International Journal of
Emerging Research in Management &Technology
ISSN: 2278-9359 (Volume-4, Issue-11)

Research Article

November
2015

Effect of Biochar Addition on Soil Carbon Emission and Nitrogen Mineralization in Some Typical Indian Soils

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Abstract:

Effect of biochar on soil carbon and nitrogen mineralization in three soils was studied for an incubation period of sixty days under laboratory conditions. In black soils, biochar addition along with farm yard manure resulted in higher carbon mineralization (192 mg CO_2 kg soil^{-1}) and lowest amount of CO_2 (145 mg CO_2 kg soil^{-1}) was released from soil with only biochar addition. Similar trends were observed in red and alluvial soils respectively in cumulative CO_2 release with addition of higher dose of biochar and FYM both at 25 t ha^{-1}. The lowest amount of CO_2 release was recorded from control for all soils (141, 122 and 130 mg CO_2 kg soil^{-1} for black, red and alluvial soils respectively). Application of FYM without biochar resulted in faster carbon mineralization and higher CO_2 release. NH_4^+-N content increased during the initial period of the incubation and then decreased after 25 days. The dynamics of NH_4^+-N was not significantly influenced by the rate of biochar application. Nitrate nitrogen (NO_3^--N) content was observed to be high viz., 36.5 to 45.5 mg kg^{-1}, 33.0 to 46.6 mg kg^{-1} and 34.3 to 44.4 mg kg^{-1} in black, red and alluvial soils respectively after 60 days of incubation. The highest increase in NO_3-N was found in alluvial soils (60.5-66.6%) followed by red soil (51.0-54.5%) and black soil (28.2-34.5%).

Key Words: Biochar, pyrolysis, carbon, nitrogen, mineralization

I. INTRODUCTION

It is crucial to maintain a threshold level of organic matter in the soil for maintaining physical, chemical and biological integrity of the soil for the sustained agricultural productivity. Efficient use of biomass by converting it as a useful source of soil amendment or nutrients is one way to manage soil health. The crop residues are either partially utilized or unutilized due to various constraints. Residue burning traditionally provides a fast way to clear the agricultural field of residual biomass but also leads to release of Green House Gases (CHGs) and our atmosphere is CO_2-impoverished with increase in CO_2 concentration from 280 ppm in 1850 to 391 ppm (e.g. [1]). Poor agricultural management practices can have serious consequences by speeding up the release of CO_2 emissions from soil, better practices can increase the soil C stock considerably, and thereby mitigate climate change. Carbon emissions must be cut to reduce increase in CO_2 levels and removing carbon from the atmosphere and storing it underground is one of the ways to do it. Therefore the strategy should be to sequester carbon in soil and one such means is incorporating charred biomass (biochar) in soil (e.g. [2]). In this context, biochar, a pyrolysis product of plant biomass offers a significant, multidimensional opportunity to reduce the carbon emissions from soils and store it. Recent studies showed that biochar could offset 12% of the current anthropogenic CO_2-C equivalent emissions from soils (e.g. [3]). Biochar is a fine grained, porous, stable carbon product remaining after plant biomass has been subjected to thermo-chemical conversion process (pyrolysis) at low temperatures (~350-600°C) in a little or no oxygen environment. It creates a recalcitrant soil carbon pool that is carbon-negative, serving as a net withdrawal of atmospheric carbon dioxide stored in highly recalcitrant soil carbon stocks. Biochar has the potential to increase soil water-holding capacity, cation exchange capacity, surface sorption capacity and base saturation when added to soil (e.g. [4], [5], [6], [7]).

The research in recent days aims to find ways to reduce the quantum of greenhouse gas emission into the atmosphere by efficient management of cultivated soils and biochar has gained much attention as a soil amendment. Besides sequestering carbon, biochar has been observed to have agronomic benefits (e.g. [8]). In soils, the majority of N exists in complex organic forms that must be ammonified to NH_4^+ and then nitrified to NO_3^- prior to plant uptake (e.g. [9]). Biochar is reported to alter the nitrogen (N) dynamics in soils (e.g. [10]). Recent studies have demonstrated that the addition of biochar to surface mineral soils may directly influence N transformations (e.g. [11], [12]). In view of the above, the present study has been undertaken with the objective to examine the effect of biochar application on carbon and nitrogen mineralization in three different soils.

