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Fakulteten för landskapsarkitektur, trädgårds- och växtproduktionsvetenskap

BIOCHAR AS SOIL AMENDMENT IN FLOW-THROUGH PLANTERS

– For increased treatment of zinc roof runoff

BIOKOL SOM JORDFÖRBÄTTRING I BIOFILTER

– För ökad rening av zinkföroreningar från tak

Froste Wiström

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ABSTRACT

In times of increased flooding, enhanced by climate change, polluted stormwater poses an increased threat to the environment through contaminated water entering waterways. Bioretention utilizes natural processes in soil and vegetation to treat pollutants and combat this threat. Biochar produced through pyrolysis, has a high cation exchange capacity (CEC) and could therefore increase treatment in bioretention systems. This research applies a literature review, interview, and a model to explore the benefits and disadvantages of biochar in order to specify a soil-mix through an understanding of the production process and preferred application rate. High purification through CEC, increased water holding capacity, and carbon sequestration being the benefits discussed. Biochar application can however, cause clogging due to weathering, which decreases the performance of bioretention systems. A scenario consisting of a zinc roof discharging runoff into a flow-through planter is set in Alnarp, Sweden. The model presents pollution load and treatment capabilities of substrates to then design four soil-mixes to allow maximum hydraulic conductivity, maximized treatment through CEC, stability over time, and enhanced plant habitat. The theoretically optimal soil-mix consists of 50% sand, 30% biochar, 10% loam, and 10% compost, accommodating these factors and providing the best solution for a substrate in a flow-through planter for the removal of zinc pollution from stormwater.

SAMMANFATTNING

Klimatförändringen ställer nya krav på dagvattenhantering då den medför ökad nederbörd med föroreningar i sjöar och hav som följd. Med bioretention går det att dra nytta av naturliga processer i jord och vegetation för att rena dagvatten och övervinna problemen med föroreningarna. Biokol producerat genom pyrolys har hög katjonutbyteskapacitet (CEC) och skulle därför kunna öka reningen i biofilter. Den här studien använder en litteraturstudie, intervju och en modell som metod för att utforska möjligheter, fördelar och nackdelar med implementeringen av biokol i dagvattensammanhang. Dessutom ökar den förståelsen för olika produktions-metoders påverkan på produkten och effekten av olika mängder biokol i jord. Fördelarna är hög CEC, ökad vattenhållande förmåga, förmågan att binda atmosfäriskt kol i marken, även kallad kolsänka. Genom vittring kan biokol däremot skapa problem i form av igensättning i biofilter. Ett teoretiskt scenario är skapat med ett zinktak kopplat till ett biofilter placerat i Alnarp, Sverige. Modellen presenterar föroreningshalter från taket och reningsförmågan hos olika substrat; den föreslår sedan fyra förslag på jordblandningar. Detta för att maximera den hydrauliska konduktiviteten, maximera reningen genom CEC, öka systemets livslängd samt för att skapa en förbättrad ståndort. Med dessa parametrar i beaktning och om uppgiften är att rena zinkföroreningar i ett biofilter, består den teoretiskt optimala jord-sammansättningen av: 50% sand, 30% biokol, 10% sandig lerjord och 10% kompost.

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Froste Wiström, 14-04-10

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1 INTRODUCTION

Anthropogenic influence on the climate is proven (ICPP 2013). Changes in weather patterns are already apparent, and as the planet heats up, many areas become more arid; others, such as Sweden, experience increased precipitation. This, in combination with increased urban density and sprawl, may intensify problems of flooding; which are said to become more frequent (ICPP 2013). Urban areas are dominated by hardscape surfaces diminishing percolation and recharge capabilities of aquifers. As well, these surfaces are often made of materials (i.e. zinc roofing) that leach pollutants into waterways (Gromaire et al. 2002).

To combat urban pollution and higher flows of stormwater, bioretention techniques are sometimes used. Bioretention is the principle of using natural processes in soil and vegetation to treat pollutants in stormwater, through systems that filtrate, detain and/or retain water (EPA 1999; Stahre 2008). Soils used in these systems contain a high share of sand because of its high hydraulic conductivity. However, this presents a dilemma: when a sandy soil is dry, it is very dry (Stromberg 2010). This is a problem when the surface is planted with vegetation that needs moisture.

In the mid 1800s, soils with a high carbon content were found in the Amazonian rain forest, called *Terra Preta de Índio* (Major, Lehmann, Rondon & Goodale 2010). These soils, or anthrosols, had been enhanced by humans through active charring of organic matter. The soils were shown to be very fertile, mainly because of their high cation exchange capacity (CEC) (Lehmann & Joseph 2009). The high CEC is due to the structure of the charred organic material, (Lehmann & Joseph 2009). This charred material, later termed *biochar*, is today produced through pyrolysis - a process where organic material is heated under an oxygen poor environment. High CEC material can also be utilized for other purposes than increasing soil fertility and to increase the performance of bioretention systems (Beck, Johnson & Spolek 2011).

