Sustainable Built Environment and Urban Transition
October 12-13, 2023, Linnaeus University, Växjö

BIOCHAR IMPROVES THE GROWTH OF URBAN SWEET CHERRY

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Abstract

The use of biochar in urban green infrastructure is increasing in cities. Creating a carbon sink by using biochar is a working technique that is available for the city planners and has been viewed as an attractive soil remediation solution. Biochar is mainly used to improve the soil conditions for urban trees and the long-term effect on tree growth is important to evaluate. Soil amended with biochar may have increased water and nutrient holding capacities, the soil texture may be improved, and the microbial community may change. These characteristics are more or less permanent and the long-term effect on the growth of the trees is important to evaluate. Biochar was added to the construction soil when sweet cherry trees were planted alongside a road in a suburban residential area in Sweden. The growth of the trees was determined for six years after establishment. Trees growing in the biochar-amended soil grew faster than the other trees. The circumference was 35% greater after six years. The N level was higher and the P level lower in the trees growing in the soil with added biochar, indicating that the growth increase may be due to increased N availability in the soil as a response to the biochar addition.

Keywords: urban trees, urban forestry, biochar, sweet cherry, nutrient retention, charcoal

1 Introduction

In addition to a poor establishment success and short life expectancy, urban trees grow less rapidly than forest trees because they rarely get favourable conditions. Urban trees however have the potential to grow fast, competition is much less than in forest stands and CO_2 and nitrogen levels are higher. As a result, the urban forest carbon storage is approximately half that of trees in forests but the storage per individual tree is approximately four times higher in urban trees (Nowak and Crane 2002). Urban trees grow large before they are removed, and large trees typically store more carbon. High nitrogen deposition and a higher CO_2 concentration in the air also increased growth of urban potted cottonwood trees as compared to when they were grown in rural environment (Gregg et al., 2003). Valuable ecosystem services and aesthetic values are therefore threatened or never achieved. The reasons for the reduced growth might be several various conditions in the urban environment, the air, the climate, or the soil to mention a few. The climate is often dry and warm, and this negatively affects tree growth if the soil cannot meet their demand of water. Other soil factors prevent urban trees achieving their full growth potential, for example compacted soils (Kozlowski 1999) and suboptimal water and nutrient

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Co-funded by the Erasmus+ Programme of the European Union

availability (Gilbertson and Bradshaw 1985). Management that improves the soil conditions will therefore have significant implications for tree establishment and health and, consequently, the delivery of ecosystem services. One product that has showed great potential for improving soil conditions is biochar. It improves the soil in the same manner that any organic matter would, with the difference being that it is not degraded. Biochar is stable against degradation for thousands of years (Sohi et al., 2010) and acts as a carbon sink because its slow degradation. In 2018 biochar production was classified as a Negative emission technology by IPCC (2018).

Biochar affects the soil in ways that improve the conditions for urban trees (Thomas and Gale 2015). Biochar has a water holding capacity that may be greater than that of the soil (Novak et al., 2012), but the water holding properties of the biochar are related to the quality of the feedstock used in the pyrolysis process. Mixing biochar and soil the water holding properties are also improved by aggregation of the soil particles (Blanco-Canqui, 2017) and an increased microbial activity (Lehmann, 2011). The cation exchange capacity of soil biochar is similar to clay (Liang et al., 2006), but, again, this is related to the feedstock used in the pyrolysis (Tan et al., 2017). Biochar is generally more or less alkaline, depending on the production temperature and the material that is pyrolyzed (Tan et al 2017). The general conclusion is that coarse and acid soil benefits the most from biochar addition. Soils in urban environments are often coarse, but the soil pH is often neutral to high. Biochar most likely has the potential to improve the properties of the general urban soil. These improvements may result in higher growth rates, further increasing the carbon capture.

The potential to increase the growth of trees through biochar use in general is considered high (Thomas and Gale 2015) and this has been shown for *Acer saccharum* and *Gleditsia triacanthos*, which grew better in a soil that had been improved with biochar (Scharenbroch et al., 2013). This experiment was, however, conducted in a testbed in an urban environment and not on street trees in the field. Biochar also increased the growth of potted Australian trees (*Corymbia maculata* and *Eucalyptus torquate*) to the same extent as compost; the pots were located on the campus of Melbourne University (Somerville et al., 2020). The effect of biochar on trees growing as street trees or the duration of the effects have not yet been shown.

