CARBON SEQUESTRATION VIA BIOCHAR APPLICATION INTO THE SOIL - SIMULATION OF THE LATE-PHASE EFFECT

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The application of biochar into the soil brings many advantages. Among other things, the storage of biochar in the soil has a global contribution: sequestration of carbon dioxide from the atmosphere. However, biochar loses its ability to directly stimulate microbial activity after remaining in the soil for an extended period, since the attractive substances in biochar that accompany the pyrolisys process will have been used up by the microbes. In this later phase, biochar mainly improves the physical characteristics of the soil; by this, it stimulates microorganisms indirectly and improves the fertility of the soil. In this paper, we describe the initial results of a pot experiment focused on late-phase biochar addition into the soil. Biochar that remained in the soil for many decades was simulated by the addition of pure activated carbon and by the addition of activated carbon combined with various doses of compost. The aboveground and underground production of biomass and the movement of nutrients in the soil were examined. The goal is to discover the relationship between the effect of stable and unstable biochar on the synergy of soil-plant-microorganism interactions.

Keywords: biochar, activated carbon, compost

INTRODUCTION

Biochar, i.e. a material created from biomass by slow pyrolysis (heating without the access of oxygen), is a highly stable material resistant to microbial decomposition. In recent years, biochar has become the centre of attention of a number of researchers from around the world, particularly due to two global issues: climate change and the need for a more sustainable soil management.

Biochar is a mixture of substances, mostly consisting of stable organic carbon which largely originates from anthropogenic CO_2. The elimination of future microbial oxidation of biochar presents an opportunity to reduce the content of CO_2 in the atmosphere, where it demonstrably influences climate change. The influence of biochar on greenhouse gases is summarized, for instance, in studies by Mukherjee et al. (2013, 2014). Biochar produced from residual or waste biomass is the only known feasible method of CCS (Carbon Capture and Storage); in some cases, carbon can remain in the soil for many centuries (Downie et al., 2009), (Lehmann et al., 2009).

Another benefit of applying biochar to the soil is the effect on sustainable soil management. Biochar improves the physicochemical properties of the soil in several ways: due to its porosity, it increases the soil's ability to retain moisture while also improving its aeration (decreases the bulk density of the soil) (Mukherjee et al., 2013). By retaining water, it also helps the soil retain the nutrients dissolved within. It can also chemically bond mineral substances and create organic mineral complexes. Its large surface area can be colonized by soil microflora which increases the cumulative surface area of interacting biological membranes. According to Prayogo et al. (2014), the application of biochar to the soil increases the quantity of microbial biomass, especially gram-negative bacteria and Actinomycetales. Biochar itself contains all the nutrients which were contained in the original biomass, and thus increases the nutrient content in the soil (Glaser et al., 2002). Unlike ash, which retains only the alkali (potassium, calcium, magnesium), biochar also contains phosphorus and sulfur.

In addition, Biochar has the effect of reducing the mineralization of nitrogen compounds (Prayogo et al., 2014). According to Prommer et al. (2014), the addition of biochar has decreased the rate of organic transformation of nitrogen by 50 to 80 %, but also more than doubled the rate of nitrification in nitrifying bacteria and Archaea. Xuet et al. (2014) state that the addition of biochar has accelerated the nitrification and denitrification processes and lead to an overall decrease of N_2O emissions, with the α diversity of communities (species diversity within one community or site) being significantly increased.

Aside from the above benefits, according to Brennan et al. (2014) and Ahmad et al. (2014), biochar reduces the bioavailability of contaminants in the soil. Brennan et al. (2014) compare in their study the application of activated carbon and biochar to the soil. After evaluating the data, they have arrived at the conclusion that the effect of both amendments on the soil was comparable. Therefore, the use of activated carbon as a replacement for biochar which has remained in the soil for a long period of time seems appropriate.