The use of biochar has other benefits as well, such as increased water holding capacity and higher availability of nutrients, resulting in healthier vegetation (Beck, Johnson & Spolek 2011). Healthy vegetation, such as large trees, supplies ecosystem services. Which aids to counter act the heat island effect, as well as help with wind management and to some extent, air pollution (Bolund & Hunhammar 1999). Further, large trees also increase interception of rain thus lowering the pressure on stormwater infrastructure. Healthier vegetation will also make the urban space more livable and enjoyable for humans and wildlife (Bolund & Hunhammar 1999). Additionally biochar sequestrates carbon. Carburated organic substance like biochar has an extremely long lifespan in the soil, 100-5000 years (Lehmann and Joseph, 2009). Atmospheric carbon is thus bound in the ground, assisting to mitigate changes in the climate (Lehmann and Joseph, 2009).

There has been extensive research done on biochar (Lehmann & Joseph 2009); however, it is still in its infancy. The engineering and landscape industry have recognized biochar’s potential but the industry is still unsure about its application. This may also be due to some problems in production and supply, as well as lack of knowledge on specification and potential use.

OBJECTIVE

To mitigate the human impact on climate and pollution there is a need to improve and develop solutions for stormwater management. Mimicking nature with bioretention systems where chemical and biological cleaning processes take place has shown to be successful. This thesis will further explore how these solutions could be refined. First, by evaluating the benefits of biochar contributing to a comprehensive understanding of its application and potential uses in bioretention applications; second, by modeling substrates to understand the factors involved in stormwater treatment. For simplification and specification, a theoretical case with zinc roofing has been selected as the source of pollution. Zinc roofs leach, imposing a high burden on the environment (Gromaire et al. 2002). The case is situated in the southern tip of Sweden, in Alnarp. However, for this case biochar is presented as a possible solution to the mitigation of pollutants in stormwater.

The objectives have resulted in the following research questions and sub-questions:

1. What are the benefits and disadvantages of using biochar as a soil amendment in a flow-through planter?
2. How should a biochar-amended soil be specified for a flow-through planter treating runoff from zinc roofing?
    a. What is the best concentration of biochar in the soil for treating runoff from zinc roofing in a flow-through planter?
    b. What fractions of the biochar should be used for best performance?
    c. Is there a preferred production method for high quality biochar for bioretention applications?

This research focuses on substrate for a flow-through planter. This is to be able to rule out disturbances in the model since flow-through planters are confined unlike bioswales and raingardens. This means the model can be assessed more reliable. Runoff from zinc roofing is chosen because disturbances in form of other pollutants are relatively low, compared for instance to street runoff.

2 METHODOLOGY

This research is deductive meaning that the research had a clear aim and focus from the beginning (Bryman 2012). To answer the thesis questions and sub-questions methods used are: literature review, interview, and model. This was to include a broad variety of sources and to approach the thesis questions from different angles.

For the literature review the main sources are peer reviewed scientific articles found through the databases: Web of Science, Google, Google Scholar, Epsilon, and Primo. Search words used are: biochar, pyrolysis, stormwater, bioretention, flow-through planter, zinc roof, cation exchange capacity, treatment, water holding capacity and carbon sequestration. Additionally, books on soil science and biochar is referred to. Complimentary websites are used, such as the Environmental Protection Agency and Biochar-International.

A qualitative interview is conducted to comprehend the implementation and limitations from someone actively testing the use of biochar (Häger 2001). The informant, Björn Embrén is the tree specialist at the Traffic Office in the City of Stockholm and has been testing biochar to improve plant habitat in tree plantations for 10 years. The interview is semi-structured with guiding questions but was mainly allowed to take its natural course; using the questions to return to the topic when necessary. This is to allow the informant to give his view of the subject, allowing for unexpected information which the questions may not cover (Häger 2001).

To calculate the impact of biochar, and to be able to compare its ability to treat pollutant cations, a model is built in Excel. This specific model is developed for this research and allows input variables to be entered for a theoretical result. For the model to work, input data is gathered from a variety of sources. The sources are mainly peer reviewed scientific articles as well as websites for weather data and chemical properties of pollutant. Additionally, several assumptions are made.

ASSUMPTIONS

For writing the model several assumptions need to be made. Some of these are supported by literature, while others have been made for the sake of being able to calculate. These assumptions may limit the results, but were necessary to be able to simplify and calculate. The assumptions are:

- Runoff from zinc roofs in Alnarp, Sweden is the same as the average of the two studies used from Paris, France and Nacogdoches, Texas.
- Zinc is the only cation that comes off the roof.
- CEC of substrates behave similarly in soil as they do in the laboratory.
- Water is able to pass through the filter media throughout the whole year.
- 75% of the stormwater passes through the substrate, the additional 25% is lost due to high flows during intense storms and evaporation.
- Water holding capacity of biochar is linear and may be extrapolated from the results by Beck, Johnson & Spolek (2011) and is applicable on other types of bioretention systems than green-roofs.
- The effect of plants on pollutants is disregarded from.

These assumptions were estimated to be the most important to include in this study. However, apart from these there are most likely others that have not been taken into account. This is the main limitation of this study.

3 LITERATURE REVIEW

WHAT IS BIOCHAR?

