TESTING BIOCHAR AS A POSSIBLE WAY TO AMELIORATE SLIGHTLY ACIDIC SOIL AT THE RESEARCH FIELD LOCATED IN THE DANUBIAN LOWLAND

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One-year field experiment with spring barley (*Hordeum vulgare* L.) was carried out to evaluate the effect of biochar amendment on the pH of Orthic Luvisol at the research site located in western Slovakia (lat. 48° 19´ 00˝; lon. 18° 09´ 00˝). Biochar with higher pH (8.8) was applied to slightly acidic soils with the initial pH at 5.6. The field experiment consisted of control, 10 and 20 t ha^{-1} (B0, B10, B20) of biochar application to soils combined with three levels of nitrogen fertilization (0, 40 and 80 kg N ha^{-1}) (N0, N40, N80). The soil pH (KCl) at depth 0–10 cm was measured once a month (March – October, 2014). Application of both biochar rates (10 and 20 t ha^{-1}) increased pH (in all months) with the magnitude of 0.13–1.09 units in all three fertilization levels (0, 40 and 80 kg N ha^{-1}) compared to the control one. However, the significant increase ($p < 0.05$) was found only in the treatment B10N0 (3 of 8 measurement events) and B20N0 (6 of 8 measurements) when no nitrogen was applied and in the treatment B20N80 (5 of 8 measurements) when 80 kg of nitrogen was applied. According to this, the biochar incorporation to soil can be suggested as a possible way to ameliorate soils and may be effective in increasing soil pH.

Keywords: biochar, soil pH, Orthic Luvisol, agro-ecosystem

Biochar (black carbon) refers to the aromatic carbon materials produced by pyrolysis of biomass (heating in an oxygen-limited environment at temperatures 400–900 °C). There have been reported a lot of positive impacts of biochar as a soil amendment such as mitigating climate change (Lehmann, 2007) through increasing soil carbon storage (Fowles, 2007) while decreasing direct GHG emission and improving soil fertility and crop productivity (Glaser et al., 2001; Major et al., 2010a; Lehmann, 2007; 2008).

In balance to this, biochar application has been shown to have barriers, as well. The barriers are the availability of biochar to farmers (no biochar producers in Slovakia up to now) and, a very important one, the legislative barrier that prevents biochar being applied to land (e.g. in Europe). The lack of biochar inclusion in current agricultural policy is due to the major uncertainty surrounding the long term behaviour of biochar, its potential negative impacts on soil quality, and the fact that it cannot realistically be removed from soil after application.

One of the very important soil chemical properties is soil pH. The pH of the soil affects the solubility of the substances in the soil, thus their availability for living organisms. The potential liming effect of agricultural residues and other plant materials has been reported (Noble et al., 1996; Tang and Yu, 1999). Decarboxylation of organic anions (as indicated by excess cations or ash alkalinity) of added plant residues consumes protons and thus increases the soil pH (Yan et al., 1996; Tang and Yu, 1999). Besides this carbon (C) transformation process, nitrogen (N) transformation is thought to be the other main process that has effect on the

soil pH fluctuation (Xu and Coventry, 2003; Xu et al., 2006). Ammonification of residue organic N consumes protons and causes soil pH to increase, whereas nitrification of mineralized residue nitrogen releases protons and causes soil pH to decrease. Small increases in soil pH following crop residue addition to soil may act to stimulate nitrification and counteract the alkalinity produced. Hence, addition of offsite liming materials, such as biochar, may offer a possible solution to manage acidity of the agricultural soils.

Biochar application to soils may have agronomic benefits such as neutralizing soil pH and providing nutrients (Jeffery et al., 2011; Yuan et al., 2011). The pyrolytic process of biochar production converts biomass acids into the bio-oil component and the alkalinity is inherited by the solid biochar (Laird et al., 2010). Producing biochar at different temperatures causes the increases of their alkalinity with increasing charring temperature (Yuan et al., 2011c). The pH of biochar is influenced by the type of feedstock used, production temperature and production duration. The effectiveness of liming materials is determined by the pH buffer capacity of the soil and neutralizing values of the amendments. The effect of biochar on increase of pH in highly weathered tropical soils had been confirmed (Glaser et al., 2001; 2002). Other studies also showed that the alkalinity of biochars was a key factor affecting their liming potential (Yuan et al., 2011b) and also showing an increase of pH when biochar with higher pH value was applied to the acidic soil (Yuan et al., 2011c) with clear increase of soil pH with increasing biochar application rates (Yuan et al., 2011a). The effect of biochar on soil pH change and mode

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of action need to be studied thoroughly using various biochars (different in type of feedstock used, production temperature and production duration) in various soils of different agro-ecosystems.

