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Impact of a woody biochar on properties of a sandy loam soil and spring barley during a two-year field experiment

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ABSTRACT

Biochar is often proposed to increase soil quality and crop yield, while sequestering carbon. Despite the growing number of studies in temperate regions, the claimed positive effects are still unsure for northwestern European soils. Moreover, there is a need to upscale results from lab and pot studies in these soil types to field experiments.

The objectives of this study were therefore to investigate the effect of biochar application to a temperate agricultural soil on soil chemical, physical and biological properties, and on crop growth and nutrient uptake under field circumstances. A field trial, located in Merelbeke (Belgium), was established in October 2011 and monitored until August 2013. The biochar applied was produced from a mixture of hard- and softwood at 480 °C. The biochar dose was 0 (control) or 20 t ha^{-1} (on dry weight basis). Over two years, biochar addition to soil did not affect soil chemical properties, except for organic carbon content and C:N ratios. Effects on bulk density, porosity and soil water retention curves were non-consistent over time, possibly due to interaction with tillage operations. Biochar increased soil water content in 2012, although mostly not significantly. However, in 2013, when soil water content was overall lower compared to 2012, it was not affected by biochar addition. Soil temperature, as measured at a soil depth interval of 8–20 cm, was not changed by biochar addition. Furthermore, biochar addition to soil did only slightly influence soil microbiological community structure during the first year after biochar application, as only certain bacterial biomarker PLFAs were significantly affected by biochar addition, but no fungal biomarker PLFAs. Hence, it was not surprising that biochar addition did not affect crop yield, N or P uptake during the first two years after biochar application.

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1. Introduction

Biochar application to soils has gained interest as a climate change mitigation strategy, since it could act as a long-term carbon (C) sink (Lehmann et al., 2006). If in addition biochar could increase crop yields and improve soil quality, this would distinguish it from costly geo-engineering measures to mitigate climate change (Sohi, 2012). Moreover, agriculture will eventually have to adapt to climate change: according to the IPCC Fourth Assessment Report (Alcamo et al., 2007), it is very likely that the intensity and frequency of summer heat waves will increase throughout Europe. Biochar could possibly be part of a long-term adaptation strategy, as it could affect soil physical properties like soil structure, porosity, particle density and water storage capacity (Atkinson et al., 2010). Biochar-amended soil could thus have the potential to retain more water during periods of drought.

A meta-analysis by Jeffery et al. (2011) revealed an average increase in crop productivity of 10% with biochar application in tropical and subtropical regions. Only one study from a temperate region (New Zealand) was included in their meta-analysis, showing the need for more research in temperate zones. Three years later, biochar research is emerging throughout these regions, including lab, pot and field studies (e.g. Bruun et al., 2012; Kammann et al., 2011; Jones et al., 2012). This is also reflected in the meta-analysis of Biederman and Harpole (2013), which included several studies from temperate regions. Their study confirmed the overall positive

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effect of biochar application on aboveground plant production and yield, although the effect was more positive in tropical regions than in temperate zones. Furthermore, biochar's effect is soil type dependent. Jeffery et al. (2011) observed in their meta-analysis positive effects of biochar in acidic and neutral pH soils, and in soils with a coarse or medium texture, suggesting that possibly two of the main mechanisms behind these effects are a liming effect and an effect of biochar on soil water holding capacity. Moreover, biochar properties depend both on feedstock and production conditions, through which biochar's impact on soil properties is expected to vary (Ronsse et al., 2013).

Despite the growing number of biochar studies, there is still a need for field experiments to confirm results from lab and pot trials. For example, net nitrogen (N) immobilization after applying biochar to soil shown in many incubation studies (Bruun et al., 2011; Ippolito et al., 2012; Knowles et al., 2011; Nelissen et al., 2012; Novak et al., 2010) is so far not supported by field experiments, as these often resulted in equal or higher crop yields (Jones et al., 2012; Lugato et al., 2013; Vaccari et al., 2011). Furthermore, in general little scientific literature has been published on biochar's effect on soil biological and physical properties under field circumstances in temperate regions. It is unsure whether biochar could increase soil water content since for example results from the field trials from Case et al. (2013), Karhu et al. (2011) and Tammeorg et al. (2014) show little effects of biochar on soil water content. In addition, lab and pot trials are usually short-term, but long-term data are needed to get better insight into biochar's long-term effect under cropping conditions.

The objectives of this study were therefore to investigate the effect of biochar application to a temperate agricultural sandy loam soil on soil chemical, physical and biological properties, and on crop (spring barley) growth and nutrient uptake under field circumstances during the first two years after biochar application. We applied a carbon-rich, stable biochar type as we expected it to work as a soil improver rather than as a fertilizer or liming agent with likely transient effects. Our main hypotheses are that biochar addition to soil (i) reduces soil mineral N availability in the short term, (ii) improves soil physical quality through decreasing soil bulk density and increasing porosity, (iii) increases volumetric soil water content (VWC), especially during dry periods, (iv) changes soil microbial community structure, and (v) increases crop yield.

