H., Chen, Y. and Wu, W. (2011) Reducing CH_4 and CO_2 Emissions from Waterlogged Paddy Soil with Biochar. *Journal of Soils and*

Sediments, **11**, 930-939. https://doi.org/10.1007/s11368-011-0376-x

[29] Feng, Y., Xu, Y., Yu, Y., Xie, Z. and Lin, X. (2012) Mechanisms of Biochar Decreasing Methane Emission from Chinese Paddy Soils. *Soil Biology and Biochemistry*, **46**, 80-88. https://doi.org/10.1016/j.soilbio.2011.11.016

[30] Khan, S., Chao, C., Waqas, M., Arp, H.P.H. and Zhu, Y.G. (2013) Sewage Sludge Biochar Influence upon Rice (*Oryza sativa* L.) Yield, Metal Bioaccumulation and Greenhouse Gas Emissions from Acidic Paddy Soil. *Environmental Science & Technology*, **47**, 8624-8632. https://doi.org/10.1021/es400554x

[31] Han, X., Sun, X., Wang, C., Wu, M., Dong, D., Zhong, T., Thies, J.E. and Wu, W. (2016) Mitigating Methane Emission from Paddy Soil with Rice-Straw Biochar Amendment under Projected Climate Change. *Scientific Reports*, **6**, Article No. 24731. https://doi.org/10.1038/srep24731

[32] Mahmud, K., Chowhdhury, M.S., Noor, N. and Huq, S.M.I. (2014) Effects of Different Sources of Biochar Application on the Emission of a Number of Gases from Soil. *Canadian Journal of Pure and Applied Sciences*, **8**, 2813-2824.