Biochar is a solid material resembling coal (fig. 1) and is produced by heating organic material under oxygen poor conditions, called pyrolysis (Lehmann & Joseph 2009). The production methods are similar to that of producing charcoal, however, the large difference is that the aim of biochar production is to use the product as a soil amendment (Bates 2010). Further, the purpose of soil amendments is to increase soil fertility, sequester carbon and/or treat stormwater. However, the terminology of biochar is somewhat unorganized. Apart from the term *biochar*, *black carbon* and sometimes *charcoal* are used for the same pyrolyzed product used as soil amendment. According to Bates (2010), black carbon refers to a wide range of oxidized products such as soot and graphite including biochar, but also that biochar does not refer to pyrolyzed waste such as plastics tires and inorganic materials.

Figure 1: Biochar derived from wood pellets. Adapted from:
Photographer Visionshare license Creative Common (CC BY-NC 2.0)

Terra preta de Índio is a term for the black soils of the Amazonian forests. These soils have been affected by humans through centuries of active burnings by natives and are estimated to be over 7000 years old containing a high percentage biochar (Marris 2006). They are also shown to be very fertile and estimated to be twice as productive as adjacent soils without any biochar content (Marris, 2006). Extensive research conducted by Johannes Lehmann from Cornell University in an attempt to uncover ways to reverse or minimize climate change show that these biochar rich anthrosols[1] of the Amazonian jungle sequestrate carbon (Lehmann 2007).

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[1] Anthrosol coming from the anthropogenic (anthro) influence on soil (sol).

PRODUCTION PROCESSES AND CONSEQUENCES

Biochar is produced through pyrolysis, which is a process where organic matter is combusted in a low oxygen environment (Sohi, Lopez-Capel, Krull & Bol 2010). The pyrolysis process has four products: char, gas, oil, and tar (Sohi et al. 2010). The main factor governing the resulting product is the temperature of the kiln (Sohi et al. 2010). Furthermore, resident time in the kiln, pressure exposure, and type of feedstock also affect the result (IBI 2014). Char has long been seen as a low value product in energy production. Therefore, technology has moved towards minimizing the amounts of char produced (Sohi et al. 2010). However, with the increased interest in biochar this will change. In the biochar production process; excess heat, gas, oil, and tar can be recovered and used for energy purposes (Lehmann & Joseph 2009). According to Gustafsson (2013) pyrolysis for energy production has great potential. This is because any form of organic matter may be used as fuel, compared to other energy production techniques where organic matter must be of a certain quality, such as in pellet or chipping combustion facilities.

The temperature in the pyrolysis kilns are 400-800°C during production**.** Kiln temperature is adjusted to what end product is desired (Lehmann & Joseph 2009). Particle size, water retention capability, nutrient content, and porosity are all aspect of production methods. Particle size of the char varies depending on the temperature during pyrolysis and the nature of the original material. A higher temperature results in smaller particles. Also, a faster increase in temperature in the pyrolysis kiln will affect the outcome. A slow increase of 5-30C°/min can allow particles up to several centimeters to become biochar (Lehmann & Joseph 2009). With this said, it is believed that particle size of biochar has little effect on crop growth or nutrient availability. Although, according to Embrén (2014) particle size of 1mm and smaller gives the best results for increasing plant growth. Biochar porosity is perhaps a more important factor and particle size could be a redundant parameter (Lehmann & Joseph 2009). This is because a high porosity will lead to a large surface area (Brady 2002). Biochar produced in a fast pyrolysis will result in a product with a lower surface area, whereas production in a slow pyrolysis will result in a biochar with a higher surface area (Lehmann & Joseph 2009). Additionally, Sohi et al. (2009) say that biochar produced during low temperature pyrolysis is more hydrophobic. Surface area is strongly connected to the CEC of the substrate (Eriksson 2011). However, Lehmann and Joseph (2009) state that there is not enough research to be able to determine the optimal production techniques for the soil amendment biochar.

Apart from production techniques not being fully developed, a large problem with biochar is the lack of supply and variable quality of the product (Embrén, 2014, personal communication). Through work to improve plant habitat for urban trees in the city of Stockholm, Björn Embrén has used biochar for 10 years, with a trial and error approach. When using it in an urban planting with *Prunus avium* he saw great results in growth. *"It was a total explosion, I've never seen anything like it!"* (Embrén 2014). This effect of biochar on growth has also been confirmed by Fransson (2014) who has seen a 35% increase in growth through field trials and is about to publish an article on the subject. Embrén continues to say that he is eager to continue using biochar as a plant substrate enhancement, mainly in structural soils; but first he must overcome the problem of a lack in supply, saying that he may resort to in-house production.

BIORETENTION

Bioretention is the principle of using natural methods for treating pollutants in stormwater. There are many bioretention techniques, however, they all detain and/or retain water, as well as treat pollutants. These techniques, or *best management practices* (BMP), use the natural processes performed by soil and vegetation to treat polluted water (EPA 1999).