II. MATERIALS AND METHODS

The biochar used in the experiment was produced from pyrolysis of subabul (*Leucaena leucocephala*) wood biomass. The biochar was produced from pyrolysis of subabul wood biomass in a reactor with electrical heating arrangements and controller to maintain the desired temperature (e.g. [13]). The pH of the subabul biochar was mildly alkaline (7.58), electrical conductivity was 2.93 dS m^{-1} with the CEC of 25 cmol (+) kg^{-1}. Total organic carbon content was high (70%). N content was 1.1%. Potassium content of the biochar was almost equal (0.5%) to calcium (0.52%) and very high when compared to phosphorus (0.05%). Biochar had equal amount of Mg (0.23%) and Na (0.25%). The volatile matter (42.86%) of plant biomass was high (pyrolysed at 350°C) and the ash content of biochar was 2.82%. Surface (0-20 cm) soil samples were collected from Bengaluru, Jabalpur and Delhi. The characteristics of the experimental soils were presented in table 1.

One hundred grams of each type of soil were taken in 500 mL conical flasks. Farm yard manure was added at the rate of 25 tonnes per hectare (1.25 g / 100 g) (F_1) and soils without farm yard manure addition (F_0) were also kept for incubation. The biochar was added at the rate of 0, 5, 10 and 25 tonnes per hectare (0, 0.25, 0.5, 1.25 g / 100 g) and thoroughly mixed with soil (B_0, B_1, B_2, B_3 respectively). Nitrogen to each conical flask was added in the form of urea solution at the rate of 150 kg N per hectare (17.38 mg / 100 g). To trap the carbon-di-oxide, 10 mL of 1 *N* sodium hydroxide was taken in a glass vial and kept hanging inside the conical flask which was closed by a rubber cork (e.g. [14]). Three replicates of each treatment were prepared, randomly placed and incubated in the laboratory at 25±2°C for 60 days. At the end of 1, 3, 5, 7, 12, 17, 25, 35, 45 and 60 days the vials with 1 *N* sodium hydroxide were taken out and titrated against 1*N*standardhydro chloric acid to estimate the quantity of CO_2-C evolved from soil.

To study the nitrogen dynamics, one hundred grams of air-dried soil (< 2 mm) of each type were weighed in plastic containers. The treatments were imposed as explained above for the carbon mineralization experiment. Based on the weight loss distilled water was added to maintain the moisture content at 60 % throughout the incubation period. Soil samples (5 g) were collected at the end of each interval as mentioned above from all the treatments and analyzed for NH_4^+-N and NO_3–N (e.g. [15]). Moisture factor was computed and applied to express the results on oven dry basis (16).

III. RESULTS AND DISCUSSION

I. *Carbon Mineralization*

Soil carbon mineralization during the incubation period was measured in terms of CO_2 released from the soil. In black soil, addition of biochar and FYM (both 25 t ha^{-1}) has resulted in higher CO_2 release (192 mg kg $soil^{-1}$) (Figure 1). Among biochar added treatments, lowest amount of CO_2 (133 mg kg $soil^{-1}$) was released from soil incubated only with biochar (5 t ha^{-1}). Similar results were reported by reference [17]. Farm yard manure application without any biochar (B_0F_1) resulted in the release of slightly higher the amount of CO_2 (127 mg kg^{-1} soil) than control and it may be due to the mineralizable carbon present in the FYM. The application of biochar along with FYM has resulted in higher CO_2 release than application of biochar alone. The cumulative CO_2 release during the incubation period in red soil and alluvial soil also followed the same trend as black soil. In red soil amended with 25 t ha^{-1}biochar and FYM released highest amount of CO_2 (188 mg kg $soil^{-1}$) and soil with only FYM application released more CO_2 (140 mg kg $soil^{-1}$) than control (fig. 2). Shenbagavalli and Mahimairaja (2012) reported similar results that higher rate of biochar application has resulted in higher C mineralization in soil.

Application of only FYM without biochar resulted in faster carbon mineralization and release of slightly higher amount of CO_2 from soil. In a similar study to this incubation experiment, Reference [18] reported that biochar application initially increased the CO_2 emission for a period of three weeks and then it decreased. The rate of biochar application had significant effect on carbon-di-oxide release which was evident from the results which shows that higher dose of biochar application increased the CO_2 release from soil initially, though the release rate was reduced after 30 days. The biochar application at the rates of 5 and 10 t ha^{-1} had produced similar results with lower CO_2 emissions (Fig. 1, 2 and 3).

