



## Soil respiration, pH and EC as influenced by biochar

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### Abstract

Biochar application to agricultural land is gaining significance as a strategy for C sequestration and improving soil health and nutrient cycling. Variable results have been reported for the effect of biochar on CO<sub>2</sub> evolution. This study was planned to assess the influence of biochar application on soil respiration (CO<sub>2</sub> evolution), soil pH and electrical conductivity (EC) in a silty clay loam soil during lab incubation experiments for a period up to 50 days. Surface soil sample (0-15 cm) was collected from a garden which had been used for growing vegetables for the last many years. The experiment was comprised of four treatments viz., 0, 5, 10 and 20 t biochar ha<sup>-1</sup>. The samples were incubated at 28 °C and taken out for CO<sub>2</sub> measurements after 2, 5 and 10 days and for EC and pH after 0, 5, 10 and 50 days of incubation periods. The rate of CO<sub>2</sub> evolution increased significantly with biochar application. During the first 2 days of incubation, the rate of CO<sub>2</sub> evolution increased by 13.1% with 5 t, 22.4% with 10 t and 34.6% with 20 t ha<sup>-1</sup> biochar over control treatment. The corresponding increases in CO<sub>2</sub> evolution were 12.8% with 5 t, 23.3 % with 10 t and 22.1% with 20 t ha<sup>-1</sup> of biochar during 5 days, and were 14.3% with 5 t, 30.4% with 10 t and 19.6% with 20 t ha<sup>-1</sup> of biochar over control during 10 days of incubation period. Almost similar trend was observed for cumulative CO<sub>2</sub> production. The soil EC and pH were also significantly greater in biochar than in the control treatment during all incubation periods. Although biochar application increased CO<sub>2</sub> evolution, the %C evolved from added biochar C decreased with increasing levels of biochar as it was 1.74 % with 5 t, 1.66% with 10 t and 0.82% with 20 t ha<sup>-1</sup> of the added biochar C during 10 days of incubation period. These results suggested that biochar application increased soil respiration, EC and pH, however, the ratio of the CO<sub>2</sub> evolved to total biochar C generally declined with increasing levels of biochar.

**Keywords:** Biochar, pH, EC, microbial activity, gases emission

### Introduction

The use of biochar on agricultural land is not only improving soil health and nutrient cycling but also increase carbon sequestration. Biochar is a rich source of organic C and is mostly resistant to microbial decay. It is produced from pyrolysis of various organic materials including plants and organic wastes. The use of biochar on agricultural land is important for the improvement of degraded soils as it improve soil properties and in turn enhance plant growth (Glaser *et al.*, 2002; Yamato *et al.*, 2006). Biochar is resistant to microbial degradation and stay in soil for longer period and thus provide long term benefit to soil fertility (Steiner *et al.*, 2007). Biochar decrease the possibility of nutrient leaching from soil and improve nutrient cycling. Biochar application benefit crop production through alteration in soil chemical reactions, providing active surfaces for the dynamics of soil nutrients, catalyze useful soil reactions, and improving physical soil conditions.

The beneficial effect of biochar on soil fertility and crop productivity is mainly associated with the positive

effect of biochar on soil microorganisms. The effect of biochar on soil microbial activity subsequently influence nutrient transformations in soil (Anderson *et al.*, 2011). The application of biochars have shown to increase soil N mineralization (Nelissen *et al.*, 2012). Song *et al.* (2013) reported increase in nitrification while Cayuela *et al.* (2013) observed increase in denitrification in soil with the application of biochar. Biochar amendment also influence other N transformations such as biological N<sub>2</sub> fixation (Rondon *et al.*, 2007). However, the effect of biochar on soil microbiological processes are not yet thoroughly established (Lehmann *et al.*, 2011) and variable responses of soil microbial biomass and activity to biochar amendment have been reported (Khodadad *et al.*, 2011). The application of biochar either increased (Luo *et al.*, 2013), reduced (Dempster *et al.*, 2012) or exhibited no effect on soil microbial biomass and activity (Zavalloni *et al.*, 2011). These variable effects of biochar could be associated with biochar characteristics as well as the prevailing soil and environmental conditions. Possible explanations for change in level of soil microbial biomass

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with amendment of biochar could be due to increase in available soil nutrients, adsorption of toxic compounds, improved soil water status and favorable soil pH condition, all of these factors have positive effects on soil microbial activity (Lehmann *et al.*, 2011). Increases in soil microbial biomass have been reported with increasing soil pH from pH 3.7 to 8.3 under similar environmental conditions (Aciego-Pietry and Brookes, 2008). Thus, the pH of biochars have considerable influence on total microbial abundance and biomass in soil.