We wished to determine whether biochar can improve the conditions for trees growing in an urban setting. Establishment has been identified as a critical phase for improving the survival of urban trees. Our aim was to test whether the growth and vitality of sweet cherry established in urban soil is improved by the addition of biochar. We also wanted to look at long-term effects, and we expected the sweet cherry to continue to benefit from the biochar addition for six years.

2 Materials and methods

The trees were grown in a typical suburban residential environment in Stockholm Sweden. The study was conducted along the street known as Herrhagsvägen (59°16'18°4') in Enskede. Herrhagsvägen runs in a south-north direction. The area is a typical suburban site with limited pressure on the green infrastructure and low traffic loads. The small houses and the orientation of the street allow the sun to reach the street. A hill to the west protects the site from westerly winds and the site has a stable local climate. The street is aligned with two rows of *Prunus avium* planted in 2 m wide grass strips between the road and the sidewalks. The mean annual temperature in the area was 6-7°C in 2009, 5-6°C in 2010, and 7-8°C in 2013 and 2016. Mean annual precipitation in the area was 600-700 mm in 2009 and 2010, and 500-600 in 2013 and 2016.

Potted *Prunus avium* ‘Plena’ trees (25-30 cm at breast height) were bought from two different nurseries, Lappen and Riddersvik, and planted in the winter of 2009 and 2010 by the City of Stockholm. The planting of the trees was undertaken by a professional contractor and supervised by the department responsible for tree care in the municipality. The trees were planted in 2×2×1 m large planting pits located in strips of three different substrates (Table 1): standard soil for planting in urban areas (Control, AMA B soil) from a Swedish soil supplier (Hasselfors garden AB); the same soil mixed with 50 % (volume/volume) pulverized biochar (Biochar); and gravel with a 50% biochar soil mixture at the surface (Gravel). Grass was established on the surface of the substrate. The biochar was from deciduous wood, pyrolyzed at a temperature of 550 °C. The ash content of the biochar was 10% and it had a pH of 8. The texture and the organic content of AMA B soil is standardized according to Swedish recommendations: the clay content should be less than 5% (particles <0.002 mm), less than 20% of the particles should be smaller than 0.1 mm and the organic content should be less than 5%. After planting, the trees were watered with 150 l water per week during the first two growth seasons after planting using tree-gaiters (http://www.treegator.com). On the first watering occasion, 4 ‰ Wallaco fertilizer was added (NPK 51-10-43) and on the following occasions 2‰. In total, each tree received 6000 l water and 12.3 l fertilizer during the first two years. After that no irrigation or fertilization was applied. The stems were cut free from branches to approximately 4 m height and at the time of the measurements the wounds had started healing.

The growth and vitality of the trees were determined on three occasions: October 23rd, 2013, June 4th, 2014, and September 11th, 2016, for 10 trees in the control treatment, 10 in the biochar treatment, and six trees in the gravel treatment. Stem circumference was determined with a measuring tape and the length of three shoots per tree was determined using a measuring stick. The shoot length was determined for the previous year in 2013 and for subsequent years up to the time of measurement in 2016, giving a continuous series from 2012 to 2016. The height of the trees, the width of the crown, and the crown height were determined using an infrared distance measuring device (DistoTM D510, Leica Geosystems, Switzerland). The crown width was determined by measuring the distance between two people aligned with the edges of the crown.

The 3rd-5th leaf from the shoot tip was collected from 3 shoots and dried at 105 °C to constant weight and stored until analysis. The total C/N ratio was determined using dynamic flash combustion elemental analysis (FLASH 2000, Thermo Scientific) and total P after acid digestion in a microwave using the molybdate blue method (John 1970). Leaf area index was determined for individual trees using a fish-eye lens (CID 110, CID Bioscience, country) in June and September 2014. LAI was measured in four directions, at 30 cm from the trunk and approximately 40 cm from the crown. A mean value for the four images was calculated after correcting for irrelevant objects. Vitality was estimated visually in four classes, where 1 is high vitality, and 4 is dead, according to the evaluation method of Östberg, et al., (2012). To complement the vitality estimation, the leaf fluorescence (Fv/Fm) was determined using a fluorometer (Handy PEA, Hansatech instruments Norfolk, UK) in September 2014.

Stomatal conductance was determined on September 11th, 2014, for the trees growing in biochar-amended soil and the control trees using a leaf porometer (Decagon Devices, Pullman, WA, USA). A mean value for five leaves of each tree was calculated. The conductance of cherry trees growing under optimal conditions was also determined Soil moisture was determined in the surface of the planting strips using a soil moisture meter (SM150T Soil Moisture Sensor, Delta-T devices, UK) in 2013. Statistical calculations were done using IBM SPSS statistics software version 24.