2. Materials and methods

2.1. Field trial

The field trial was established the 20th of October 2011 in Merelbeke, Belgium (50°58′ N, 3°46′ E; 29 m above sea level). Prior to the start of the experiment, during the 2011 growing season, the field had been cropped with maize (*Zea mays*). The different soil horizons were analyzed for soil texture and organic carbon (Table 1). The A_p horizon (0–35 cm) can be classified as sandy loam (USDA), and contains only 0.71% organic carbon. According to WRB, this soil can be classified as a Haplic Luvisol (Dondeyne et al., 2013).

The biochar applied in the field trial was produced during slow pyrolysis at 480 °C from hard- and softwood (69% Norway spruce (*Picea abies*), 19% beech (*Fagus sylvatica*) plus other wood species). 80% of the biochar particles had a size ranging from 0.5 to 8 mm, 5% was >8 mm and 14% <0.5 mm (Bruun and Hauggaard-Nielsen, Personal communication). The biochar analysis procedures for CHN, pH-KCl, CEC, volatile matter and ash content are described in Nelissen et al. (2014a). Biochar C, H and N contents were 68.1%, 1.5% and 0.4%, respectively; C:N mass ratio and H:C atomic ratio were 164 and 0.257, respectively. Biochar pH-KCl was 8.6 and cation exchange capacity 46.3 $cmol_c\ kg^{-1}$. Volatile matter and ash content were 12.0% and 8.3%, respectively (Nelissen et al., 2014a). Biochar's labile C fraction, as assessed through microbial C mineralization over time, amounted 3.95 $mg\ C\ g^{-1}$ biochar-C (0.4%) 381 days after the start of the incubation, but not all labile C had been mineralized when the experiment was stopped (Nelissen et al., 2014b). This result is in the same range as observed in other studies in which biochar labile C fraction was determined using a similar method (Baldock and Smernik, 2002; Cheng et al., 2008; Cross and Sohi, 2011; Hamer et al., 2004; Zimmerman, 2010). The BET specific surface area of the biochar was 295 $m^2\ g^{-1}$ (Lopez-Capel et al., unpublished). For comparison, according to the EBC (2012), biochar's BET surface area should preferably be higher than 150 $m^2\ g^{-1}$.

The experimental design of the field experiment was completely randomized with four replicates and involving one factor with two treatments: 0 and 20 t biochar ha^{-1} (on oven-dry weight base). So in total, there were eight plots; the size of each plot was $7.5 \times 12\ m^2$ and the plots were separated 3 m from each other in the tillage direction. The biochar dose of 20 t ha^{-1} corresponds to 5.4 $g\ kg^{-1}$ soil (=3.7 $g\ C\ kg^{-1}$ soil) assuming an incorporation depth of 0.25 m (see below) with a bulk density of 1.47 $g\ cm^{-3}$ (see Section 3). For biochar application, each plot was subdivided into eight sub-plots, after which 26.95 kg of fresh biochar (which is the equivalent of 22.50 kg oven-dry biochar) was weighed, mixed with water in order to avoid dust losses, and applied by hand to each subplot. After application, the biochar was non-inversely incorporated (10–15 cm) using a rigid tine cultivator. One day after biochar application, the field was cultivated using a spading rotary cultivator in order to incorporate the biochar in the profile to a depth of 25 cm. The field was left fallow during winter. In March 2012, the field was cultivated using a rigid tine cultivator, after which at the beginning of April, the field was tilled with a moldboard plough (25–30 cm) and spring barley (*Hordeum vulgare* L. (cv. Quench)) was sown at 3 500 000 seeds ha^{-1} (which corresponds to 200 kg ha^{-1}). In May, the field was fertilized using calcium ammonium nitrate at a dose of 70 kg N ha^{-1} according to local fertilizer recommendations (van Dijk and van Geel, 2012). P and K were not applied since soil P and K concentrations were optimal for crop growth (Maes et al., 2012). The fertilizer was broadcasted on the surface, and was in granular form. Harvest took place in August. In October, the field was cultivated using a rigid tine cultivator and a spading rotary cultivator, after which winter rye (*Secale cereale* L.) was sown (150 kg ha^{-1}) as cover crop. At the beginning of April 2013, the field was cultivated using a rigid tine cultivator and tilled with a moldboard plough. Spring barley was sown at 3 500 000 seeds ha^{-1}. In May, the field was fertilized using the same fertilizer and dose as in 2012, and the field was harvested in August. In both 2012 and 2013, weeds were controlled using Bofix (4 L ha^{-1}) and grain beetles using Karate 2.5WG (200 mL ha^{-1}) or KarateZeon (50 mL ha^{-1}), in 2012 and 2013, respectively.

From October 2011 to August 2013, several soil chemical, physical and biological soil properties were monitored. Also several crop properties were analyzed. A time schedule of all measured parameters is given in Table 2.

2.2. Weather data

Daily average temperature and precipitation data were collected from the weather station located at the ILVO research institute (Merelbeke), where the field trial is located. The ILVO station has a mean annual temperature of 10.7 °C and a mean annual rainfall of 879 mm (1992–2012). The first months of the 2012 growing season (April–July) were wet (Fig. 1), while August was dry. The first half of the 2013 growing season (April–June) was cold. July was warm,

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