Acta fytotechn zootechn, 20, 2017(4): 72–77
http://www.acta.fapz.uniag.sk

Original Paper

Effect of biochar on soil CO_2 production

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Article Details: Received: 2016-06-13 | Accepted: 2016-12-13 | Available online: 2017-12-31

http://dx.doi.org/10.15414/afz.2017.20.04.72–77

The study focuses on looking for answers to the following questions: 1. Is biochar application a suitable solution for reducing CO_2 emissions? 2. What application rate significantly reduces CO_2 production to the atmosphere? 3. Does have the application of enriched biochar a justification in relation to reducing CO_2 production? The experiment was established on Haplic Luvisol at the experimental site of SUA in Nitra (Dolná Malanta), where we measured CO_2 emissions from the soil to the atmosphere under the following treatments: different rates (0, 10, 20 t ha^{-1}) of pure biochar (B0, B10 a B20) and enriched biochar (EB10, EB20) combined with different levels of mineral nitrogen at doses of 0, 40 and 80 kg ha^{-1} (N0, N40, N80). Overall, the average values of CO_2 emissions were lower by 19.8%, 13.3%, 12.9%, 9.4% and 8.7% in B10N0, B20N40, B20N0, B20N80 and B10N40 treatments as compared to B0N0 (control) during the studied period. On the other hand, the average values of CO_2 were higher by 20% in B10N80 treatments as compared to control (B0N0). Application of enriched biochar whether individually (EB10N0, EB20N0) or with additional N (EB10N40, EB20N40, EB10N80, EB20N80) increased average CO_2 by 29.7%, 34.6%, 36.0%, 44.9%, 45.8% and 53.6% as compared to control (B0N0). The cumulative CO_2 emissions for the whole studied period (2014) were in the following order from the lowest one B10N0 < B20N0 < B20N40 < B20N80 < B10N40 < B0N0 (control) < B10N80 < EB20N40 < EB20N80 < EB10N80 < EB20N0 < EB10N0 < EB10N40.

Keywords: biochar, enriched biochar, N-fertilization, CO_2 emission

1 Introduction

Concentration of atmospheric CO_2 increased from 280 ppm before the industrial revolution to today's 380 ppm and it is expected to increase to 440–660 ppm by 2050 (Juma, 1994). Increase of CO_2 concentration in the atmosphere led to the development of different scenarios, estimates of impacts of global changes on ecosystems productivity, which were also presented at the recent (2015) Climate Change Summit in Paris. The participants agreed on an urgent solution of the situation, since due to increased production of greenhouse gases from industrial and agricultural production causing the global averaged land and ocean temperature on the Earth warming of 0.85 °C (0.65 to 1.06) over the period 1880 to 2012, which could have fatal impacts in the future (IPCC, 2014).

Greenhouse gases (CO_2, N_2O and methane) in the atmosphere are involved in global warming. Global soil respiration contributes by 60 Gt C per year to the atmosphere. This flux has been almost balanced with photosynthesis in the past (Juma, 1999). Plant biomass contains 25% and soil organic matter contains up to 75% of total carbon in terrestrial ecosystems (Lal, 2008). Since there is well known effect of the soil organic matter transformation on CO_2 in the air, that is absorbed by plants from the air through photosynthesis. It is very important to keep the balance between these both processes. Increased CO_2 emissions to the atmosphere may affect this balance. Agricultural sector is an important emission producer (Bielek, 2001). Released CO_2 from the soil may reach a high values. These are hundreds of kilograms, up to several tons per hectare per year (Anderson, 1995). As a consequence of the expected increase in the atmospheric CO_2, the interest of environmentalists to reduce CO_2 emissions from soil and to increase C stock in soil (Gregorich et al., 1998) is growing. More CO_2 can be released from agricultural used soils than from other soils. More CO_2 is produced in fertilized soils than in non-fertilized. Dry soils after subsequent increase of soil moisture (after rain) release more CO_2 than not dried soils and more productive soils release more CO_2 as compared to less productive soils (Reicosky and Lindstrom, 1995; Pascual, et al., 1998). For this reason, it is necessary to focus on increase of soil fertility, in particular through increase of soil organic matter, as it is known its beneficial effect on the production capacity of the soil. There has been recorded

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a steady decline in livestock population over the last two decades in the SR, which has led to a decline in organic fertilizer production with a consequent disturbance of the balance of the organic matter on the agricultural soils. From the point of view of reducing CO_2 from agriculture, the equal balance of organic substances has an essential importance and so the new resources must be looked for. One of the possible and innovative solutions could also be the application of biochar, which is a significant source of organic carbon (Fischer and Glaser, 2012). Over the last decade, biochar mainly due to its positive effects deserve the attention of agricultural practice. Applied biochar to soil improves soil chemistry (Jeffery et al., 2011), increases soil sorption capacity (Yuan and Xu, 2012; Heitkötter and Marschner, 2015), increases the soil organic carbon content (Šimanský, 2016) and its retention in the water-stable aggregates (Šimansky et al., 2017). Biochar increases soil water retention capacity, total porosity and reduces values of soil bulk density (Kammanm et al., 2011). The biochar particles pool with soil particles, resulting in stable soil aggregates and a favorable structural state (Jien and Wang, 2013).

