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Biochar effects on CO₂ emission and nitrogen mineralization in sandy and laterite soils

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Abstract

An incubation study was conducted in a laterite and sandy soil to study the effect of biochar and FYM on soil carbon and nitrogen mineralization under laboratory conditions at Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani, Trivandrum, Kerala during May 2019 to November 2019. The Comparison of the CO₂ emission by biochar and FYM showed a significant reduction in CO₂ emission in biochar applied treatments both in laterite and sandy soil. In both the soil NH₄-N and NO₃-N fraction was found to be higher in the soil applied with FYM during the initial stages of incubation but during the final stages the highest fractions were in biochar treated soils. The study discloses that addition of biochar could reduce CO₂ loss and improve nitrogen mineralization.

Keywords: CO₂ emission, carbon mineralization, nitrogen mineralization, NH₄-N & NO₃-N

Introduction

Direct application of crop residues into soils can improve soil physicochemical characteristics but can lead to crop management problems due to delay in decomposition. Further, accumulation of crop residues often interrupt land preparation and affect crop establishment and early crop growth, and therefore farmers choose burning of residues as a fast way to clear the agricultural field and facilitate crop management practices. This burning of crop residues and direct residue incorporation can lead to global warming by contribution of greenhouse gasses like CO₂.

Sequestering carbon both in the vegetation and soil is the best method to mitigate GHG emissions. Conservation agriculture, biomass recycling, crop rotations and use of organic amendments are some strategies by which carbon can be sequestered. Hence conversion of biowaste into biochar and using this as a soil amendment is one of the best methods to sequester carbon into the soil. Several studies show that biochar C remains stable in soil thus effectively sequestering carbon besides improving other soil properties like water holding capacity and nutrient availability.

Biochar is a carbon loaded product resulting from the pyrolysis of organic material at moderately low temperatures (<700°C) (Lehmann, 2007) ^[10]. It has the capacity to hoard carbon for longer duration in soil as it is chemically and biologically more stable than the source material. Biochar production and its storage in soils have been recommended as one of the possible ways of decreasing the atmospheric CO₂ concentration. Woolf *et al.* (2010) ^[24] reported that biochar could reduce 1.8 Pg CO₂ equivalents, which accounts for 12% of anthropogenic greenhouse gas emissions. Biochar can attract soil dissolved organic carbon (Thies and Rillig 2009) ^[21] and decrease the CO₂ emission (Liang *et al.*, 2008) ^[13].

Nitrogen is one of the nutrient elements that plants require in large quantities. Organic nitrogen is the key form of nitrogen present in soil which must undergo mineralization into inorganic nitrogen (NH₄⁺ and NO₃⁻) to be taken up by plants. The inorganic nitrogen in soil can be maintained by biochar addition since it will improve the rate of nitrogen mineralization thereby the plant growth (Song *et al.*, 2006; Liu *et al.*, 2018) ^[18, 14]. Several studies shows that with the application of biochar the rate of nitrification, abundance of ammonium-oxidizing bacteria and nitrogen availability increased (Deluca *et al.*, 2006; Ball *et al.*, 2010; Lehmann *et al.*, 2003) ^[5, 1, 12] and the N₂O emission and NH₃ volatilization decreased (Spokas *et al.*, 2009; Steiner *et al.*, 2010) ^[19, 20]. Biochar also has positive effects on soil bulk density, water holding capacity and the soil biomass abundance (Jeffery *et al.*, 2011; Fu *et al.*, 2019) ^[9, 6].

Hence this study aims to assess the effects of biochar on soil carbon and nitrogen mineralization in both laterite and sandy soils.

Materials and Methods

An incubation experiment was carried out using laterite and sandy soils of Trivandrum district, Kerala, India, to evaluate the CO₂ emissions on addition of biochar (paddy husk biochar (PHB) and coconut frond biochar (CFB)) and FYM @ 0.5, 1.0 and 1.5 g 100 g⁻¹ soil kept at field capacity. The experiment was conducted at the Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani, with 100g of laterite and sandy soils taken in 500 ml conical flasks to which treatments were imposed. CO₂ evolved was trapped in vials containing 1N sodium hydroxide (NaOH) (10 mL) kept hanging within conical flasks closed with a rubber cork (Jenkinson and Powlson, 1976). Each treatment with three replications were prepared and incubated in the laboratory for 210 days. At the end of 30, 60, 90, 120, 150, 180 and 210 days the vials with 1 N NaOH were taken out and titrated against 1N standard hydrochloric acid to quantify the amount of CO₂-C evolved from soil and expressed as mg of CO₂ evolved per 100 g soil.