The CO_2 release per day from soils applied with higher dose of biochar increased up to an initial 12 days of the incubation period after it decreased upto 25 days and then it decreased rapidly (>50%). Carbon mineralization increases rapidly after biochar additions to soil (e.g. [19]) but the effect is typically short-term in nature, lasting no more than a few weeks. The effect of biochar on the soil CO_2 emissions obviously depends on the soil environment and the microbial community present, as well as the physical and chemical characteristics of the biochar. Microbial growth and activity may be stimulated by labile biochar fractions (volatile matter), while a more indirect biochar effect causing CO_2 emission could be improved soil water retention promoting decomposition of native soil organic matter (e.g. [20]). Carbon-di-oxide release per day was found to be lowest (0.33 mg kg $soil^{-1}$) after 45 days from soil in which higher dose (25 t ha^{-1}) of biochar was applied (fig. 4). The CO_2 release per day was lower in treatments in which biochar alone was applied. In all the three type of soils viz., black soil, red soil and alluvial soil, the CO_2 release per day followed the same trend of increase in C mineralization at the initial period upto 12 days and decreased slightly upto 25 days and then further decreased (> 400 %) after 25 days to 60 days.

Carbon loss from the soil was low (0.23, 0.28 and 0.26 % in black, red and alluvial soils respectively) when higher quantity of biochar was added to the soil (table 2) and the loss of carbon was found to be high in soils without biochar addition. In a similar laboratory study it was demonstrated that biochar reduced carbon loss by 30 – 37.2% (e.g. [21], [22]) and application of biochar to soil may be an appropriate management practice for increasing soil C storage (e.g. [23], [24]). Results support that biochar produced by pyrolysis at 350°C resulted higher volatile matter content which stimulated the soil microorganisms by the provision of a readily available substrate and lead to initial short-term CO_2 emissions(e.g. [17]). Reference [3] also reported similar results that greater amount of CO_2 releases from biochar produced at lower temperature.

II. *Nitrogen Mineralization*

The initial NH_4^+-N and NO_3^--N content were 2.5 and 3.8, 2.1 and 3.2, 2.0 and 3.1 mg kg^{-1} in black, red and alluvial soils respectively. Since nitrogen was added in the form of urea, NH_4^+-N content increased in the soil during the initial period of the incubation due to ammonification and then decreased after 25 days because of nitrification in black soil. In control, NH_4^+-N content increased with incubation period (4.1 to 30.4 mg kg^{-1}) upto 25 days and then it decreased to 11.2 at the end of 60 days (table 3). NH_4^+-N content was lesser in soils applied with biochar when compared to control. It may be due to adsorption of NH_4^+-N onto biochar particles (e.g. [25]). Reference [2] suggested that biochar can adsorb both NH_4^+ and NO_3^- from soil thus reducing the availability of inorganic N at least temporarily, but perhaps concentrating it for microbial use.

It might also be possible that some amount of decomposition might have occurred when fresh biochar is added to soil (Liang *et al*., 2006), which could induce net immobilization of inorganic N already present in the soil. The reduction could be due to high C/N ratio of biochar and greater potential for N immobilization (Lehmann *et al*., 2006). However, that immobilization potential associated with biochar additions to soil would be greatly limited by the recalcitrant nature of biochar (e.g. [26]).

In this study the dynamics of NH_4^+-N was not significantly influenced by the rate of biochar application in all the three type of soils. This may be attributed to the adsorption capacity and rate of release of adsorbed NH_4+-N from the surfaces of the biochar. However, there was a marked increase in the NH_4^+-N content in the soil after the incubation period of 60 days in all the biochar applied soil. The increase in NH_4^+-N content was highest in alluvial soil treated with only FYM not biochar. The biochar applied soil also showed increase in the NH_4^+-N content and higher NH_4^+-N content was observed in soil applied with lower rate (5 t ha^{-1}) of biochar though higher rate did not significantly increase or decrease the NH_4^+-N in alluvial soil. The percentage increase in NH_4^+-N content was high in alluvial soil compared to black soil and red soil. The results show that in all the three type of soils, biochar application did not reduce the NH_4^+-N content significantly. This may be due to the low NH_4^+-N adsorption capacity of the biochar used for this study.