Based on the above mentioned statements, our study focused on looking for answers to the following questions: 1. Is application of biochar to Haplic Luvisols (the most intensive agricultural used soils in the Slovak Republic) a suitable solution in terms of reducing CO_2 emissions? 2. What application rate significantly reduces CO_2 production to the atmosphere? 3. Does have the application of enriched biochar a justification in relation to reducing CO_2 production?

2 Material and methods

The field experiment was established at the experimental site of Slovak University of Agriculture (Malanta) in the Nitra region of Slovakia (lat. 48° 19´ 00´´; lon. 18° 09´ 00´´). The study covered the period from March to November 2014, taking in the whole growing season of spring barley (*Hordeum vulgare* L.). The entire experimental field was plowed prior to setting up the experiment, followed by randomly allocating treatments and finally by biochar and fertilizer application to the soil surface and their immediateincorporation into the 0–10 cm soil layer using a combinator. Spring barley was planted on 11th March 2014 at a commercial seed density of 200 kg ha^{-1}. The soil before experiment was classified as Haplic Luvisol and in A horizon contained on average 9.13 g kg^{-1} of soil organic carbon and had on average slightly acid pH (pH_{KCl} = 5.71). The site belongs to a very warm agro-climatic region with average annual temperature ≥10 °C with precipitation being 550 mm (30 year climate normal). The mean air temperature and rainfall in 2014 was 10.3 °C and 640.8 mm, respectively.

Experiment included following treatments: 1. B0N0 – no biochar, no N fertilization, 2. B10N0 – biochar at rate of 10 t ha^{-1}, 3. B20N0 – biochar at rate of 20 t ha^{-1}, 4. B10N40 – biochar at rate of 10 t ha^{-1} with 40 kg N ha^{-1}, 5. B20N40 – biochar at rate of 20 t ha^{-1} 40 kg N ha^{-1}, 6. B10N80 – biochar at rate of 10 t ha^{-1} with 80 kg N ha^{-1} and 7. B20N80 – biochar at rate of 20 t ha^{-1} with 80 kg N ha^{-1}, 8. EB10N0 – enriched biochar with N (nitrogen added to biochar after its production) at rate of 10 t ha^{-1}, 9. EB20N0 – enriched biochar with N at rate of 20 t ha^{-1}, 10. EB10N40 – enriched biochar with N at rate of 10 t ha^{-1} with another additional 40 kg N ha^{-1}, 11. EB20N40 – enriched biochar with N at rate of 20 t ha^{-1} with another additional 40 kg N ha^{-1}, 12. EB10N80 enriched biochar with N at rate of 10 t ha^{-1} with another additional 80 kg N ha^{-1}, 13. EB20N80 – enriched biochar with N at rate of 20 t ha^{-1} with another additional 80 kg N ha^{-1}.

The biochar was produced by pyrolysing paper fiber sludge and grain husks (1 : 1 w/w) (company Sonnenerde, Austria). Biomass was pyrolysed at 550 °C for 30 minutes in a Pyreg reactor (Pyreg GmbH, Dörth, Germany). Nitrogen enriched biochar mixed with compost (EB) was produced by composting biochar together with the compost in ratio 50 : 50% v/v (30 : 70% w/w) with spraying 10% ammonium sulfate liquid in ratio of 800 liters to 1 ton of biochar before mixing with the pile of input organic material for composting. Nitrogen in all fertilized treatments was in the form of Calcium-ammonium nitrate (LAD 27).