To study the nitrogen mineralization, five kilogram of air-dried surface soil (< 2 mm) of laterite and sandy soil were taken in plastic pots and the treatments were imposed and mixed thoroughly. The treatments included a control and farm yard manure (FYM), paddy husk biochar (PHB) and coconut frond biochar (CFB) at 25, 50 and 75 g 5kg⁻¹ soil. The soil was maintained at 60 % of field capacity throughout the incubation period using distilled water. Soil samples were collected and analyzed for NH₄-N and NO₃-N (Bremner, 1965) [2] at the specified time intervals for the experiment.

Results and Discussion

CO₂ Emission

The CO₂ emission study was aimed at elucidating the CO₂ evolution pattern and quantity of CO₂ released by the biochar and FYM treatments. With enhancement in days of incubation a decreasing trend was observed in CO₂ emission (Figure 1 & 2), with the maximum evolution during the initial days both in laterite and sandy soils for all the treatments. In laterite soil at 30th day, 100g soil + 1.5g FYM recorded the highest CO₂ evolution (103.4 mg CO₂ 100 g soil⁻¹) followed by 100g soil + 1.0g FYM (95.70 mg CO₂ 100 g soil⁻¹) and 100g soil + 0.5g (67.10 mg CO₂ 100 g soil⁻¹). All treatments receiving biochar either from rice husk or coconut frond resulted in lower CO₂ emission than treatments receiving FYM at 1-1.5g till the end of incubation period. FYM applied at 0.5g also had higher CO₂ emission till 150 days compared to the biochar treatments. The lowest CO₂ evolution was noted at 100g soil + 0.5g PHB (12.10 mg CO₂ 100 g soil⁻¹) followed by 100g soil + 0.5g CFB (14.66 mg CO₂ 100 g soil⁻¹) excluding soil alone treatment (7.7 mg CO₂ 100 g soil⁻¹). Sandy soil also followed the same trend as in laterite soil in the emission pattern of CO₂ from soil. 100g soil + 1.5g FYM application showed the highest CO₂ emission in sandy soil (84.7 mg CO₂ 100 g soil⁻¹) and the lowest emission was at 100g soil + 0.5g PHB (9.97 mg CO₂ 100 g soil⁻¹). Dainy (2015) [4] also reported similar results on comparison of CO₂ evolution by coconut husk biochar, FYM and vermicompost treated soil, with a significant decrease in CO₂ emission in biochar amended soil over FYM and vermicompost treatments. Application of FYM resulted in release of higher amounts of

CO₂ from soil due to faster rate of carbon mineralization than biochar treatment (Vasu D, 2015) [22].

In the present study a very slow emission of CO₂ over the entire period of incubation and more sequestration of C was observed by addition of biochar when compared to FYM. Due to the recalcitrant nature of biochar it is better to convert biomass to biochar and then add to soil instead of adding fresh biomass because it can remain in soil without degradation for longer period of time (Gaunt and Lehmann, 2008) [7]. Islami *et al.* (2011) [8] compared the rate of decomposition of various organic amendments and reported that compared to cattle manure, biochar from coconut shell resulted in the lowest value for decomposition which implies that biochar with aromatic structure is more resistant to decomposition. In a similar study it was confirmed that biochar decreased CO₂ emission from soil by 30 – 37.2% (Chen *et al.*, 2014; Mukherjee *et al.*, 2014) [3, 15] and biochar application to soil may be a suitable management practice for maintaining soil C (Yin *et al.*, 2013; Zhang *et al.*, 2015) [25, 26].

Nitrogen Mineralization

NH₄-N content was higher in both the soils treated with biochar and FYM when compared to control (Table 1, 2). During the initial days of incubation NH₄-N content were more in soils treated with the respective rates of FYM compared to biochar in both laterite and sandy soils. After 90 days of incubation, a decline in NH₄-N content occurs for FYM treated soil due to its faster rate of mineralization. As the incubation period progresses, the NH₄-N content of biochar treated soils shows an increasing trend up to 150 days of incubation except at the 60th day in case of laterite soil and 90th day in case of sandy soil. The decline in 60th and 90th day for laterite and sandy soil respectively can be due to microbial immobilization. After 150 days till the end of incubation, a decreasing trend was seen which can be attributed to adsorption of NH₄-N on the biochar surface. Biochar can adsorb both NH₄⁺ and NO₃⁻ from soil and directed it for microbial use and thus temporarily reduce its availability (Lehmann *et al.*, 2006) [11]. NH₄-N adsorption can also be related to the CEC of biochar. One kilogram of coconut husk biochar with a CEC of 15.78 cmol (+) kg⁻¹ can adsorb and retain 2880 positively charged NH₄-N (Rajakumar, 2019) [17]. In laterite soil NH₄-N content was more in CFB treatment than PHB treatment, high surface area with more adsorption sites of PHB will be the reason for this. But in sandy soil the NH₄-N is more in PHB treatment due to its high porosity that helps to maintain a good microbial population. The effects of biochar on soil functions is based on its characteristics like chemical composition, surface chemistry, particle and pore size distribution as well as physical and chemical stabilization mechanisms in soil (Verheijen *et al.*, 2010) [23].