STORMWATER CARRIES POLLUTANTS

Precipitation in the form of rain and snow – called stormwater – is often highly polluted in urban environments. Stormwater collects pollution from a variety of surfaces, all with many different sources of pollution; such as some roofing materials and pollution from traffic (Göbel, Dierkes & Coldewey 2007). Pollution that cannot be traced to a specific source is defined as non-point-source pollution (EPA 2012). These non-point-source pollutants have the potential to be successfully treated through bioretention techniques integrated into stormwater infrastructure. Bioretention systems decrease the pollutant load on water discharged into water bodies (Guo 2013). Polluted urban stormwater can, if preventive measures are not taken, pollute groundwater, waterways, and the oceans (Göbel, Dierkes & Coldewey 2007). Studies have shown that bioretention has large effects on stormwater pollution removal, 92% for metals, 65% for Total Kjeldahl Nitrogen, and 60-80% for ammonium (EPA 1999) As mentioned above, roofing materials can be a source of pollution, and one commonly used type is zinc roofing (Gromaire, Chebbo & Constant 2002).

ZINC ROOFING AS A SOURCE OF POLLUTANTS

Zinc is a common roof material, 40% of roofs in Paris (Gromaire, Chebbo & Constant 2002). Zinc roofing sheets are made of an alloy consisting of 99.5% zinc and 0.5% titanium and copper (Gromaire, Chebbo & Constant 2002). Modern zinc products have a purity of 99.995% but all zinc products also contain a small fraction of cadmium (Gromaire, Chebbo & Constant 2002). Corrosion of zinc roofs are affected by many factors such as: humidity, frequency of rain, pH of rain, and concentrations of the substances SO_2, NO, NO_2 and O_3 in the atmosphere. SO_2 is the main driver of corrosion and will generate zinc hydro sulphates that are soluble in water (Falk et al. 1998; see Gromaire, Chebbo & Constant 2002). During rainfall, corroded zinc can be washed off roofs into the stormwater system, up to 64 metric tons are annually produced on Parisian zinc roofs (Gromaire, Chebbo & Constant 2002). Karlén, Odnevall Wallinder, Heijerick, Leygraf, and Janssen (2001) have shown that runoff loads from zinc roofs remain relatively constant over time but are affected by the rate of SO_2 in the atmosphere. If the zinc pollution is not dealt with at the source it will become diluted with other stormwater and more difficult to treat. Instead if polluted stormwater is treated directly 'in situ' it can be done so more effectively (Jurries 2003). This could be done using bioretention, employing BMPs, such as the *flow through-planter* (fig. 2).

Figure 2: Illustration of zinc roof connected to flow-through planter for treatment of zinc runoff

FLOW-THROUGH PLANTER, A BIORETENTION BMP

A flow-through planter is a stormwater bioretention BMP that detains and treats polluted runoff (fig. 2) (Portland 2006). Flow-through planters are also a landscape element, and consist of an impervious container with an inlet and an outlet. Runoff is treated with filtration through a soil substrate consisting of sand and soil (Portland 2006). This stormwater BMP is adaptable to many situations, as they can vary in shape and size and can be built in the ground or placed above ground, thus easy to retrofit and connect to an existing downspout from a zinc roof. A drainage pipe drains excess water away from the system into the conventional stormwater infrastructure. There should also be an overflow outlet that can convey water during high flows (Portland 2006). Vegetation adapted to a fluctuating water table should be used for sustainable growth and optimal biological treatment (Portland 2006).

BENEFITS OF BIOCHAR IN BIORETENTION

In order to explore the benefits of using biochar as a soil amendment in flow-through planters, a literature review is conducted. The benefits include increased water treatment, increased water holding capacity, and carbon sequestration.

STORMWATER TREATMENT UTILIZING CATION EXCHANGE CAPACITY

Biochar has been shown to have a high cation exchange capacity[2] (CEC) (Herbert, Hosek, & Kripalani 2012). Cations are positive ions that are attracted to negative surfaces (Brady 2002), such as the surface of biochar (Lehmann & Joseph 2009). Biochar also has a high porosity with fine pores, meaning that biochar has a very high surface area in relation to its volume, which allows a high exchange of ions to take place (Liang, Lehmann, Solomon, Kinyangi, Grossman, O'Neill, Skjemstad, Thies, Luizão, Petersen, & Neves 2006). The main reason biochar has the ability to reduce the pollution of stormwater is that it increases the CEC of the soil. Through soil analysis of Amazonian anthrosols Liang et al. (2006) was able to demonstrate a clear pattern. The CEC in the anthrosols was up to 1.9 times greater than adjacent soils with no content of biochar, which can be explained by the high soil surface area of biochar (Liang et al. 2006). The same article shows that the anthrosols had 4.8 times greater soil surface area in relation to un-impacted soils. The increased CEC is also a result of a high charge density of biochar (Liang et al. 2006).