The objective of this study was to evaluate the effect of biochar amendment on the pH of slightly acidic Orthic Luvisol at the research site located in western Slovakia. We hypothesized that the biochar with higher pH (8.8) has a strong ability to increase the soil pH of the studied soil with the initial pH at 5.6.

Material and methods

Field site and experimental design

This field trial was conducted at the experimental site of SAU-Nitra (Nitra – Malanta) in the Nitra region of Slovakia (lat. 48° 19´ 00´´; lon. 18° 09´ 00´´) during March – October, 2014. The soil type is classified as Orthic Luvisol (FAO, 1998). The average annual air temperature was 10.3 °C and annual precipitation was 640 mm during the studied year.

Soil samples (0–10 cm) from 10 random locations (experimental field trial) were taken on 4th of March to get an initial value of soil pH (in KCl) before lying out of experiment (7th of March), applying biochar (10th of March) and sowing the crop (11th of March). The replicated ($n = 3$) trial plots (4 × 6 m) were laid out in a randomized block design and planted with spring barley (*Hordeum vulgare* L.) in the experimental field that has been used for crop production over the last several years. The experiment (3 replicates) consisted of

following treatments separated by a protection row 0.5 m in width (Figure 1):

T1. B0N0 – soil
T2. B10N0 – soil + biochar (10 t ha^{-1})
T3. B20N0 – soil + biochar (20 t ha^{-1})
T4. B0N40 – soil + fertilizer (40 kg N ha^{-1})
T5. B10N40 – soil + fertilizer (40 kg N ha^{-1}) + biochar (10 t ha^{-1})
T6. B20N40 – soil + fertilizer (40 kg N ha^{-1}) + biochar (20 t ha^{-1})
T7. B0N80 – soil + fertilizer (80 kg N ha^{-1})
T8. B10N80 – soil + fertilizer (80 kg N ha^{-1}) + biochar (10 t ha^{-1})
T9. B20N80 – soil + fertilizer (80 kg N ha^{-1}) + biochar (20 t ha^{-1})

Biochar characterization and pH measurements

Biochar used for the field experiment was produced from paper fiber sludge and grain husks (1 : 1 w/w) (company Sonnenerde, Austria) by pyrolysis at 550 °C for 30 minutes in a Pyreg reactor (Pyreg GmbH, Dörth, Germany) (Table 1).

The soil pH (KCl) at depth 0–10 cm was measured once a month (March – October, 2014) in soil: 1 M KCl solution (1 : 2.5) following shaking suspension for 30 minutes using a pH meter (HI 2211, HANNA Instruments, RI, USA).