During the initial stages of incubation in both the soils as in the case of NH₄-N, NO₃-N was also high in FYM treated soil than biochar treated soil (Table 3, 4). But with the progress in incubation period the NO₃-N content was high in biochar treated soil. The enhancement in NO₃-N is the direct effect of biochar and other organic and inorganic inputs in increasing the population of nitrifying organisms there by increasing the net nitrification (Rajakumar, 2019) [17]. The highest value for NO₃-N content was seen at 5kg soil + 75g paddy husk biochar (108.26 mg kg⁻¹, 78.96 mg kg⁻¹ at 150 days of incubation in laterite soil and 180 days of incubation in sandy soil). After 150 and 180 days in laterite and sandy soil respectively, there is a slight decrease in NO₃-N content up to the end of experiment in both the soil treated with biochar which can be attributed to microbial denitrification. There are a number of

studies explaining the increase in net nitrification rate due to addition of biochar to soils (Deluca *et al.*, 2006) [5]. The biochar applied to soil may moderate soil temperature, improve soil moisture and aeration, thus increasing the nitrifier activities (Nguyen *et al.*, 2017) [16].

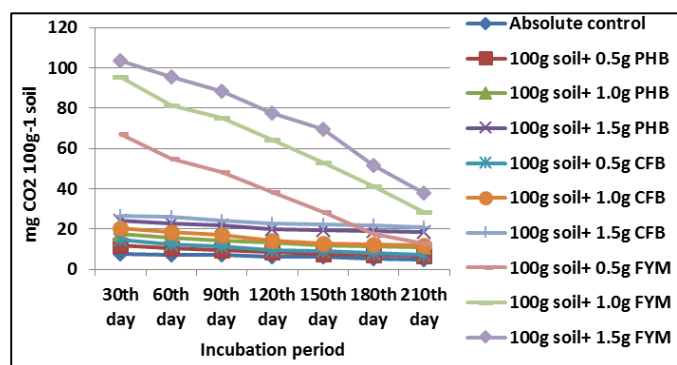


Fig 1: Effect of treatments on CO₂ emission at monthly intervals, mg CO₂ 100 g⁻¹ soil (Laterite soil)

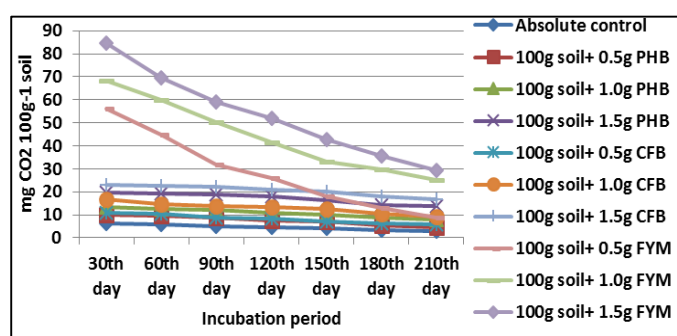


Fig 2: Effect of treatments on CO₂ emission at monthly intervals, mg CO₂ 100 g⁻¹ soil (sandy soil)

Table 1: Effect of treatments on NH₄N at different periods of incubation, mg kg⁻¹ (Laterite soil)

Treatments	30 th day	60 th day	90 th day	120 th day	150 th day	180 th day	210 th day
T1-Absolute control	33.6	36.96	32.66	28.00	25.57	27.06	25.20
T2-5kg soil + 25g PHB	35.09	31.54	37.71	41.07	44.80	42.00	39.20
T3-5kg soil + 50g PHB	39.20	32.66	34.91	38.27	41.07	39.20	36.21
T4-5kg soil + 75g PHB	39.94	31.36	34.34	36.96	39.57	38.27	34.53
T5-5kg soil + 25g CFB	35.84	33.22	38.26	43.86	46.67	44.42	41.44
T6-5kg soil + 50g CFB	40.88	34.90	38.45	41.25	46.29	43.12	39.20
T7-5kg soil + 75g CFB	44.80	38.08	39.94	42.00	44.80	40.88	36.40
T8-5kg soil + 25g FYM	39.76	36.96	39.57	36.40	39.20	35.09	33.78
T9-5kg soil + 50g FYM	43.86	40.51	43.86	39.94	38.26	33.97	33.23
T10-5kg soil + 75g FYM	45.54	43.68	46.66	43.86	40.88	32.48	28.93
SEm (±)	0.768	0.863	0.774	0.628	0.682	0.625	0.592
CD(0.05)	2.304	2.589	2.323	1.884	2.046	1.876	1.776