Data on CEC of biochar is difficult to find and varies throughout the reviewed literature; however, the studies presented here show a clear pattern. A study by Gundale and DeLuca (2006) on the CEC of charcoal from Ponderosa pine and Douglas-fir show values ranging from 19.42 to 34.48 meq/100g[3]. A second study, by students at California Polytechnic State University, San Luis Obispo calculated – through a class lab study using the absorbance NH_4^+ method – that biochar produced from timber has a CEC of 60 meq/100g (Herbert, Hosek, & Kripalani 2012). A 'designer biochar' was also tested which has a CEC of 138 meq/100g, however, it is not presented what type of product the term 'designer biochar' refers to (Herbert, Hosek, & Kripalani 2012). Additionally, a lab study by Morrow (2013), with methylene blue shows that biochar has the potential of sorbtion pollutants in stormwater. The study showed that smaller fractions of biochar had best sorption results. A long retention time is also important for good pollutant sorption (Morrow 2013). However, this study does not explore if the methylene blue sorption is related to the CEC of biochar. Lastly, Sohi et al. (2009) found that CEC increases over time in biochar. If this is due to mechanical breakdown of the particles or if a hydrophobic tendency decreases over time is not possible to determine from this research.

It has also been shown that biochar has a potential in soil remediation (Beesley, Moreno-Jiménez, Gomez-Eyles, Harris, Robinson, & Sizmur 2011), as it has a positive effect in the retention of phyto-toxic substances such as Cd and Zn. Biochar

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[2] Cations are positive charged ions. Cation exchange capacity (CEC) is defined as the total amount of the cations that soil can absorb. CEC is measured in the number of moles of cations that one unit of mass soil can absorb. The measurement is written as milliequivalents per 100g of soil (meq/100g) it can also be written as $cmol_c/kg$ which gives the same value, 1 meq/100g = 1 $cmol_c/kg$ (Brady 2002).

[3] The data from Gundale and DeLuca (2006) is also referred to in the comprehensive book Biochar for Environmental Management by Lehman and Joseph (2009).

with higher CEC and surface area might show an even greater result. Other metals might also be affected by the CEC (Beesley et al. 2011). The immobilization of Ni_2 and Cd_2 are such metals shown by Uchimiya, Lima, Thomas Klasson, Chang, Wartelle, & Rodgers (2010) to be affected by an increase in soil pH through the application of biochar. The production temperature of biochar affects the pH; where a higher pyrolysis temperature results in a higher pH (Ueno et al. 2007; see Sohi et al. 2009). Therefore, adding biochar leads to an increase in soil pH, which in turn leads to immobilization of Ni^{2+} and Cd^{2+}. Several possible mechanisms in soil contribute to the adsorption of metal contaminants. These mechanisms in soil remediation can also be applied to stormwater treatment.

WATER HOLDING CAPACITY OF BIOCHAR

The main reason for constructing bioretention systems is purification of runoff. However, for purification to be fully effective, different types of processes need to take place (Jurries 2003). The biological breakdown of organic pollutants is very important for total purification (Vidali 2001). Apart from this bioretention could enhance denitrification processes in soil. Denitrification is the process that turns nitrate into nitrous oxide and subsequently to nitric gas (N_2). Biological soil remediation is mostly carried out by microorganisms, although some is done by vegetation through phytoremidation. The population of microorganisms is, however, dependent on a stable population of vegetation which will be favored by a stable habitat. With healthy vegetation purification increases (Jurries 2003). Soils with a high sand content are unable to retain much plant available water due to the low amount of meso-pores (Eriksson 2011). Therefore by increasing the water holding purification will be improved.

Biochar has been shown to increase the water holding capacity of soil (Beck, Johnson & Spolek 2010). Research conducted by Beck, Johnson & Spolek (2010) showed that a biochar content of 7% in soil increased water holding capacity by 4.4%. They continue by stating that this increase could affect the retention of stormwater and also improve plant habitat through more plant available water (Beck, Johnson & Spolek 2010). As well, soil micro porosity increases with the application of biochar, which increases water holding capacity, the increase in water retention is described as significant for plant production (Sun, Moldrup, Elsgaard, Arthur, Bruun, Hauggaard-Nielsen & de Jonge 2013). Lehmann and Joseph (2009) state that biochar, having a high surface area and containing a large percentage of macropores, can have a high water holding capacity.

Much of the research on biochar has focused on the agricultural aspects, where productivity is the main focus. However, findings from the agricultural field can successfully be brought into stormwater management. Chan, Van Zwieten, Meszaros, Downie & Joseph (2007) depicted through pot trials with biochar – at application rates of 10 t/ha, 50 t/ha, and 100 t/ha – that the water holding capacity increased with increased applications of biochar. They concluded that biochar had a significant impact on water holding capacity and radish production (Chan et al. 2007)[4].

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[4] Chan et al. (2007) also found that biochar creates a more favorable root environment increasing the ability of plants to utilize the N applied as fertilizer.

CARBON SEQUESTRATION

A third positive effect of biochar is carbon sequestration (Major et al. 2010). The carbureted organic substance or biochar has an extremely long lifespan in soil, 100-5000 years. It thereby has the potential to store atmospheric carbon by binding it into the ground, thus mitigating the green-house gas effect and changes in the climate (Major et al. 2010). Much research has been done on biochar from a climate change mitigation viewpoint. It is believed that the carbon cycle can be altered and carbon can be stored in soil for many years, thereby sequestering anthropogenic carbon from the atmosphere, allowing us to mitigate damages (Major et al. 2010).