The majority of authors state the need for further research into biochar, especially regarding its long-term effects on the soil, before it can be more widely used in field conditions. It is thus the goal of this experiment to clarify the effects of biochar which has already been used microbially in the soil-plant-microbe system (late-phase biochar). For the simulation of biochar impoverished of nutrients, we used activated carbon. To answer the question of how biochar which has remained in the soil for a long period of time (several years) influences the movement of nutrients and water in the soil after application and thus affects the fertility of the soil, we performed and evaluated a pot experiment. In the experiment, activated carbon was applied along with different doses of compost, and a relation was sought between the experimental variants.

MATERIALS AND METHODS

Delimitation of the sampling site

Soil samples were taken from the vicinity of the Banín municipality. The municipality is located in the Pardubice region approximately 10 km south of Svitavy and ca 3 km northwest of Březová nad Svitavou. The entire site is located in the 2nd degree groundwater protection zone (GWPZ) Březová nad Svitavou. All sites of the GWPZ are counted among vulnerable areas (according to the nitrate directive, implementing regulation of Decree No. 103/2003 Coll.).

This location was selected due to the prevalent agricultural activity and also due to the fact that the site has long been studied by the Department of Agrochemistry, Soil Science, Microbiology and Plant Nutrition. Sampling was conducted in the cadastral territory of the Banín municipality. The local soil has undergone degradation via mineral plant nutrition. A plant supported by the application of mineral fertilizers is not forced to stimulate the soil environment by supplying organic substances to it, and thus allocates assimilates mainly to the production of aboveground material. The plant is thus also deprived of the protective function provided by microbial colonization. The use of mineral fertilizers supports organisms which have so far been limited due to insufficient nutrients, and other losses of organic material in the soil can occur due to the soil's mineralization and the absence of incoming organic matter, which causes further damage to the existing remnants of organic matter in the soil. The basic nutrients introduced into the soil and not used by the plants stimulate the activity of the microflora, which then only lacks one thing: the organic matter.

The sampling site consisted of brown earth with a soil substrate of mixed slope sediments. The locality of the cadastral territory Banín falls within the MT2 climate region, as does 20 % of the Czech Republic. It is a moderately warm and moderately humid region with average annual temperature of 7 – 8 °C and a total annual precipitation of 550 – 700 mm.year^{-1}.

Experiment design

The main aim of this study was to perform a laboratory pot experiment to confirm or disprove the above mentioned hypotheses. Eight variants repeated in fours have been created for the experiment. Into each plastic pot, a high-density polyethylene (HDPE) bag was inserted which was perforated to ensure that all the leachate water passes through a disc filled with mixed ion exchange resin located at the bottom of the pot. The discs have been placed at the bottom of the pots in order to capture the ammonia (NH_4^+ - N) and nitrate (NO_3^--N) nitrogen leaving the system. The experiment used a mixed ion exchange resin in a cation exchanger : anion exchanger ratio of 1 : 1. The experiment used AER type A520E (anion exchanger) and CER type C100E (cation exchanger) grains produced by Purolite. The discs were covered by a layer of send, which was then topped by soil with different admixtures based on the experiment variants listed in Figure 1:

Figure 1 Experiment setup

A1	Check (soil sample)
A2	Check (soil sample)
A3	Check (soil + activated carbon)
B1	Soil + activated carbon + 50 % of the recommended dose of compost
B2	Soil + activated carbon + 100 % of the recommended dose of compost
B3	Soil + activated carbon + 200 % of the recommended dose of compost
B4	Soil + activated carbon + 300 % of the recommended dose of compost
C1	Agroperlite + 100% of the recommended dose of compost

The recommended dose for compost, activated carbon and biochar was 50 t.hectar^{-1}; for agroperlite, a volume equivalent to the 50 t.hectar^{-1} dose of activated carbon was used.

All soil, biochar, activated carbon and compost samples have been sifted through a 5x5 mm grid sieve and have subsequently been homogenised. The activated carbon used had a particle size of 2.36-4.75 mm and consisted of coconut shells, with water content of max. 5 %, ash content of max. 5 %, bulk density of 500 ± 50 g.l^{-1} and a pH of 8-10. The "Black Dragon" compost used in the experiment had the following parameters: humidity 30-65 %, burnable material content min. 20 %, total nitrogen in dry matter min. 0.6 %, pH 6-8.5, unverifiable admixture content max. 2 % and C : N ratio max. 30. After the pots have been assembled, they were planted with *Lactuca sativa L.* Afterwards, the experimental pots were moved to a phytotron. The plants remained in the phytotron at a temperature of 20 °C and humidity of 78 % for 100 days with a circadian rhythm set to 16 hours of light and 8 hours of darkness. The experimental variants were irrigated throughout this period with equal amounts of water.