Nitrate nitrogen content was observed to be high in all the soils viz., 36.5 to 45.5 mg kg^{-1}, 33.0 to 46.6 mg kg^{-1} and 34.3 to 44.4 mg kg^{-1} in black, red and alluvial soils respectively after 60 days probably due to minimal loss of NO_3-N by leaching or denitrification (table 3, 4 and 5). Nitrate accumulation was observed since there was neither uptake nor major losses from soils. The increase in the NO_3-N content in biochar applied soils followed the same trend as that of increase in NH_4^+-N content in all the three types of soils. The highest increase in NO_3-N was found in alluvial soils (60.5-66.6%) followed by red soil (51.0-54.5%) and black soil (28.2-34.5%). It may also be possible that some of the NO_3–N might have lost through microbial denitrification. Biochar has the potential to catalyze the reduction of N_2O to N_2 thus potentially reducing the emission of this important greenhouse gas to the atmosphere, and thus it could directly or indirectly influence denitrification. The process of denitrification requires the presence of substrate (available C) and a terminal electron acceptor, such as NO_3^- (e.g. [9]).

IV. CONCLUSIONS

The present study reveals that addition of biochar has reduced the percentage of carbon loss and increased the soil carbon storage from all the three studied soils even though higher dose of biochar and farm yarm manure catalyzed loss of carbon at initial stages. It can be concluded that the increase in NH_4^+-N content was due to retention by biochar and then decreased to due increase in nitrification in soils and the accumulation of NO_3-N might be due to continued nitrification and minimal loss from all soils.

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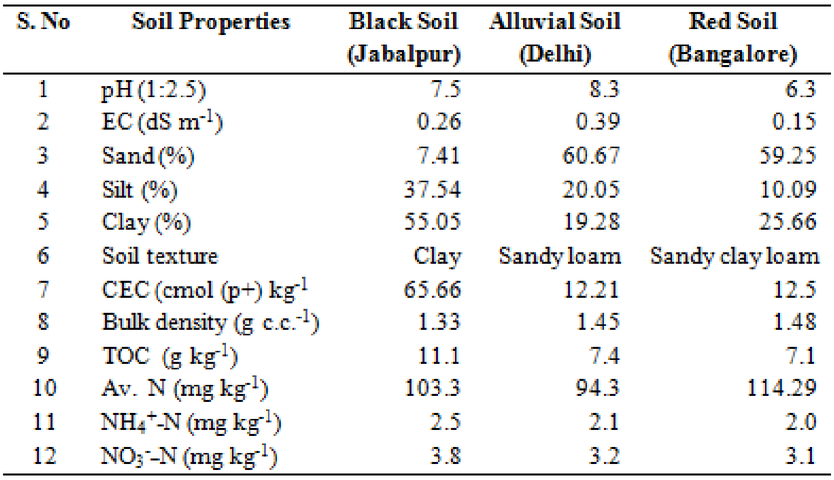
Table I. Characteristics of Experimental Soils



S. No	Soil Properties	Black Soil (Jabalpur)	Alluvial Soil (Delhi)	Red Soil (Bangalore)
1	pH (1:2.5)	7.5	8.3	6.3
2	EC (dS m^{-1})	0.26	0.39	0.15
3	Sand (%)	7.41	60.67	59.25
4	Silt (%)	37.54	20.05	10.09
5	Clay (%)	55.05	19.28	25.66
6	Soil texture	Clay	Sandy loam	Sandy clay loam
7	CEC (cmol (p+) kg^{-1}	65.66	12.21	12.5
8	Bulk density (g $c.c.^{-1}$)	1.33	1.45	1.48
9	TOC (g kg^{-1})	11.1	7.4	7.1
10	Av. N (mg kg^{-1})	103.3	94.3	114.29
11	NH_4^+-N (mg kg^{-1})	2.5	2.1	2.0
12	NO_3^--N (mg kg^{-1})	3.8	3.2	3.1

Table II. Effect of Biochar on Carbon Loss from different soils

Soil Type	Treatment	TOC (mg)	Added C (mg)	Total C (mg)	Loss of CO_2 (mg)	Loss of C (mg)	C in soil (mg)	% loss of C
Black Soil (Jabalpur)	B_0F_0	1110	0	1110	14.1	3.85	1106.15	0.35
	B_1F_0	1110	175	1285	14.5	3.95	1281.05	0.31
	B_2F_0	1110	350	1460	15.1	4.12	1455.88	0.28
	B_3F_0	1110	875	1985	16.5	4.50	1980.50	0.23
	B_0F_1	1110	250	1360	15.6	4.25	1355.75	0.31
	B_1F_1	1110	425	1535	17.9	4.88	1530.12	0.32