In a simplified natural carbon cycle, equal amounts of carbon is stored as organic matter in the ground as being released back into the atmosphere through decomposing of organic matter, the net carbon withdrawal is 0%, (fig. 3 left) (Brady 2002). When organic matter is turned into biochar a net carbon withdrawal of 20% is accomplished in the greenhouse gas budget by storing carbon in the ground (fig. 3 right).

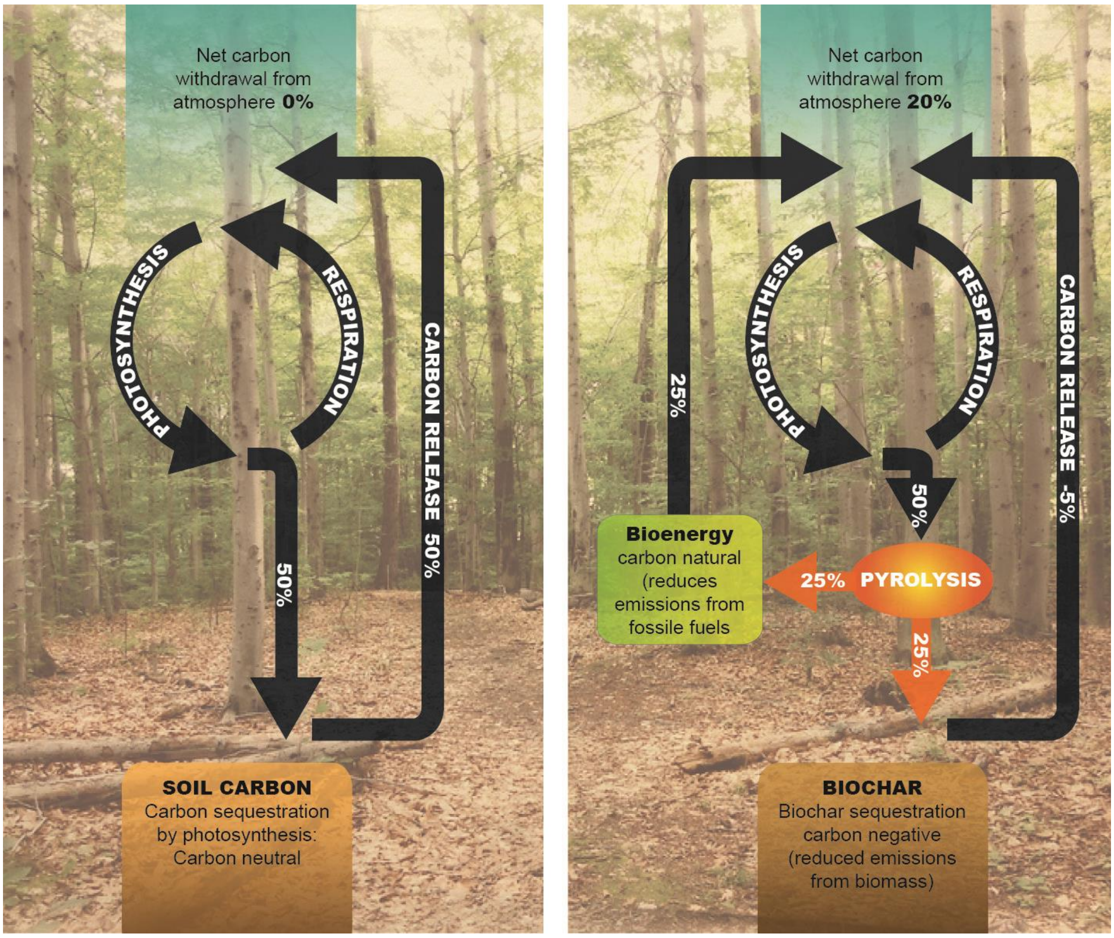


Figure 3: Two greenhouse gas budgets comparing the natural carbon cycle (left) to a carbon cycle with pyrolysis of organic materials to sequester carbon in the ground (right). The carbon cycles are simplified for comparative reasons. Adapted from (Lehmann 2007)

Lehmann (2007) shows three examples of how biochar could reduce greenhouse gases in the atmosphere by sequestering 10 % of the yearly fossil fuel emissions in the US. These include: turning forest residues into biochar; pyrolysis of fast growing vegetation, turning organic matter into biochar; and utilizing crop residues for biochar production to offset anthropogenic atmospheric carbon (Lehmann 2007). However, there is controversy amongst scientists that this will actually work. A recent review of biochar research and climate change mitigation claims that there is not enough data on the long-term effects of biochar to be conclusive (Gurwick, Moore, Kelly & Elias 2013). There are too many parameters and variables that interact to be able to give a clear picture. The lifespan of biochar in soil is said to range from as little as 8 years to a similar number that Lehmann and Joseph (2009) says of 4000 years (Gurwick et al. 2013). One parameter is that biochar affects the microbial community, which increases decomposing rates of organic material (Rousk, Dempster & Jones 2013). This could lead to an unbalance in the green-house gas budget (Gurwick et al. 2013).