Biochar amendments have also shown to improve soil quality (Sohi *et al.*, 2010; Sohi, 2012), increased water holding capacity and nutrient retention (Glaser *et al.*, 2002; Steiner *et al.*, 2007), increased soil biological activity (Anderson *et al.*, 2011; Lehmann *et al.*, 2011) and improved nutrient use efficiency (Ippolito *et al.*, 2012; Van Zwieten *et al.*, 2010).

The application of biochar have also shown to increase soil electrical conductivity (EC) and pH (Liang *et al.*, 2006; Gundale and DeLuca, 2006; Warnock *et al.*, 2007; Chan *et al.*, 2008). The effect however varied with salt contents of biochar as its characteristics are variable (Spokas, 2010). For example, biochar produced from switchgrass and corn stover, under similar temperature, had lower aromatic C and high ash contents than those produced from woody materials such as red oak and wood wastes (Brewer *et al.*, 2011). This paper report the results of biochar effect on soil respiration, pH and EC in calcareous soil during lab incubation experiments.

## Materials and Methods

A lab incubation experiment was conducted to evaluate the effect of different levels of biochar (*viz.*, 0, 5, 10 and 20 t ha<sup>-1</sup>) on CO<sub>2</sub> evolution, soil pH and EC in a silty clay loam soil. A surface (0-15 cm) soil sample was collected from a garden which had been used for growing vegetables for the last many years. The soil sample was broken down by hand and sieved using 2 mm sieve. The composite soil sample was analyzed for important soil characteristics (Table 1). Biochar used in this study was prepared from branches and trunk of Acacia trees and had pH 7.01, EC 1.57 dS m<sup>-1</sup>, total C 578 g kg<sup>-1</sup>, Ca 2.68 g kg<sup>-1</sup> and Mg 10.0 mg kg<sup>-1</sup> (Arif *et al.*, 2016)

## Incubation experiments

In order to assess the effect of biochar on CO<sub>2</sub> evolution, moist soil sample was amended with biochar at 0, 5, 10 and 20 t ha<sup>-1</sup>. Fifty gram soil samples, in triplicate, from each treatment along with 5 ml of 0.3 N NaOH in a vial were taken in a conical flask and incubated at 28 °C for 2, 5 and 10 days. The vial was taken out at each incubation period and titrated against 0.1 N HCl in the presence of 10

ml 1 M BaCl<sub>2</sub> solution using phenolphthalein as indicator. The amount of HCl consumed in titration was used to calculate the amount of CO<sub>2</sub> in each flask. A blank was also run simultaneously with each set of incubation.

For assessing the effect of biochar on soil pH and EC, soil sample was split in four treatments. Five hundred gram soil sample of each treatment was taken in incubation pots, in triplicate, and amended with biochar at 0, 5, 10 and 20 t ha<sup>-1</sup>. All pots were incubated at 28 °C and taken out for analysis of pH and EC at 0, 5, 10 and 50 days of incubation.

**Table 1 Important characteristics of soil (0-15 cm) used in the experiment**

Soil property	Unit	Value
Sand	%	12
Silt	%	53
Clay	%	35
Textural class	-	Silty clay loam
Soil organic matter	%	1.45
Total N	%	0.08
Total mineral N	ug g <sup>-1</sup> soil	43.5
AB-DTPA extractable P	ug g <sup>-1</sup> soil	7.82
AB-DTPA extractable K	ug g <sup>-1</sup> soil	110
Soil pH in saturated soil paste	-	8.10
Soil EC in saturated soil paste	dS m <sup>-1</sup>	0.15
Lime	%	12.5

## Laboratory analysis

### Microbial activity

Rate of CO<sub>2</sub> evolved during each incubation period was taken as a measure of microbial activity (Shah *et al.*, 2016). Microbes when active decompose organic materials and liberate CO<sub>2</sub>.

### Determination of soil pH and EC

For the determination of soil pH and EC, saturated soil paste was prepared, left overnight and then extracted using a vacuum pump (U.S Lab Staff, 1954). The extract was read for pH using pH meter (InoLab pH 720, WTW Series, Germany) and for EC on EC meter (EC Meter 4510, Conductivity Meter, Jenway, UK).