Statistical analysis

The statistical processing of the data included the determination of means and standard deviations. One-way
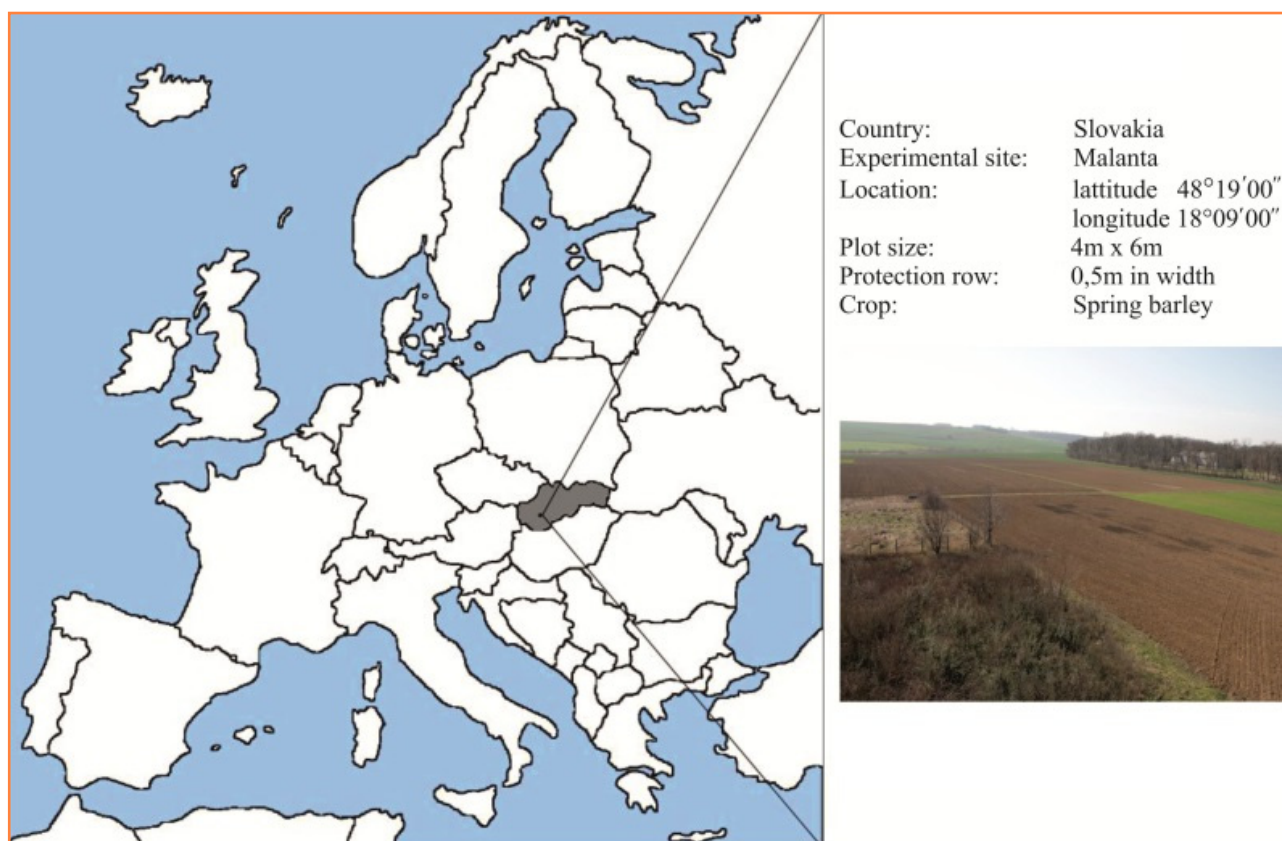

Figure 1   Field site and the aerial view on the field plots

Table 2   Basic chemical and physical properties of the biochar (biochar certificate Nr. 1013069001 provided by company Sonnenerde, Austria)

Biochar		
pH	KCl	8.8
Ca	g kg⁻¹	57
Mg	g kg⁻¹	3.9
K	g kg⁻¹	15
Na	g kg⁻¹	0.7
Total C	g kg⁻¹	53.1
Total N	g kg⁻¹	14
C/N	–	37.9
SSA	m² g⁻¹	21.7
Ash	%	38.3

analysis of variance (ANNOVA) at $p < 0.05$ was performed to examine the effect of biochar at different application rates on soil pH. Significant differences between means of three replications were identified using a least significant difference (LSD at $p < 0.05$) test using STATGRAPHICS Centurion statistical software.

Results and discussion

Figures 2–4 presents soil pH change of all treatments during the 8 month field experiment at the experimental site of SAU-Nitra (Nitra-Malanta) in the Nitra region of Slovakia. The average initial soil pH before applying biochar was 5.6.

Biochar applied at 10 and 20 t ha⁻¹ without mineral fertilizer application immediately increased soil pH (March measurements) by 0.35 and 0.59 unit for BC10N0 and BC20N0, respectively compared to control (BC0N0). This trend continued to the end of the experiment for both biochar treatments with the magnitude of soil pH increase in the order: BC0N0 > BC10N0 > BC20N0. Application of 10 t ha⁻¹ of biochar (B10N0) increased soil pH by 0.13–0.56 with significant increase ($p < 0.05$) found in May, July and September (3 of 8 measurement events) as compared to control. The magnitude of soil pH increase was even larger with the higher biochar application rate (B20N0) where the soil pH increased by 0.47–0.78 during all months with a significant increase ($p < 0.05$) from May to October (6 of 8 measurements). Comparison of the pH

values at the beginning and the end of the experiment (temporal change) within each treatment showed different results. The soil pH in control treatment (B0N0) in October was higher by 0.14 units compared to control value of soil pH at the beginning of experiment (March). Similar trend was found in the treatment B20N0 with higher pH in October by 0.04 units compared to pH value in March. Opposite was found in case of B10N0 where the soil pH in October was lower by 0.08 as compared to pH in March.