3 Results

After four years of growth, the trees had a circumference of 36.2±3.5 cm in the unamended soil, 35.5± 2.7 cm in the gravel and 49.0± 3.0 cm in the soil with biochar. The stem circumference was 35% higher in the trees growing in biochar than the trees growing in only soil or gravel (fig 1, p=0.01, general linear model SPSS). The difference was also detectable in 2014 and 2016. The diameter growth increase from 2013 to 2016 was higher for the trees growing in biochar amended soil (2.1±0.5 cm) than the control trees (1.5± 0.5 cm, p=0.04, Generalised linear model, SPSS) and those growing in gravel (1.2±0.3 cm, p=0.004, Generalised linear model, SPSS).

The crowns of the trees growing in biochar-amended soil had become approximately 20% wider, compared to the trees in the soil without biochar (Table 2). This change was also confirmed by the shoot length measurements. In 2012, the mean length of the shoots of the trees growing in the biochar-amended soil was 49±8.8 cm, compared to 36±8.0 cm in the trees without biochar in the soil (t-test p=0.006). The shoots were shorter in 2013, but the length of the shoots of the trees growing in biochar-amended soil was longer (24±3.0 cm) than the shoots of the trees in the control soil (17±5.0 cm, p=0.004). The shoots were even shorter in 2014 and there was no difference between the two treatments; this was also the case in 2015 and 2016. The mean shoot length during these years was 14±5.0 cm. The trees had grown to the same height.

There is an indication that the trees that grew in biochar-amended soil had a higher leaf N concentration (2.19±0.18 mg N/g leaf) than the trees in soil without biochar (1.87±0.20 mg N/g leaf, General linear model, SPSS 28.0.11, p=0.012) four years after establishment. When an outlier is removed, the difference is statistically significant (p<0,001), mainly due to lower standard deviation in the control trees (leaf N concentration in control trees= 0.093±0.010 mg N/g leaf). Leaf P levels, however, exhibited the opposite pattern: trees in the biochar treatment had a lower leaf P concentration than those growing in the control (0.33 and 0.47 mg P g-1 leaf, respectively, General linear model SPSS 28.0.11, p=0.002). This may indicate that the P in the biochar is not available to the trees and that the increased growth dilutes the concentration of nutrients other than N in the biochar-treated trees.

The visual vitality of the trees was estimated to be good in the autumn of 2013 and 2016, they were placed in class 1, i.e. the highest vitality. In 2014 the vitality of the trees had been reduced and several desiccated shoots were detected in the crowns. There was, however, no difference between the trees growing in soil amended with biochar and those in unamended soil. It was observed that the trees that had grown in biochar-amended soil dropped their leaves later than the other trees. Determining the vitality using leaf fluorescence (Fv/Fm) did not reveal any difference between the trees. The ratios found were slightly lower for both trees growing on biochar-amended soil and the control, 0.71±0.04 and 0.69±0.08 respectively, than the value that is considered optimal (0.80), indicating mild stress. The leaf area index was the same in the trees ameliorated with biochar or not in 2014 (t-test, p=0.13). There were, however, indications that the trees growing in biochar-amended soil had a lower LAI compared to trees growing in soil alone, 2.0 ±0.6 and 2.7±0.9 respectively (t-test, p=0.12). The levels were similar to levels in *Prunus avium* trees growing under good conditions in an experimental field at Alnarp Campus (LAI=2.4). No difference was detected in the stomatal conductance of the leaves of the *Prunus avium* trees grown with or without biochar (t-test p=0.44). The stomatal conductance of the control trees was 396±87 mmol $m^{-2}s^{-1}$ and the trees with biochar added to the soil 429±91 mmol $m^{-2}s^{-1}$.

4 Discussion

The biochar addition to the planting soil increased the growth of the *Prunus avium* trees at Herrhagsvägen in Stockholm. Both the stem circumference and the crown width increased with the biochar addition. The difference in stem circumference was large, amounting to 30 (what?). A similar but less pronounced response to biochar was found in *Samanea saman* and *Suegada multiflora* in a pot experiment using urban soil in Singapore (Ghosh et al., 2015). The two species in that study responded to biochar addition with increased height and increased stem circumference, the N-fixing *S. saman*, however, exhibited larger responses than the non-N fixing species.