### Other soil analysis

Steam distillation method of Mulvaney (1994) was used to determine mineral N in soil while Kjeldhal method of Bremner (1996) was used to determine total N in soil. Available P and K were determined in AB-DTPA soil extract (Soltanpur and Shwab, 1977). The soil extract was read for P on Spectrophotometer and K on Flamephotometer (Jenway, UK). Soil organic matter was determined using K<sub>2</sub>Cr<sub>2</sub>O<sub>7</sub> as an oxidizing agent in the



presence of  $H_2SO_4$  following the Walkley and Black procedure (Nelson and Sommers, 1996). The lime in soil was determined by the acid-neutralization method as described in U.S. Lab Staff (1954) and Bouyoucos hydrometer method of Gee and Bauder (1986) was used to determine soil texture.

### Statistical analysis

Data was analysed statistically following Completely Randomized design using statistical package Statistix 8.1 and means were compared using LSD test (Steel *et al.*, 1997).

### Results and Discussion

A laboratory incubation experiment was conducted to assess the effect of biochar amendment on rate of  $CO_2$  evolution, soil EC and soil pH in a calcareous soil. The results obtained are presented and discussed below:

#### $CO_2$ evolution

The results obtained on rate of  $CO_2$  evolution as influenced by various doses of biochar are presented in Table 2. The results showed that the rate of  $CO_2$  evolution was consistently greater in the biochar amended than in the unamended soil during 10 days of incubation period. The results further showed that the rate of  $CO_2$  evolution increased with increasing level of biochar application. During the first two days of incubation, biochar application at 5 t ha<sup>-1</sup> increased the rate of  $CO_2$  evolution by 13.1% compared with the control treatment (Table 2). The corresponding increases were 22.4% with 10 t and 34.6% with 20 t ha<sup>-1</sup> biochar application over control treatment during 2 days of incubation period. During 5 days of incubation, the increases in  $CO_2$  evolution were 12.8% with 5 t, 23.3% with 10 t and 22.1% with 20 t ha<sup>-1</sup> of biochar compared with the control. Moreover, the increases in  $CO_2$  evolution during 10 days of incubation were 14.3% with 5 t, 30.4% with 10 t and 19.6% with 20 t ha<sup>-1</sup> of biochar over control treatment. These results suggested that application of biochar substantially increased the rate of  $CO_2$  evolution in soil. The rate of  $CO_2$  generally increased with increasing levels of biochar application.

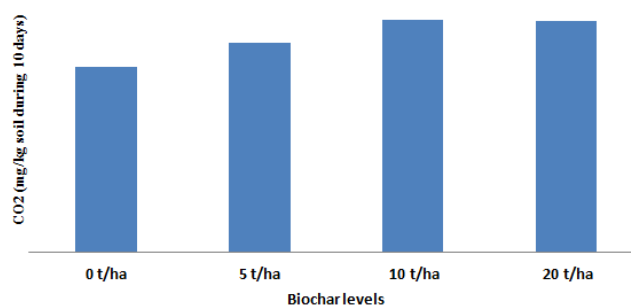
The cumulative  $CO_2$  production showed similar response to biochar application as the rate of  $CO_2$  evolution (Fig 1). The results showed that cumulative  $CO_2$  production was consistently greater in the biochar than in the control treatment during all incubation periods. The results further showed that the amount of  $CO_2$  produced was somehow related with the level of biochar applied. The maximum amount of 389 ug  $CO_2$  g<sup>-1</sup> was produced with the application of biochar at 20 t ha<sup>-1</sup> during 2 days of incubation period. The next highest amounts of 261 ug  $CO_2$  g<sup>-1</sup> was produced with 10 t and 242 ug  $CO_2$  g<sup>-1</sup> with 5 t ha<sup>-1</sup> of biochar during

2 days. It was evident that biochar at 20 t ha<sup>-1</sup> increased  $CO_2$  production by 35 % over control during 2 days. The corresponding increases during 2 days were 22% with 10 t and 13.1% with 5 t ha<sup>-1</sup> of biochar. The pattern of increase in  $CO_2$  production with biochar at 5 and 10 t ha<sup>-1</sup> at day 5 and 10 was almost similar as at day 2. However, the extent of increase in  $CO_2$  production with 10 t ha<sup>-1</sup> biochar gradually declined with time as it was 35% at day 2, 28% at day 5 and 25% at day 10.

