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Biochar-compost substrates do not promote growth and fruit quality of a replanted German apple orchard with fertile Haplic Luvicsol soils

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ABSTRACT

In fruit growing areas, the new establishment of apple orchards on soils previous planted with apple trees is problematic, because plant vitality, yield, and fruit quality of the new planted trees are suppressed through specific apple replant diseases. We hypothesized that the addition of biochar mixed with compost could help to combat the negative impact of replant disease by improving soil fertility and by altering microbial composition of the fatigue soil. To test this, we applied 3 kg of two biochar-compost substrates containing 15% and 30% of biochar into the planting holes prior replanting of apple trees (*Malus domestica*; c.v. 'Braeburn' trees on M9). We then evaluated plant growth, nutrient content of the leaves as well as fruit yield and quality in comparison to a fertilized and untreated control trial. However, apart from some even negative effects on plant growth, the other investigated parameters did not respond to the application of biochar-compost substrates. Hence, both biochar compost additions as well as the granular fertilizer did not suppress apple replant diseases and thus failed to improve the overall performance of the apple trees over the three years of investigation.

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1. Introduction

In the 21st century, the social demand on agriculture is not only to produce high-quality food for a growing world population but farming also has to deal with careful use of resources and the mitigation of climate change. Plant based and pyrolyzed biochar used as a soil amendment could help to achieve all these requirements. The charred biomass is characterized by a high carbon content, which is recalcitrant to microbial degradation and therefore, can be more or less permanently sequestrated in agricultural soil (Glaser et al., 2002; Singh et al., 2012). At the same time, soil properties such as water holding capacity (WHC), cation exchange capacity (CEC) and nutrient retention can be affected positively by biochar treatment (Liu et al., 2012; Ventura et al., 2013). However, plant responses to biochar application varied, resulting not only in enhanced but also in suppressed crop yields (Borchard et al., 2014; Schmidt et al., 2014; Kloss et al., 2014).

The combination of biochar and compost might prevent negative effects of biochar on plants (Pietikäinen et al., 2003; Zimmerman, 2010; Prost et al., 2013). Such applications may be of particular interest for apple orchards that need to be re-established on soils formerly grown also with apple trees, i.e., which are prone to specific apple replant diseases (ARD). It frequently occurs in multi-generation apple orchards (Mazzola and Manici, 2012). The ARD results in suppressed root and tree growth as well as in lower yield and worse fruit quality (Henfrey et al., 2015). Site specific properties like soil and microclimate interact in multiple ways with biological causes of the ARD syndrome, including impacts from nematodes, and pathogenic microorganisms; other side effects under discussion are nutrient imbalances, herbicide residues, and soil compaction (Mazzola and Manici, 2012; Braun et al., 2010). In addition Manici et al. (2013) confirmed that especially root endophytic fungi may be main reasons for the below average performance of ARD affected trees. New orchards in affected sites could benefit from the incorporation of biochar-compost substrates into soil through an increased microbial activity (Lehmann et al., 2011), changes in microbial composition (Jin, 2010), increased nutrient availability, and a general revitalization of soil fertility (Liu et al., 2012; Leinfelder and Merwin, 2006; Mazzola and Manici, 2012). Hence, we hypothesized that the use of biochar-compost substrates

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might be a promising option to combat these factors of the disease complex.

The objectives of this study were to evaluate whether and to which degree the addition of biochar-compost substrates to an apple orchard may alleviate ARD symptoms by improving both (1) plant growth, and (2) fruit production under replant conditions. For this purpose, we reestablished apple trees (*Malus domestica, c.v.* 'Braeburn' trees on M9), added biochar-compost substrates as well as mineral mixed fertilizer to the planting holes, and quantified the plant response, leaf nutrient supply, and fruit quality during three growing seasons (2012–2014).

2. Material and methods

2.1. Study site and experimental setup

The experimental site (50°37′23.94 N/6°59′29.73 E; altitude of 177 m) was established nearby Rheinbach, Germany. Mean annual temperature and rainfall were 10.0 °C and 602.1 mm in 2012, 9.5 °C and 607.2 mm in 2013, 11.2 °C and 717.5 mm in 2014, and 10.6 °C and 686.0 mm in 2015. Soil type was a fertile haplic Luvisol (WRB, 2015), which had a clayey-silty texture with 75.8% silt, 18.2% clay and 6.0% sand. General properties of the study site are shown in Table 1. The soil was planted with apple orchards in the fourth generation since 1968. At the study site, the presence of apple replant disease has been expressed by diagnostic ARD symptoms such as stunted vegetative growth, reduced above- and below-ground biomass production, and decreased yields of replanted apple trees (Kümmeler, 1982; Henfrey et al., 2015). For our study site, Manici et al., 2013 determined the root endophytic fungi *Ilyonectria* spp., *Thelonectria* sp. and *Pythium* spp. as one of the main components for the below average performance.