Table 2: Effect of treatments on NH₄N at different periods of incubation, mg kg⁻¹ (Sandy soil)

Treatments	30 th day	60 th day	90 th day	120 th day	150 th day	180 th day	210 th day
T1-Absolute control	22.4	24.64	22.4	24.64	23.33	21.28	19.04
T2-5kg soil + 25g PHB	27.81	33.97	31.92	33.78	36.40	34.34	32.66
T3-5kg soil + 50g PHB	30.80	33.60	30.80	30.80	33.60	31.92	28.74
T4-5kg soil + 75g PHB	30.24	32.67	28.74	26.88	29.68	27.81	26.32
T5-5kg soil + 25g CFB	25.76	29.68	27.63	29.87	33.60	33.60	30.24
T6-5kg soil + 50g CFB	28.00	29.87	27.67	28.18	31.92	30.24	28.37
T7-5kg soil + 75g CFB	28.00	30.43	30.43	29.31	31.36	29.12	27.81
T8-5kg soil + 25g FYM	28.37	32.67	30.80	28.37	26.88	27.06	24.08
T9-5kg soil + 50g FYM	32.66	34.35	33.23	31.92	29.31	28.37	27.06
T10-5kg soil + 75g FYM	33.60	34.91	33.79	33.23	32.66	31.36	28.74
SEm (±)	0.636	0.669	0.659	0.559	0.674	0.545	0.482
CD(0.05)	1.908	2.008	1.978	1.679	2.023	1.634	1.447

Table 3: Effect of treatments on NO₃N at different periods of incubation, mg kg⁻¹ (Laterite soil)

Treatments	30 th day	60 th day	90 th day	120 th day	150 th day	180 th day	210 th day
T1-Absolute control	76.16	78.4	74.48	70.56	65.14	66.45	62.16
T2-5kg soil + 25g PHB	79.14	83.06	87.36	91.28	96.88	94.26	89.41
T3-5kg soil + 50g PHB	81.76	85.68	91.28	98.00	103.8	99.86	93.70
T4-5kg soil + 75g PHB	87.36	90.34	95.57	103.2	108.3	104.2	98.74
T5-5kg soil + 25g CFB	77.46	80.26	84.37	89.22	94.26	89.97	85.68
T6-5kg soil + 50g CFB	78.02	81.2	88.66	92.96	98.56	94.26	89.41
T7-5kg soil + 75g CFB	81.76	87.36	92.96	97.62	102.3	97.44	92.40
T8-5kg soil + 25g FYM	79.14	83.62	80.08	75.04	81.76	77.46	72.61
T9-5kg soil + 50g FYM	84.00	87.36	83.06	78.21	85.86	81.76	76.34
T10-5kg soil + 75g FYM	87.92	91.28	88.66	83.44	89.22	83.81	78.77
SEm (±)	0.787	0.918	1.038	1.169	0.992	0.787	1.572
CD(0.05)	2.362	2.753	3.115	3.509	2.976	2.362	4.715

Table 4: Effect of treatments on NO₃N at different periods of incubation, mg kg⁻¹ (Sandy soil)

Treatments	30 th day	60 th day	90 th day	120 th day	150 th day	180 th day	210 th day
T1-Absolute control	52.08	56.93	53.95	51.33	49.65	53.20	56.75
T2-5kg soil + 25g PHB	57.12	61.60	58.24	66.27	68.88	70.56	65.71
T3-5kg soil + 50g PHB	63.09	67.57	64.40	68.88	72.80	74.11	71.87
T4-5kg soil + 75g PHB	67.76	72.05	68.88	73.36	77.46	78.96	76.91
T5-5kg soil + 25g CFB	52.26	57.49	57.12	64.40	67.57	70.00	64.96
T6-5kg soil + 50g CFB	53.01	62.16	58.80	67.76	71.87	73.55	69.44
T7-5kg soil + 75g CFB	59.36	66.45	63.84	71.87	74.66	77.46	72.80
T8-5kg soil + 25g FYM	58.24	64.58	56.37	53.94	53.20	57.12	54.88
T9-5kg soil + 50g FYM	64.58	68.88	63.84	60.67	57.68	61.6	58.8
T10-5kg soil + 75g FYM	69.07	73.92	65.52	62.72	57.68	64.96	62.72
SEm (±)	0.941	1.189	1.351	0.796	0.968	0.766	1.079
CD(0.05)	2.824	3.569	4.054	2.688	2.903	2.297	3.239

Conclusions

Biochar amendment had significant effect on decreasing CO₂ emission, compared to FYM. The maximum CO₂ emission was recorded at 5kg soil + 75g FYM in both soil types. There was a positive effect on mineral nitrogen fractions with the addition of biochar because it influences soil microbial communities improving N mineralization and biological N fixation.

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