**Table 2: Effect of biochar on rate of  $CO_2$  evolution during 10 days of incubation period**

Biochar level (t/ha)	Day 2	Day 5	Day 10
	ug $CO_2$ g <sup>-1</sup> soil d <sup>-1</sup>		
0	107d*	86c	56c
5	121c	97b	64b
10	131b	106a	73a
20	144a	105a	67ab

\*Means followed by different letter(s) within columns are significantly different (P<0.05)



**Figure 1: Effect of biochar on cumulative  $CO_2$  production (mg kg<sup>-1</sup> soil) from soil during 10 days of incubation**

These results suggested that biochar application substantially increased  $CO_2$  production during 10 days of incubation and the increase was proportional to the amount of biochar applied. Since  $CO_2$  production is associated with microbial activity, it can be concluded that biochar application remarkably improve the soil microbial activity. Our results are in line with some of the published literature. For example, Hameed *et al.* (2014) found that biochar application caused tremendous increase in urease activity, microbial biomass-C & -N, total organic C and CEC. Kamal (2014) reported that application of biochar alone or in combination with phosphorus significantly increased microbial population, microbial biomass-C, microbial biomass-N and microbial biomass-P, as well as enzymatic activities such as urease and phosphatase activity. Kolb *et al.* (2009), Anderson *et al.* (2011) and Lehmann *et al.* (2011) reported that changes in soil properties with biochar in turn differentially influenced microbial activity and



community structure. Kolton *et al.* (2011) and Graber *et al.* (2010) established that changes in soil microbial communities bring about changes in nutrient transformations which can have impact on crop growth. Our results are however contrary to the belief that biochar use as soil amendments can increase C storage (Woolf *et al.*, 2010) and hence mitigate CO<sub>2</sub> emission. This may be possible in long-term but we measured CO<sub>2</sub> within 10 days after biochar amendment. Moreover, CO<sub>2</sub> evolution also

the contribution of C to atmosphere generally declined with increasing levels of biochar application. These results are in line with the findings of several studies who observed decreased CO<sub>2</sub> evolution from soil with biochar application (Egamberdieva and Wirth, 2015; Yao *et al.*, 2015).

### Soil EC

The results obtained on soil EC as influenced by different levels of biochar are presented in Table 4. The

**Table 3 Percent C of added biochar evolved as CO<sub>2</sub> during 10 days of incubation**

Biochar applied (t ha <sup>-1</sup> )	Biochar C* (kg ha <sup>-1</sup> )	CO <sub>2</sub> evolved in 10 days (mg kg <sup>-1</sup> )	C evolved as CO <sub>2</sub> from biochar (mg kg <sup>-1</sup> )	C evolved as CO <sub>2</sub> from biochar (kg ha <sup>-1</sup> )	%C of biochar evolved as CO <sub>2</sub> in 10 days
0	-	697	-	-	-
5	2890	789	25	50	1.74
10	5780	873	48	96	1.66
20	11560	871	47	94	0.82

\* C content in biochar 578 g C/kg biochar (Arif *et al.*, 2016)

**Table 4: Effect of biochar on soil electrical conductivity during 50 days of incubation period**

Biochar level (t ha <sup>-1</sup> )	Incubation period (days)			
	0	5	10	50
	Soil EC (dS m <sup>-1</sup> )			
0	1.00b*	1.06b	1.07b	0.92a
5	1.06b	1.12ba	1.11a	1.12a
10	1.19a	1.15a	1.25a	1.22a
20	1.29a	1.27a	1.31a	1.25a

**Table 5: Effect of biochar on soil pH during 50 days of incubation period**

Biochar level (t ha <sup>-1</sup> )	Incubation period (days)			
	0	5	10	50
0	7.27c*	7.22c	7.33b	7.54b
5	7.56b	7.45b	7.56a	7.55b
10	7.80a	7.58ab	7.62a	7.67ab
20	7.85a	7.65a	7.49a	7.79a

\*Means followed by different letter(s) within columns are significantly different (P<0.05)

depends on temperature of biochar preparation. A number of previous studies have shown highly variable CO<sub>2</sub> production from soils amended with biochars produced at temperature ranging from 350 °C to 850 °C (Fabbri *et al.*, 2013; Malghani *et al.*, 2013).