The N levels in the *Prunus* trees were slightly less than recommended for production trees (Murray et al 2016). In the study by Neilsen et al., (2007), the N levels were between 2.5 and 3.3 % of dry mass and the P levels were between 0.17 and 0.24 %. The P concentration in the trees in our study is higher, indicating that P is not limiting the growth in the urban *Prunus* trees. The P in the biochar is either low, not available for the trees or taken up much slowly, thus, diluted in the tissue due to the vigorous growth in the biochar treatment. N was not diluted, and more was taken up to support the higher biomass, this indicate that N is the limiting factor for growth. The greater growth may be due to a higher N availability in the soil that was mixed with biochar. Ghosh et al., (2015) found higher foliar N, P and K levels in trees growing in biochar-amended soil compared to trees growing without biochar amendment. We expected that the cherry trees in this study would show higher N concentrations in their tissue. Sewage sludge biochar has been shown to increase total nitrogen concentration in urban soil by 1.5 times (Yue et al., 2017) and nitrogen is easily taken up by plants. However, we could not confirm this conclusively, although the results do indicate a higher N level in the leaves four years after planting. In a study by Sharenbrough (2013), no relationship was found between the nitrogen in the biochar treatment and the growth response, which implies that there are several mechanisms acting to improve the growth of the trees, such as improved water availability. Increased water availability can also promote growth in trees. It is likely that the amount of water available for the trees is higher in the biochar-amended soil. This effect would remain and support the growth of the trees in the biochar treatment. Water and nutrient availability are, however, closely linked, and it is difficult to separate the two factors. Measurements did not show any difference in stomatal conductance, which supports that a better nutritional status is the most influential factor in this study.

The large growth response in our study raises the question of whether the soil used was a good growth medium for the trees. The trees planted in gravel alone grew to the same size as those planted in the soil. The growth rate of the trees at Herrhagsvägen was 2.9 cm $year^{-1}$, which is comparable to 3.0 cm $year^{-1}$ from a study of street trees in Copenhagen, (Bühler et al., 2007).

The improved growth associated with biochar seems to remain over the years: the growth increase was higher in the trees growing in biochar-amended soil after six years. A period of six years is, however, not long in relation to the lifespan of the tree. The trees grew thicker but not taller, indicating that the response was expressed in the stem diameter rather than stem elongation. The short-term vitality of the trees was neither improved nor reduced by the biochar amendment. The trees growing in biochar had cracks in the bark on the stem, indicating that there might be problems with adaptation for winter hibernation.

The LAI measurements of the individual *Prunus* trees were in the lower range of LAI (2.5 to 10) for deciduous forest trees (Breuer et al., 2003). The LAI measured for single trees might be expected to be lower than the average for whole stands due to the edge effect. The LAIs for the *Prunus* trees at

Herrhagsvägen were comparable to those reported for trees in urban parks and a suburban forest in Gothenburg (Klingberg et al., 2017). Using LAI may be a coarse tool for detecting treatment effects for single trees and the error is probably high.

5 Tables

TABLE I. Planting conditions at Herrhagsvägen, Stockholm testing the effect of biochar on the growth of sweet cherry in commersial urban soil during 6 years.

Substrates	**Planting conditions**		
	Planting time	***Substrate***	***Number of trees***
Control	Nov-Dec 2009	AMA B soil	10
Biochar	Nov-Dec 2010	AMA B soil + 50% biochar per volume	10
Gravel	Nov-Dec 2009	Gravel 32-64 mm	6

TABLE II. Above ground growth of the crown and full sweet cherry trees growing in control, biochar and gravel at Herrhagsvägen, Stockhom Sweden from 2010 to 2016.

Tree growth properties	**Treatment**		
	Control	***Biochar***	***Gravel***
Crown diameter (m)	4.3±0.6	5.2±0.5	4.3±0.5
Crown hight (m)	3.8±0.4	3.7±0.3	3.5±0.3
Tree heigt (m)	6.4±0.4	6.1±0.6	6.3±0.2

6 Author Contributions

Both authors have collected data and participated in the writing of the manuscript. AMF has done the main writing and most of the data analysis and calculations.

7 Funding

This research was made possible by the contribution of Vinnova through the projects 2021-01589 and 2012-01271.

8 Acknowledgments

This research was done with the contribution of the City of Stockholm that let us evaluate their trees. The City financed the test and established the trees that was later studied. They also supported the research with high lifts to make leaf sampling and measurements possible.

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