The soil surface CO_2 flux was measured weekly in all treatments during the whole studied period using closed chamber technique. The metal collar frame was inserted 10 cm deep into the soil in every plot and left undisturbed until harvest/disking occasion. On every gas sampling, the chamber (30 cm in diameter and 25 cm in height) were water sealed onto bottom collars and gas samples (20 mL) were collected through tube fittings (sealed with septum) at 0, 30 and 60 min after chamber deployment using an air-tight syringe (Hamilton) and transferred to pre-evacuated 12 mL glass vials (Labco Exetainer). Gas samples were analyzed for CO_2 using a gas chromatograph (GC-2010 Plus Shimadzu) equipped with a thermal conductivity detector. The GC was calibrated using 3 certified standard gas mixtures (CO_2, N_2O and N_2) in the expected concentration ranges. CO_2 fluxes between soil/crop and atmosphere were calculated from the change of concentration during the chamber closure using a linear approach.

3 Results and discussion

The daily soil CO_2 dynamics are shown in Figure 1 A, B, C. The application of the tested biochars has significantly increased the production of CO_2 in the corresponding treatments. We must emphasize that this significant increase from the beginning of the measurements was also caused by addition of N-fertilization, through which the negative C : N ratios of biochar and crop residues present at the field site during experiment set-up were eliminated. There was observed a significant increase in CO_2 production starting from the first measurement day (66 days from the beginning of the year) at all treatments (Figure 2). The most significant CO_2 production of this day was found at both application rates of enriched biochar, with an average increase of CO_2 being 89% and 41% at 10 and 20 t ha^{-1} of enriched biochar, respectively as compared to control. It can be connected with intensive biological activity in these treatments. Enriched biochar included more labile carbon and nitrogen forms. Generally, biochar is very stable compared to other organic matter amendments (Lopez-Capel et al., 2016). Biochar, due to its mostly inert nature, is often applied to soils in conjunction with organic or mineral fertilizers (Laird et al., 2010) or biochar producers enrich themselves with nutrients and it is then reflected in intensive mineralization processes of biochars and production of higher amount of CO_2.

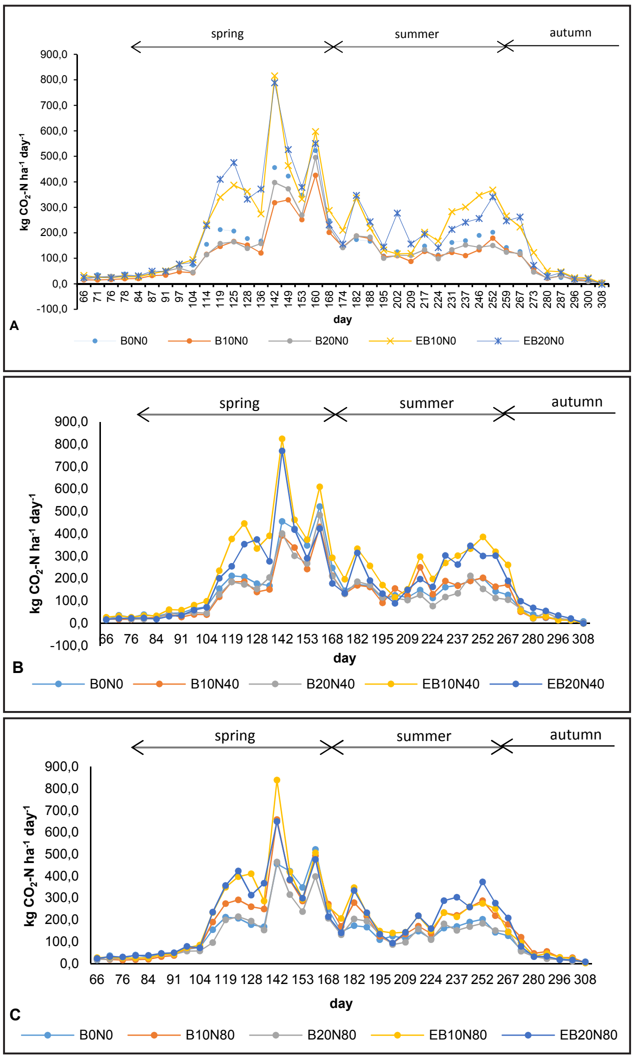

Figure 1 CO_2 emissions A) in different rates of pure and enriched biochar treatments, B) in biochar with 40 kg N ha^{-1} and C) in biochar with 80 kg N ha^{-1}

The soil CO_2 emissions during the next period varied in all treatments and almost all treatments showed clear spring and autumn maximum of CO_2 production (mean: in spring at day 142 and in autumn at day 259). The CO_2 dynamics had polynomic pattern over the studied period in all treatments. However, when comparing the average increase in CO_2 production in relation to application of biochar and enriched biochar both combined with N fertilizers with the control, we always found that the CO_2 emissions after application of 20 t ha^{-1} of biochar or enriched biochar were lower than after application of lower rates (10 t ha^{-1}). Moreover, the period of higher CO_2 production was shorter in comparison with the period when 10 t ha^{-1} of biochar was applied (Figure 2). On the other hand, a more significant effect on CO_2 release during the studied was observed due to applied enriched biochar to the soil, with stronger effect being found at the application rate of 10 t ha^{-1}.