	B_2F_1	1110	525	1635	18.1	4.94	1630.06	0.30
	B_3F_1	1110	1050	2160	19.2	5.24	2154.76	0.24
Red Soil (Bengaluru)	B_0F_0	710	0	710	13.0	3.55	706.45	0.50
	B_1F_0	710	175	885	13.9	3.79	881.21	0.43
	B_2F_0	710	350	1060	14.2	3.87	1056.13	0.37
	B_3F_0	710	875	1585	16.0	4.36	1580.64	0.28
	B_0F_1	710	250	960	14.0	3.82	956.18	0.40
	B_1F_1	710	425	1135	16.9	4.61	1130.39	0.41
	B_2F_1	710	525	1235	17.6	4.80	1230.20	0.39
	B_3F_1	710	1050	1760	18.8	5.13	1754.87	0.29
Alluvial Soil (Delhi)	B_0F_0	740	0	740	12.2	3.33	736.67	0.45
	B_1F_0	740	175	915	13.3	3.63	911.37	0.40
	B_2F_0	740	350	1090	14.0	3.82	1086.18	0.35
	B_3F_0	740	875	1615	15.3	4.17	1610.83	0.26
	B_0F_1	740	250	990	12.7	3.46	986.54	0.35
	B_1F_1	740	425	1165	13.5	3.68	1161.32	0.32
	B_2F_1	740	525	1265	14.6	3.98	1261.02	0.31
	B_3F_1	740	1050	1790	17.8	4.85	1785.15	0.27

Table III. N fractions (mg kg^{-1}) in black soil during the incubation period

Treatment	Incubation period (days)																			
	NH_4^+-N (mg kg^{-1})										NO_3^--N (mg kg^{-1})									
	1	**3**	**5**	**7**	**12**	**17**	**25**	**35**	**45**	**60**	**1**	**3**	**5**	**7**	**12**	**17**	**25**	**35**	**45**	**60**
B_0F_0	4.1	7.1	10.3	12.5	20.1	26.8	30.4	24.2	14.9	11.2	5.2	7.3	10.2	18.2	24.1	29.2	35.5	39.1	42.4	46.6
B_1F_0	3.9	5.8	8.5	11.7	18.2	25.1	30.0	26.2	15.2	12.1	5.0	6.8	9.2	16.9	23.5	27.2	33.1	35.2	37.1	43.4
B_2F_0	3.5	5.8	7.7	11.1	17.5	23.2	28.4	25.7	16.1	11.5	4.6	6.7	8.8	16.0	22.8	26.5	31.8	33.3	37.0	41.9
B_3F_0	2.3	4.1	5.0	7.2	11.2	14.5	20.6	22.5	14.1	9.5	3.2	5.8	7.9	12.2	15.6	21.0	24.4	26.8	30.2	33.8
B_0F_1	4.0	7.3	10.2	13.0	22.1	28.4	32.8	24.1	17.2	12.5	5.2	7.6	11.6	19.5	27.3	33.1	36.2	41.2	43.0	47.1
B_1F_1	3.8	7.0	9.5	11.5	21.3	26.7	31.2	23.5	17.0	12.6	4.8	6.9	10.0	17.4	25.2	30.2	34.5	38.3	41.2	45.5
B_2F_1	3.5	6.3	9.0	9.8	18.4	24.8	29.0	22.5	16.7	12.1	4.1	6.5	8.9	15.2	24.1	27.4	32.3	36.1	39.8	42.3
B_3F_1	3.0	4.2	5.5	8.8	13.9	18.5	22.8	20.1	15.0	10.0	3.7	6.1	8.6	14.5	19.2	23.1	28.3	32.8	33.3	36.1
CD (0.05)	0.44	0.43	0.91	0.90	1.41	1.83	3.14	1.81	1.12	0.88	0.31	0.27	0.47	0.99	1.40	1.77	2.20	2.17	2.85	3.11
Sm(±)	0.20	0.18	0.38	0.38	0.64	0.77	1.44	0.75	0.51	0.35	0.12	0.10	0.16	0.42	0.64	0.70	0.97	0.97	1.08	1.39