In the treatments with the medium level of N fertilization (40 kg N ha⁻¹) was found that the average soil pH immediately increased with similar trend to the end of the experiment as compared to biochar application rates (BC10N40, BC20N40) (Figure 3). However, there was not found any significant difference ($p < 0.05$) between both biochar treatments (BC10N40, BC20N40) as compared to the control (B0N40) during the whole studied period. Also, the magnitude of average soil pH increase was not always in the order: BC0N40 > BC10N40 > BC20N40 as it was found in the biochar treatments with no N fertilizer application (Figure 2 and 3). Application of both biochar rates (10 and 20 t ha⁻¹) increased soil pH by 0.43–0.85 and by 0.53–0.87 for B10N40 and B20N40, respectively as compared to B0N40. Temporal change of soil pH within treatments showed no change in the treatment B0N40 and B20N40 when comparing pH values of March and October. The soil pH in B10N0 in October was lower by 0.05 units compared to pH value in March.

In the treatments with the higher level of N fertilization (80 kg N ha⁻¹) it was found that the biochar applied at 10 and 20 t ha⁻¹ immediately increased soil pH (March measurements) by 0.66 and 0.93 unit for BC10N80 and BC20N80, respectively compared to BC0N80 (Figure 4). This trend continued to the end of the experiment for both biochar treatments with the magnitude of soil pH increase in the order: B0N80 > BC10N80 > BC20N80. Similar was found also in the treatments which were not fertilized. Application of 10 t ha⁻¹ of biochar increased soil pH by 0.49–0.67 with no significant increase ($p < 0.05$) found compared to control plots
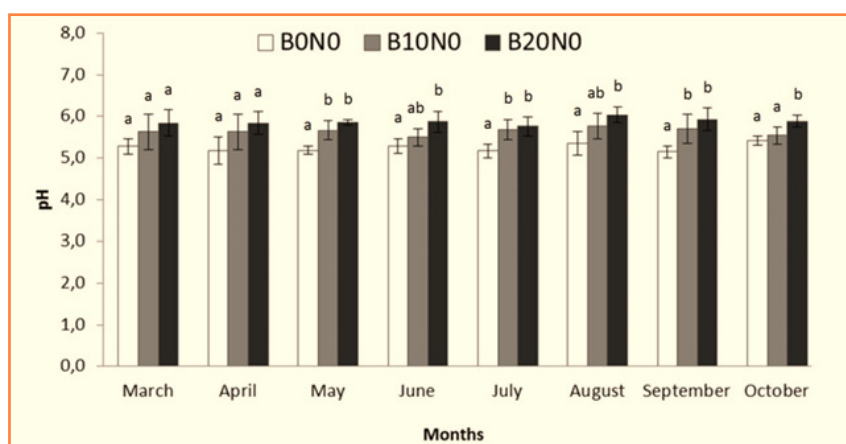