4 MODEL

To answer the second question and sub-questions – how to specify a biochar amended soil for a flow-through planter – a scenario was set up (fig. 2). The scenario consists of a galvanized zinc roof situated in Alnarp, Sweden. The roof is connected to a flow-through planter and runoff from the roof is conveyed into the flow-through planter. The flow-through planter contains a soil mix with biochar as a soil amendment. The following calculations attempt to give a theoretical number for the amount of biochar needed to treat runoff from 1m^2 zinc roof, and compare this to other substrates. Additionally, four soil-mixes are designed to further understand how to specify a biochar amended soil for a flow-through planter. Input data for the model has been collected from a variety of sources, which are listed in the following points:

- Data for pollution loads from zinc roofs were gathered from two separate publications, an average was then calculated for the model. The first source had a goal of calculating total pollution load from zinc roofs in Paris – the average load being 7.8 mg/l (Gromaire et al. 2002). The second source is from a field trial in Nacogdoches, Texas. Here roofing was arranged to track pollution rates from different types of roofing materials; one of which was zinc. The zinc pollution load measured was 11.788 mg/l (Chang, McBroom & Scott Beasley 2004). The average value from these two sources is 9.794 mg/l.
- Zinc when dissolved in water is a positive ion with a charge of 2, Zn^{2+}. The molar mass of zinc is 65.409 g/mol (LACC n.y).
- Data on cation exchange capacity (CEC) is collected from several studies. Jurries (2003) presents data on CEC of different substrates; sand 1-5 meq/100g, 5 meq/100g is used, loam has a CEC of 15 meq/100g. For compost CEC is 200-400 meq/100g, an average of 300 meq/100g is used. (Gundale & DeLuca 2006) determine CEC on charcoal of Ponderosa pine and Douglas-fir to an average of 25.98 meq/100g. Data for biochar CEC has been gathered from Herbert et al. (2012) where biochar from timber had a CEC of 60 meq/100g and a designer biochar had a CEC of 138 meq/100g.
- Rain data is collected from SMHI for Alnarp, Sweden (SMHI 2009). There is 700 mm of precipitation in this part of the country. The yearly runoff volume is adjusted down to 90% due to the fact that some water will divert from the system and not pass through the flow-through planter.

- Average biochar bulk density is 0.5 g/cm^3 for biochar derived from White pine, Bass wood, Red oak, and Hard maple at 900°C pyrolysis (Byrne & Nagle 1997; see Lehmann & Joseph 2009).
- Bulk density of sand is 1.44 g/cm^3, loam 1.6 g/cm^3, charcoal 0.24 g/cm^3, and compost 0.48 g/cm^3 (EPA 2006).
- Increase in the water retention per % of biochar is 0.63% (Beck, Johnson & Spolek 2011).

To model the substrate quantity for a flow-through planter the following equation was used.

$$\frac{R * M * V * e * A * 1000}{CEC} = S$$

R - Runoff from roof (g/l)
M - Molar mass of pollutant (g/mol)
V - Yearly volume of precipitation (l/year)
e - charge of ion
A - Adjustment value, typically 0.75 (75%)
CEC - Cation exchange capacity of substrate (meq/100g)
S - Weight of substrate needed for treatment (kg/year)

The outcome of this model show that to treat 75% of the annual runoff from 1m^2 zinc roof either 3.14 kg sand, 1.05 kg of loam, 0.61kg of charcoal, 0.26 kg biochar from timber, 0.11kg designer biochar or 0.052kg compost is needed (fig. 4). This is due to the differences in cation exchange capacity. In relation to the weight of sand it takes 33.33% loam, 19.25% of charcoal, 8.33% of biochar from timber 3.61% of designer biochar and 1.67% of compost to treat 75% of the annual runoff, (table 1). 6000% more sand is needed compared to the most efficient substrate, compost.