Table IV. N fractions (mg kg^{-1}) in red soil during the incubation period

Treatment	Incubation period (days)																			
	NH_4^+-N (mg kg^{-1})										NO_3^--N (mg kg^{-1})									
	1	**3**	**5**	**7**	**12**	**17**	**25**	**35**	**45**	**60**	**1**	**3**	**5**	**7**	**12**	**17**	**25**	**35**	**45**	**60**
B_0F_0	2.2	4.5	8.6	11.7	18.2	24.5	29.2	23.9	20.1	12.0	3.3	4.5	9.3	14.9	22.8	28.2	33.4	38.2	43.2	45.5
B_1F_0	2.3	4.2	8.1	10.9	16.3	22.9	28.4	21.1	18.8	10.3	3.3	4.3	9.2	12.8	21.4	27.0	30.9	36.8	41.4	44.0
B_2F_0	2.2	3.8	7.7	8.6	14.5	20.2	26.4	18.5	15.8	10.1	3.1	4.0	8.7	11.5	21.2	25.5	28.3	32.8	37.1	41.2
B_3F_0	2.1	3.1	5.2	7.1	11.4	18.4	21.3	15.3	13.8	9.4	3.1	4.1	8.8	10.5	18.3	24.5	26.7	31.1	35.7	39.5
B_0F_1	2.8	4.4	8.4	12.8	20.6	25.9	31.4	26.7	22.5	13.6	3.1	4.4	10.1	15.0	23.4	30.1	35.8	39.3	44.1	47.1
B_1F_1	2.4	4.3	7.9	11.5	19.2	23.5	27.3	22.2	18.4	11.6	3.0	4.5	9.8	14.5	20.5	29.4	36.0	40.1	43.1	45.9
B_2F_1	2.3	4.1	7.2	10.2	18.3	20.4	25.2	19.6	16.7	11.1	2.7	4.2	9.4	12.8	18.8	26.7	34.6	37.1	42.5	44.0
B_3F_1	2.1	4.0	6.9	8.3	14.8	16.9	21.6	18.2	14.2	10.2	2.6	4.0	8.9	9.9	15.0	21.5	28.7	32.5	36.7	40.2
CD (0.05)	0.20	0.22	0.34	0.38	0.61	1.11	1.33	1.38	2.15	0.88	0.21	0.21	0.40	0.79	1.67	2.01	2.22	3.10	3.18	3.33
Sm(±)	0.08	0.10	0.12	0.13	0.21	0.42	0.55	0.56	0.94	0.36	0.08	0.08	0.17	0.36	0.63	0.91	0.95	1.41	1.42	1.50

Table V. N fractions (mg kg^{-1}) in alluvial soil during the incubation period

Treatment	Incubation period (days)																			
	NH_4^+-N (mg kg^{-1})										NO_3^--N (mg kg^{-1})									
	1	**3**	**5**	**7**	**12**	**17**	**25**	**35**	**45**	**60**	**1**	**3**	**5**	**7**	**12**	**17**	**25**	**35**	**45**	**60**
B_0F_0	2.8	4.3	6.2	9.4	18.3	26.8	32.4	24.5	20.4	14.1	3.5	5.2	9.4	16.1	23.4	28.3	34.5	37.7	39.5	43.1
B_1F_0	2.6	4.4	6.0	8.8	16.8	23.8	31.1	22.8	18.8	13.2	3.4	5.0	8.8	15.8	21.9	28.0	31.1	35.5	38.8	42.1
B_2F_0	2.5	4.2	6.1	8.1	14.1	22.4	29.1	20.4	16.6	12.8	3.0	4.9	8.4	15.0	21.0	26.0	28.2	33.3	36.0	39.0
B_3F_0	2.4	4.1	5.2	6.8	10.2	18.2	25.4	16.2	14.5	10.3	3.1	4.5	7.8	12.8	17.8	21.4	25.0	30.5	31.2	34.4
B_0F_1	2.7	4.2	6.3	10.2	19.1	29.4	34.8	25.8	21.7	15.7	3.4	5.1	10.0	17.1	25.7	28.4	36.7	39.8	41.2	44.0
B_1F_1	2.6	4.2	6.2	9.8	18.3	27.3	33.1	22.8	18.6	14.3	3.2	5.0	9.6	16.3	25.0	28.0	34.9	37.8	39.9	42.2
B_2F_1	2.6	3.9	5.7	8.8	16.3	24.3	30.2	18.4	16.6	14.0	3.1	4.6	9.2	14.5	24.1	26.1	33.5	36.0	37.1	40.0
B_3F_1	2.5	3.8	5.0	8.0	12.6	20.4	25.9	15.3	14.6	12.1	3.0	4.1	8.8	10.7	21.2	23.0	29.1	31.6	32.1	36.0
CD (0.05)	0.14	0.19	0.24	0.53	1.80	2.14	2.98	3.04	3.31	1.01	0.12	0.25	0.27	0.75	1.19	1.21	1.55	2.70	2.44	3.11
Sm(±)	0.06	0.08	0.11	0.21	0.88	0.94	1.41	1.41	1.44	0.41	0.05	0.11	0.12	0.33	0.51	0.51	0.56	1.22	1.20	1.48