Figure 2   Soil pH during the field experiment (March – October, 2014) on Orthic Luvisol planted with spring barley amended with biochar and no nitrogen fertilizer in 2014 (± standard deviation, $n = 3$). Different letters indicate significant difference between treatments means by the LSD test ($p < 0.05$)
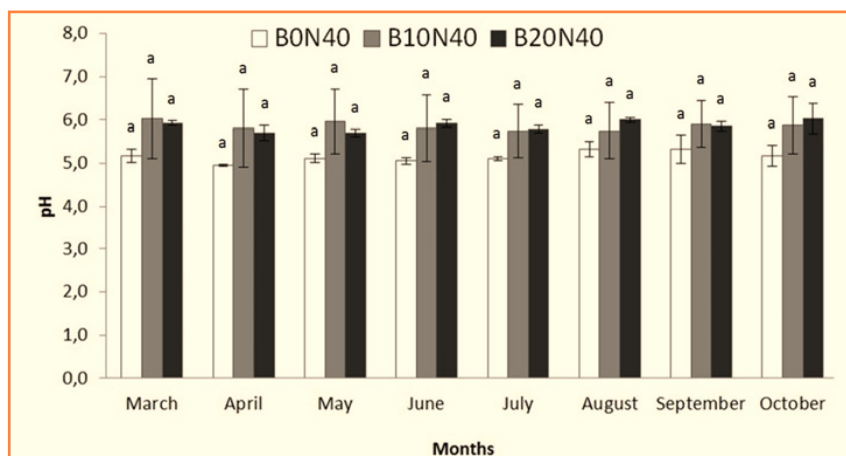
Figure 3   Soil pH during the field experiment (March – October, 2014) on Orthic Luvisol planted with spring barley amended with biochar and fertilized with 40 kg N ha^{-1} in 2014 (± standard deviation, n = 3). Different letters indicate significant difference between treatments means by the LSD test (p <0.05)
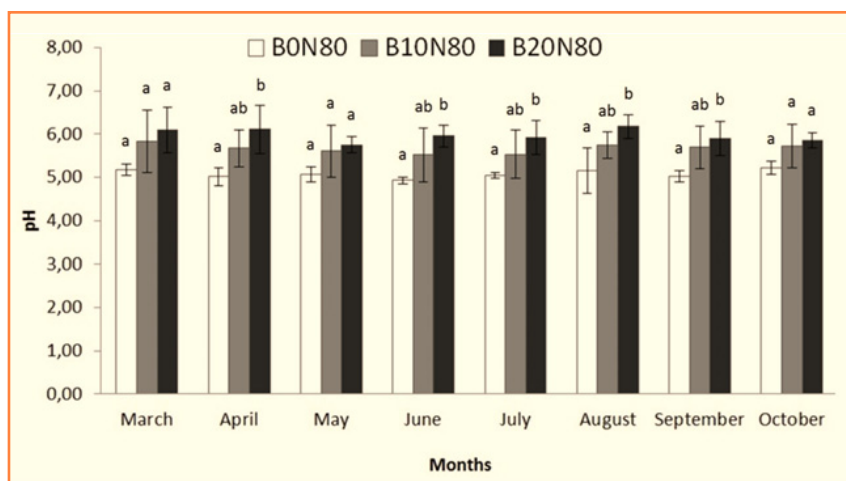

Figure 4   Soil pH during the field experiment (March – October, 2014) on Orthic Luvisol planted with spring barley amended with biochar and fertilized with 80 kg N ha^{-1} in 2014 (± standard deviation, n = 3). Different letters indicate significant difference between treatments means by the LSD test (p <0.05)

during the whole period. However, the magnitude of the increase was larger for the higher biochar application rate (20 t ha^{-1}) where the soil pH increased by 0.62–1.09 during all months with a significant increase (p <0.05) from April to September except of May (5 of 8 measurement events). Temporal change of soil pH within treatments showed that the soil pH in control treatment (B0N0) in October was higher by 0.05 units compared to the control value of soil pH at the beginning of experiment (March). Opposite was found in case of both biochar treatments. The soil pH in October was lower by 0.11 and 0.25 unit for BC10N80 and BC20N80,

respectively compared to pH values at the beginning of experiment.

Other scientific studies also showed an increase of pH when biochar with higher pH value was applied to the acidic soil (Yuan et al., 2011c) with clear increase of soil pH with increasing biochar application rates (Yuan et al., 2011a). In previous studies, the increase in soil pH caused by organic material amendment was mainly attributed to organic anions present in the materials, and this was indicated by the concentration of excess cations over inorganic anions, that is, ash alkalinity (Yan et al., 1996). Hence, after biochar addition into soil, organic anions can undergo

decarboxylation and consume protons. Additionally, organic anions and other negatively charged functional groups present in organic matter can undergo association reactions with H+ ions (Tang and Yu, 1999; Xu et al., 2006). Therefore, it is expected that in this study, both of these processes are likely to contribute to the increases in soil pH after biochar application.

Conclusions

According to evaluation of the data it can be concluded that incorporation of biochar to the slightly acidic soils was an effective way to increase soil pH up to at least 8 months after application in case of all biochar and fertilization treatments. Thus, our hypothesis that the biochar with higher pH (8.8) has a strong ability to increase the soil pH of the studied soil with the initial pH at 5.6 was confirmed. This indicates that a single biochar application may provide benefits at least over one year cropping season, however, long-term field studies are still lacking and needed to determine when a steady state is reached or if and when a decline starts to occur. The results also indicate that magnitude of soil pH would be increased by increasing biochar application rates, which was found in case of no nitrogen applied and in case of higher nitrogen application rate. Therefore, biochar could be suggested as a valuable tool for the management of agro-ecosystems and a plausible way to ameliorate soils and may be effective in increasing soil pH.

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