The wide variability of CO_2 in soils is presented in the literature (Alvarez et al., 1995; Reicosky and Lindst, 1995; Duiker and Lal, 1999; Popelarova et al., 2002; Dukes and Hungate, 2002; Jacinthe et al., 2002). Differences in dynamics of CO_2 release are attributed to the different management practices, climatic conditions and soils. Fertilization is an important factor influencing CO_2 production. Generally, more CO_2 is produced in fertilized soils than in non-fertilized soils (Reicosky and Lindstrom, 1995; Pascual, et al., 1998). Biochar is considered as soil additive, which contributes to an increase of carbon sequestration (Singh and Cowie, 2014; Han et al., 2016), through decrease of CO_2 production. Overall, the average amount of released CO_2 over the reference period was significantly affected by the application of different rates of biochar (Table 1). Average

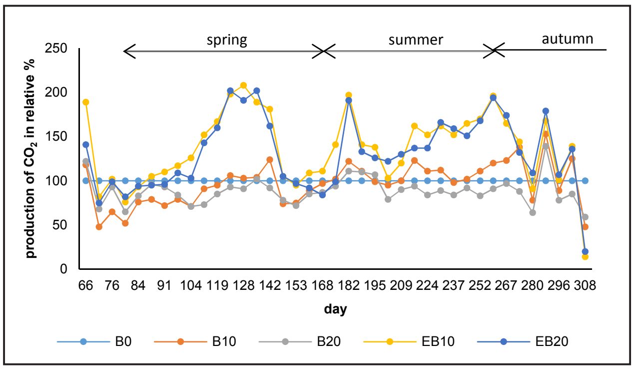

Figure 2 Relative effects of pure and enriched biochars on CO_2 emissions

values of CO_2 emissions over the entire period were lower by 9.8%, 13.3%, 12.9%, 9.4% and 8.7% in treatments B10N0, B20N40, B20N0, B20N80 a B10N40, respectively, as compared to B0N0 (control). On the other hand, the average values of CO_2 were higher by 20% in B10N80 treatment as compared to control (B0N0). Application of enriched biochar, whether alone (EB10N0, EB20N0) or combined with another additional N (EB10N40, EB20N40, EB10N80, EB20N80) increased the average values of CO_2 emissions over the entire period by 29.7%, 34.6%, 36%, 44.9%, 45.8% and 53.6% as compared to B0N0 treatment (Table 1). Release of CO_2 into the atmosphere is one of the ways through which carbon is lost from the soil stock. The amounts of released CO_2 from the soil can be relatively high reaching values from hundreds of kilograms up to several tons per hectare per year (Anderson, 1995). According to Bielek (2001), the average loss CO_2 from 1 hectare of soil in Slovakia is 4.2 t CO_2 $year^{-1}$, which is 1.15 t ha^{-1} of C.

Table 1 Average daily CO_2 production from 1 hectare in relation to different types and rates of biochars with or without N fertilization

Treatments	Average daily CO_2 production ($kg\ ha^{-1}\ day^{-1}$)
B0N0	146b
B10N0	117a
B20N0	127a
B10N40	133ab
B20N40	126a
B10N80	175c
B20N80	132ab
EB10N0	211efg
EB20N0	212fg
EB10N40	223g
EB20N40	189cd
EB10N80	198def
EB20N80	196de

Different letters between lines (a, b, c….) indicate that treatment means are significantly different at *P* <0.05 according to LSD test

Table 2 Changes in dynamic of CO_2 production

Control	$y = 1183.4x – 5737.6$	$R^2 = 0.9669$
B10N0	$y = 960.32x – 5064.6$	$R^2 = 0.9656$
B20N0	$y = 1044.1x – 5216.8$	$R^2 = 0.9632$
EB10N0	$y = 1704.5x – 8659$	$R^2 = 0.9731$
EB20N0	$y = 1713.4x – 8248.1$	$R^2 = 0.9706$
B10N40	$y = 1094.3x – 6188.8$	$R^2 = 0.9699$
B20N40	$y = 1038.9x – 5232.2$	$R^2 = 0.9652$
EB10N40	$y = 1818.3x – 9131.8$	$R^2 = 0.973$
EB20N40	$y = 1514.5x – 8028.4$	$R^2 = 0.9748$
B10N80	$y = 1417.7x – 7381.9$	$R^2 = 0.9726$
B20N80	$y = 1072.8x – 5516.4$	$R^2 = 0.9702$
EB10N80	$y = 1607.7x – 7695.8$	$R^2 = 0.9693$
EB20N80	$y = 1568.5x - 7742$	$R^2 = 0.9762$