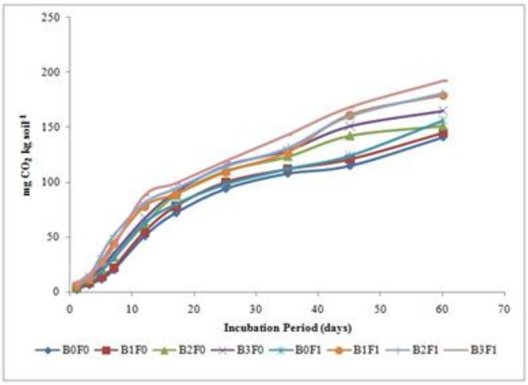


Figure I. Cumulative CO_2 evolution from black soil during incubation period

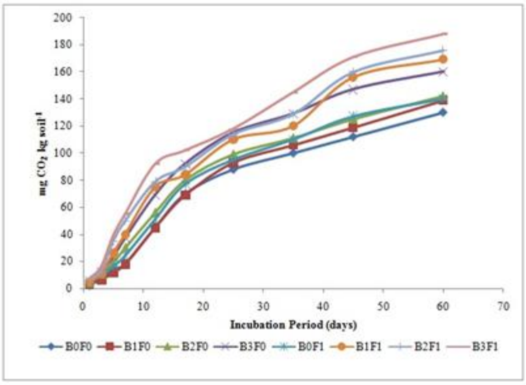


Figure II. Cumulative CO_2 evolution from red soil during incubation period

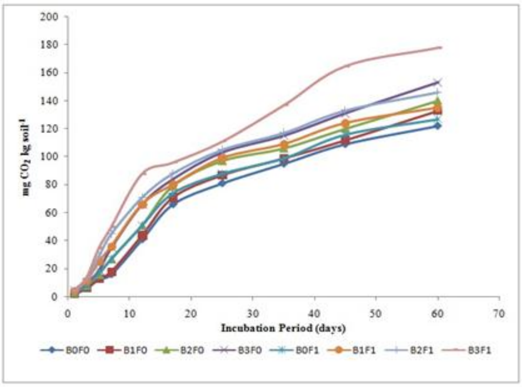


Figure III. Cumulative CO_2 evolution from alluvial soil during incubation period

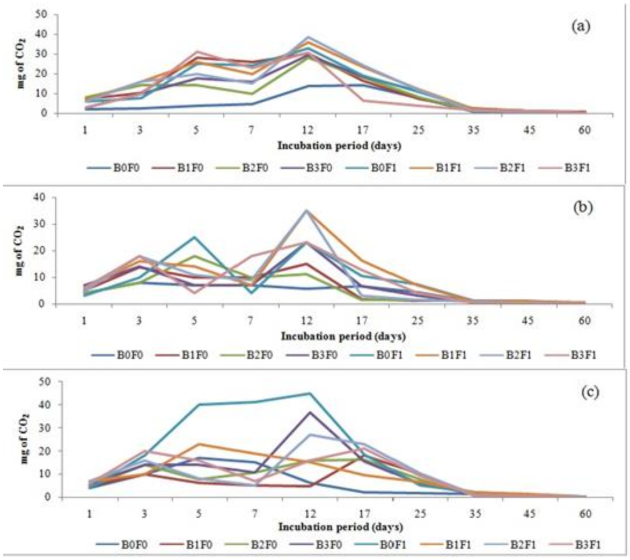


Figure IV. CO_2 evolution per from (a) black soil; (b) red soil and (c) alluvial soil