The test facility was established as a randomized block design containing four different treatments in a threefold replication. Treatments consisted of an untreated control and three different planting hole applications of a mixed fertilizer and two biochar-compost substrates characterized by biochar amounts of 15% and 30%. In every treatment plot, 15 'Braeburn' trees on M9 were planted in one row with a distance of 1 m between the single individuals and 3.5 m between the rows. Before application and planting, soil preparation was performed by a rotary spading machine.

2.2. Substrates and fertilizer

Before planting the trees, 40 g mixed fertilizer or 3 kg dry matter of the two different biochar-compost substrates containing 15% (BCS15) and 30% (BCS30) biochar were manually applied in each planting hole. The mixed fertilizer is called Novovit Frutta and was produced by the Plantan GmbH, Buchholz, Germany. The fertilizer comprises the macro- and micronutrients ammonium nitrogen, nitrate, phosphate, potassium, and magnesium oxide, boron, copper, manganese, molybdenum, zinc, and iron. Additionally, it consists of granulate that is able to store and slowly release water. After soil application, the granulate turns into a gel-like structure that encloses tree roots, a process that according to the manufacturer has a deterrent effect on mice. The substrate should not contain any rodenticides. The biochar-compost substrates were produced by the Palaterra mbH, Hengstbacherhof, Germany. Carbon Terra GmbH, Wallerstein, Germany produced the used biochar from forest wood residues, which were pyrolysed at temperatures of up to 700 °C. The compost mixed with the biochar consisted of green cuttings and garden debris as well as fermentation remains. Both ingredients of the biochar-compost substrates were mixed and successively composted as well as fermented. Properties of the fertilizer and the substrates are shown in Table 1.

2.3. Measurements and harvesting

Plant response to the biochar-compost substrates and the fertilizer was assessed by measuring plant development (number of shoots, annual shoot growth, and diameter of the tree trunk), the nutrient contents of the leaves, fruitfulness (fruit setting per 100 flower clusters), and fruit yield in tons (Mg) per hectare (ha) as well as quality (soluble solids concentration, starch pattern index, and acid concentration). Excluding the outer trees of a treatment row to avoid edge effects, parameters were measured at 13 trees per plot in a threefold replication. The mean value of these subsamples was used for further calculations. In December of each year, number of shoots was counted and shoot growth was measured for all trees in accordance with the guidelines for horticultural performance test (Arbeitskreis obstbauliche Leistungsprüfung, 2015). The diameter of the tree trunk was determined at a height of 40 cm from the ground in two perpendicular directions.

At the beginning of August 2012 and 2014, the leaf nutrient content was determined by collecting leaves from the middle of 20 long shoots considering all trees of every treatment plot, which were free of infestations by pests or disease. Leaves were dried by 40 °C until constant weight was achieved, pulverized, and 0.5 g of each sample was extracted using a pressure digestion after Loftfield et al. (1986). Following the digestion, P was determined colorimetrically after Murphy and Riley (1962). The nutrient content of K was measured using atomic absorption spectrometers (VDLUFA, 1995). Nitrogen was determined by dry combustion using a Carbon/Nitrogen-analyzer (NA 2000; Fisons Instruments, UK).

In the third year after planting, fruitfulness of the different treated trees was assessed by counting flower clusters in May and thereafter, fruit setting in June. Both parameters were determined on a whole tree basis. The values were expressed in numbers of fruit settings per 100 flower clusters.

In October 2014, also apple yield was recorded determining the number of fruits and their weight per tree. Depending on optical density and refractive index, the soluble solids concentration in the fruit juice of 15 apples per treatment plot was measured using a refractometry (Atgo PR-32, Japan). The starch pattern index was determined through image analysis system on a 1–10 scale halving and coating 15 apples per treatment plot with potassium iodide (Meinhold et al., 2011). Total titratable acid concentration was determined through the titration of expressed juice with 0.1 molar caustic soda (Funke and Blanke, 2006).

2.4. Statistical analysis

Homogeneity and normality of the variance was tested by Levene's- and Shapiro-Wilk-test. The significance was tested with a one-way analysis of variance (ANOVA) using Statistica 8.0 (StatSoft, Inc., Tusla, US). For comparison of means, we used Fisher's LSD test ($p < 0.05$) as recommended by Webster (2007).

3. Results

During the first two years, the number and growth of the shoots showed no response to substrate and fertilizer application (Table 2). In 2014, both parameters were significantly lowered in the BCS30 treatment relative to the control; in addition, the trunk diameter of the BCS30 treated trees was significantly reduced relative to the fertilized trees in 2012 (Table 2).

Nutrient contents of the leaves were only elevated in comparison to the control in the year of substrate and fertilizer application. Thereby, fertilizer addition enhanced the supply of all measured

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