The cumulative CO_2 emissions were calculated (Figure 3 A, B, C) including their linear, logarithmic, power and exponential models. According to the values of coefficients of determination (R^2), the linear model was the best to express the CO_2 emissions (Table 2). The results show that the application of enriched biochar applied to the soil separately alone or with additional nitrogen significantly increased the CO_2 production compared to the control soil. Opposite was found after application of biochar alone or combined with N-fertilization whit lower cumulative CO_2 emissions being observed as compared to the control soil. The decisive effect on cumulative CO_2 production in case of just biochar was an

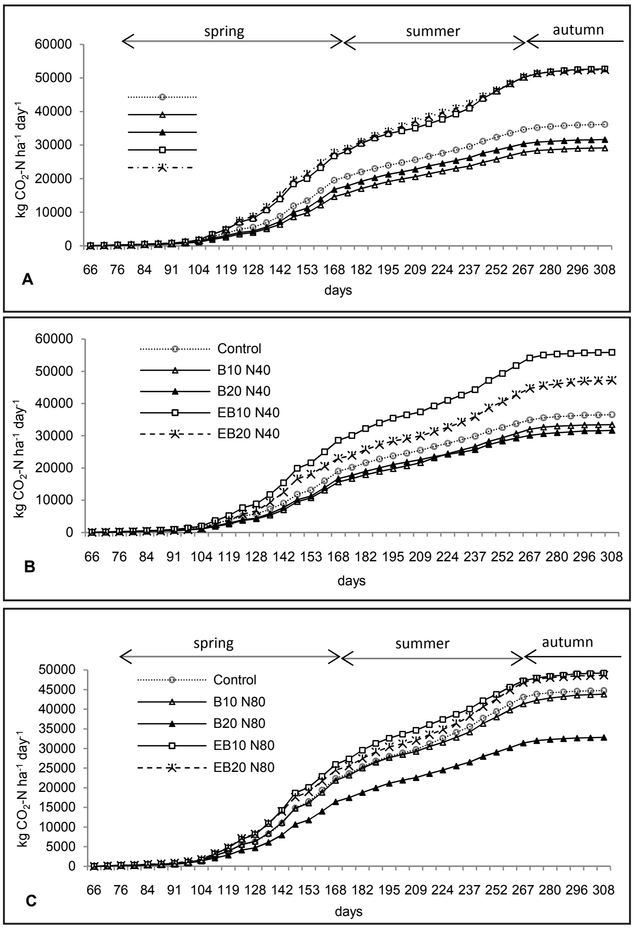

Figure 3 Cumulative fluxes efects A) pure and enriched biochar rates B) biochars with 40 kg N ha^{-1} and C) biochars with 80 kg N ha^{-1} on CO_2 emissions

added N and thus higher CO_2 production cumulatively increased in B10N80 than in B20N80 treatments but also in B10N40 than B20N40. In the case of a lower dose of enriched biochar (10 t ha^{-1}), the reaction of the added N fertilization was different. There was found a significant increase in cumulative CO_2 production at the 40 kg of N applied. Opposite was found in case of 80 kg N ha^{-1} where we observed a decrease of cumulative CO_2 production as compared to the EB10N0 treatment. In the case enriched biochar applied at higher rate (20 t ha^{-1}), we observed a decrease in cumulative CO_2 production at both doses of N fertilization.

4 Conclusions

Applied biochar at both application rates but also in combination with 40 kg N ha^{-1} had a significant effect on decrease of CO_2 production. The combination of a lower biochar rate together with a higher nitrogen dose proved to be not suitable, because this treatment significantly increased the CO_2 production. Also enriched biochar, whether applied alone or with another additional N-fertilizer significantly increased the amount of CO_2 produced.

Our results show that pure biochar appears to be an effective tool for decreasing CO_2 emissions to the atmosphere, which contributes to an increase of carbon sequestration in the soil. On the other hand, the application of enriched biochar is not reasonable in terms of reducing CO_2 production from the soil as a significant greenhouse gas, which might be its problem when adopting to agricultural practice.

Acknowledgments

This study was supported by Slovak Grant Agency VEGA, No. 1/0604/16 and 1/0136/17 and Slovak Research and Development Agency under the contract No. APVV-15-0160.

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