Table 3 represents the evolution of C as CO<sub>2</sub> from the applied biochar C. The data revealed that although the total CO<sub>2</sub> evolution increased with increasing levels of biochar, the % C evolved as CO<sub>2</sub> of the added biochar C decreased with increasing levels of biochar C during 10 days of incubation. The data showed that %C of biochar evolved as CO<sub>2</sub> in 10 days was 1.74% with 5 t, 1.66% with 10 t and 0.82% with 20 t ha<sup>-1</sup> of biochar application suggesting that

results showed that the effect of biochar on soil EC was significant (P<0.05%) during all incubation periods. The results were significant (P<0.05) at day 0, 5, 10 and 50 days of incubation periods. The soil EC generally increased with increasing levels of biochar application. The soil EC ranged from 1.00 in the control to 1.29 dS m<sup>-1</sup> in treatment receiving maximum biochar at 20 t ha<sup>-1</sup> at day 0. The corresponding soil EC values were 1.06 dS m<sup>-1</sup> in soil with no biochar to 1.27 dS m<sup>-1</sup> in soil receiving biochar at 20 t ha<sup>-1</sup> at day 5. At day 10, soil EC ranged from 1.07 dS m<sup>-1</sup> in the control to 1.31 dS m<sup>-1</sup> in soil with biochar at 20 t ha<sup>-1</sup>. After 50 days of incubation period, the soil EC was 0.92 dS m<sup>-1</sup> in the control to 1.25 dS m<sup>-1</sup> in soil with biochar at 20 t ha<sup>-1</sup>.



These results suggested that the effect of biochar on soil EC was significant during all incubation periods and effect increased with increasing levels of biochar application. The increase in soil EC with biochar amendments could be due to the presence of salts in biochar. Previous studies have also shown that biochar increased soil electrical conductivity (EC) and pH (Liang *et al.*, 2006; Gundale and DeLuca, 2006; Warnock *et al.*, 2007). The effect, however, varied with salt contents of biochar as biochar characteristics are highly variable (Spokas, 2010). For example, biochar produced from switchgrass and corn stover, under similar temperature, had lower aromatic C and high ash contents than those produced from woody materials such as red oak and wood wastes (Brewer *et al.*, 2011).

### Soil pH

The results obtained on soil pH as influenced by different doses of biochar during 50 days of incubation period are presented in Table 5. The results showed that biochar application caused considerable increase in soil pH immediately after its application (i.e., at 0 day). The soil pH increased with increasing levels of biochar at day 0. The effect of biochar on soil pH maintained during later incubation periods. Moreover, the increase in soil pH was generally associated with the levels of biochar applied as increasing values were noticed with increasing levels of biochar. Our results indicated that maximum increase of 8.0% in soil pH was noticed with biochar at 20 t ha<sup>-1</sup> compared to 7.3% increase with 10 t and 4% with 5 t biochar ha<sup>-1</sup> during 0 day of incubation period. At the day 5, the maximum increase of 5.96% in soil pH was observed with biochar level of 20 t ha<sup>-1</sup>. Similarly, the maximum increase in soil pH of 3.96% was observed in treatment receiving biochar at 10 t ha<sup>-1</sup> during 10 days. Whereas the maximum increase in soil pH of 3.31% was noted with biochar at 20 t ha<sup>-1</sup> during 50 days of incubation period. The results further showed that there was a decreasing trend in soil pH in all treatments with increasing incubation period. It was also observed that the decrease in soil pH was more evident during early days of incubation compared with later incubation period.

These results suggested that biochar application caused considerable increase in soil pH immediately after its application but the increase was not sustained at same extent during later incubation periods. Still soil pH was somehow greater in biochar treatments and the increase in soil pH was generally correlated with increasing level of biochar. Contrary reports have been obtained for the effect of biochar on soil pH in published literature. The application of biochar may increase or decrease soil pH, depending mainly on the salt contents of the biochar used.

The pH of biochars may be as low as 4 to as high as 12, depending on the source of biochar, pyrolysis temperature and extent of oxidation (Cheng *et al.*, 2006; Lehmann, 2007; Chan and Xu, 2009). Aslam *et al.* (2014) and Khalid *et al.* (2014) reported that biochar had both physical and chemical effects on soils, for example, on soil pH, soil structure, and the availability of micronutrients. Yuan *et al.* (2011) reported that biochar from legume materials increased soil pH much compared to biochars from non-legume materials.

### Conclusion

This study has shown that biochar application substantially enhanced microbial activity which resulted in liberation of large amount of CO<sub>2</sub> during short incubation period. Moreover, biochar application also caused considerable increase in soil EC and pH during short-term incubation. However, %C of biochar evolved as CO<sub>2</sub> during 10 days of incubation generally declined with increasing levels of biochar carbon.

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