After the period ended, the experiment concluded and the experimental pots were disassembled in the laboratory. The aboveground and underground parts of the plant were separated and the disc with ion exchange resin was removed. The dry matter of the plant biomass was determined.

Ion exchange discs were dried at laboratory temperature and their content was transferred into plastic containers. Ammonia (NH_4^+ - N) and nitrate (NO_3^- - N) nitrogen was extracted from the ion exchanger structure using a NaCl solution of precise concentration. The plastic containers with ion exchangers were shaken for 1 hour on the laboratory shaker. The quantity of mineral nitrogen in each of the infusions was determined via a distillation-titration method based on Peoples et al. (1989). The distillation was performed using a Behr S3 unit and titration using an automated burette Titronic 96.

Statistical analysis

Potential differences in results were analysed by the one-way analysis of variance (ANOVA) in combination with the post-hoc Tukey´s test. All analyses were performed using the Statistica 12 software.

RESULTS

The main objective of this paper was to determine the hypothetical dose of compost which would correspond to the portion of freshly applied biochar which is easily accessible to microorganisms as a source of carbon and energy, and which is responsible for increased initial stimulation of the microbial activities in terms of soil fertility, yields and nitrogen loss.

Figure 2 Box plot - aboveground biomass

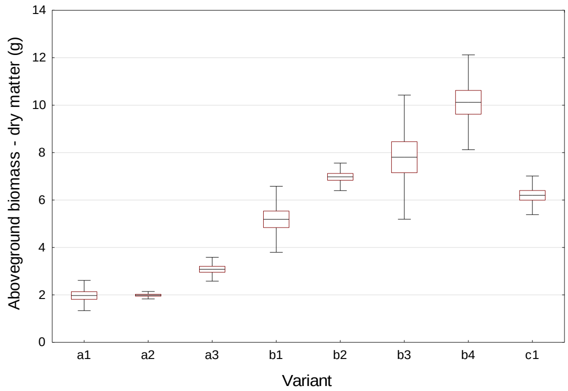
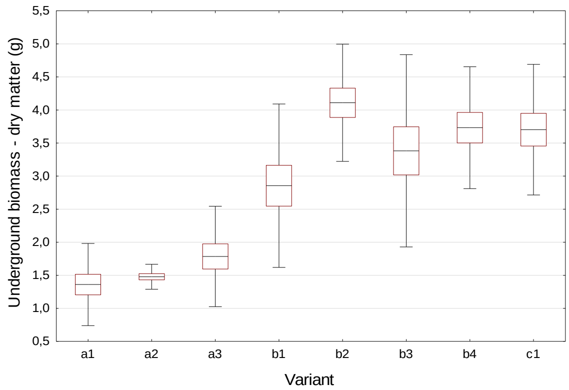


Figure 3 Box plot - underground biomass



Figures 2 and 3 show that the biochar variant had no positive effect on the aboveground or underground biomass in comparison to the check. Variant A2 (with biochar), however, displayed a statistically demonstrable influence on the reduction of ammonia nitrogen loss from the system when compared to variants A1 and A3, as shown in Figure 4.

The application of compost with activated carbon in variants B1, B2, B3 and B4 did not lead to the increase of ammonia nitrogen loss from the system when compared to the A2 variant. However, the yield of the aboveground biomass increased with increasing compost dose. Each doubling of the compost dose was met by an approximately equal increase in the aboveground biomass. The check variant A1 evidenced a statistically demonstrable increase in ammonia nitrogen loss when compared to the other variants (with the exception of A3). This means that the application of biochar along with compost has lead to the reduction of ammonia nitrogen loss from the system, with the primary production improving with increased doses of compost (as mentioned above).

Figure 4 Box plot (mg) N-NH 4

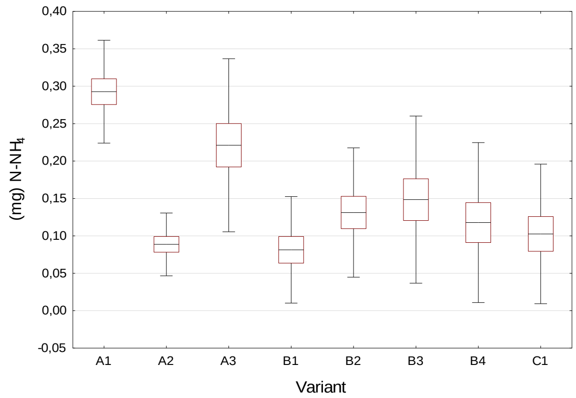
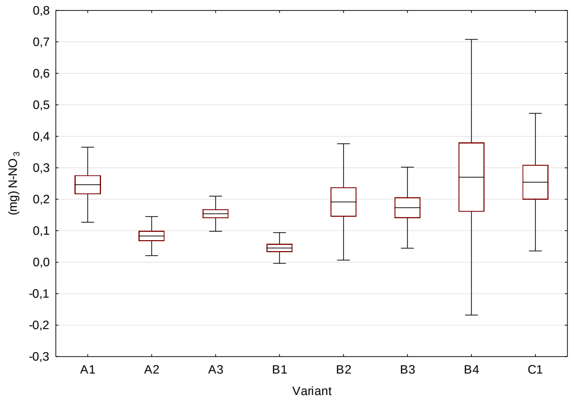


Figure 5 Box plot (mg) N-NO 3



The root/shoot ratio (R/S) also significantly differs between the variants (Figure 6). As mentioned by Bláha (2007), low availability of nutrients can cause a more significant weight loss in the aboveground section of the plant than in the underground section, thus increasing the R/S ratio.

Figure 6 Root/shoot ratio

Variant:	A1	A2	A3	B1	B2	B3	B4	C1
R/S Ratio	0.69	0.74	0.58	0.55	0.59	0.43	0.37	0.60

We can assume that the determining factor of the R/S ratio change is the lack of nitrogen or the change of physical conditions within the soil, or both. The significant influence of the physical conditions within the soil is displayed in variant C1 (activated carbon and agroperlite), whose R/S ratio is the same as in variant B2, with no significant differences between the yields of aboveground matter. This proves that even without the addition of nutrients, the C1 variant is comparable to B2 (100 % of the recommended dose of compost). Variants B3 and B4 have a significantly lower R/S ratio.

In other variants, the experimental plant had to invest more into the root system at the expense of the aboveground section of the plant, which can signal a lack of nitrogen in the vicinity of the root system.

The loss of ammonia nitrogen from the system between the variants has not shown statistically demonstrable differences, as can be seen in Figure 5.

CONCLUSION

This paper describes the initial results of a pot experiment focused on the addition of late-phase biochar into the soil. The initial results show that the addition of biochar has not significantly affected plant production (1 % increase in primary production compared to the check), while 50 % of the recommended dose of compost with activated carbon had a significantly higher effect than biochar did (162 % increase in primary production compared to the check). As a follow-up to this experiment, further research should focus on the application of various types of biochar, and on experiments in field conditions.

Additional research should also be devoted to thorough analysis of the biochar used, and subsequently to discovering the reasons why the expected increase in primary production observed in other studies did not occur.

A significant discovery was the lack of increase in mineral nitrogen loss when applying activated carbon with compost in triple the recommended dose, with production increasing by up to four times. This finding may be particularly significant for areas where emphasis is placed on protecting the ground water, as is the case in our locality of interest, the 2nd degree groundwater protection zone Březová nad Svitavou, which served as the source of samples for this experiment.

On the basis of the comparability between the C1 and B2 variants, we can ascertain that the application of compost influences the plant production mainly due to the changes to the physicochemical characteristics of the soil.

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