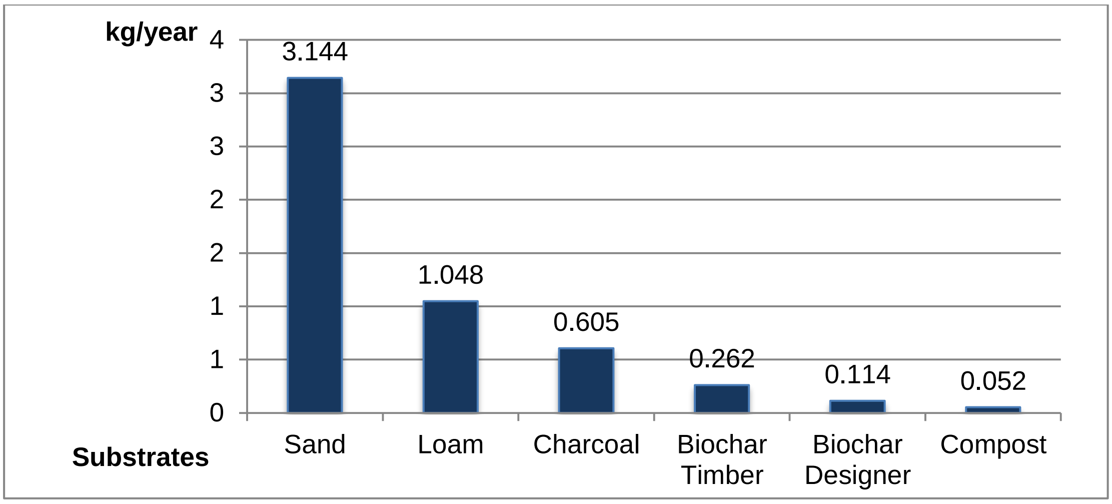


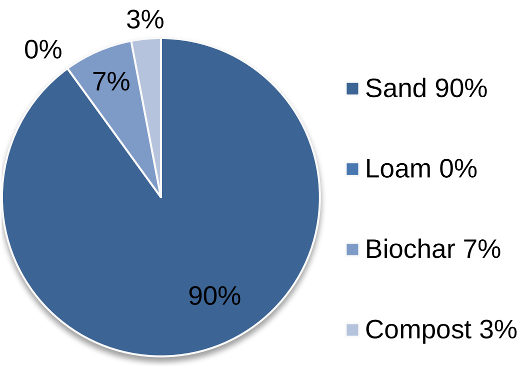
Figure 4: Chart showing annual kg of substrates needed to treat Zn runoff from 1m^2 zinc roof

Table 1: Table showing kg of substrate needed in percentage in relation to sand and reversely in relation to compost.

	Unit	Sand	Loam	Charcoal	Biochar Timber	Biochar Designer	Compost
Substrate needed in relation to sand	%	100%	33,33%	19,25%	8,33%	3,61%	1,67%
Substrate needed in relation to compost	%	6000%	2000%	1155%	500%	217%	100%

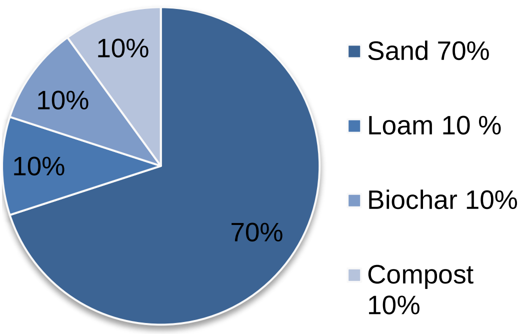
To further evaluate the impact of treatment ability of the different substrates the scenario of a zinc roof connected to a flow-through planter is refined further. The zinc roof and thus size of catchment area is decided to be 100m^2, considered to be half the total roof surface of a normal sized house. The lifecycle of the flow-through planter has been estimated to be 20 years with the motivation that the plants will need to be replaced after that. Four soil-mixes were developed consisting of varying ratios of sand, loam, biochar (derived from timber) and, compost (fig. 5). The recipes for the soil-mixes were based on AMA Type 1 soils (Svensk Byggtjänst 2010). They are designed to have different physical characteristics for stormwater treatment, plant habitat, and lifecycle of bioretention.

Soil-Mix 1



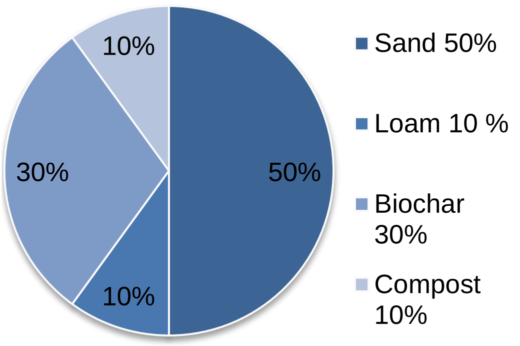
Total volume of Soil-mix (m^3)	8.2
Increase in water holding capacity (due to biochar content)	4%
Size in relation to catchment area (500mm soil depth)	16%

Soil-Mix 2



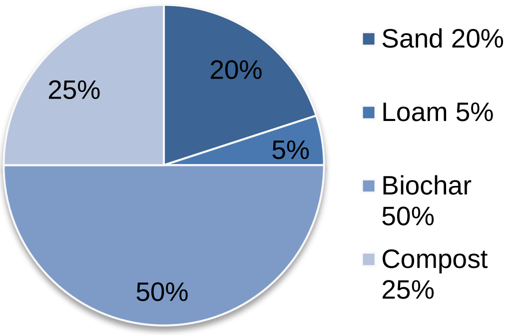
Total volume of Soil-mix (m^3)	6.7
Increase in water holding capacity (due to biochar content)	6%
Size in relation to catchment area (500mm soil depth)	13%

Soil-Mix 3



Total volume of Soil-mix (m^3)	4.9
Increase in water holding capacity (due to biochar content)	19%
Size in relation to catchment area (500mm soil depth)	10%

Soil-Mix 4



Total volume of Soil-mix (m^3)	2.1
Increase in water holding capacity (due to biochar content)	32%
Size in relation to catchment area (500mm soil depth)	4%

Figure 5: Table showing 4 soil-mixes with different content of sand, Loam, Biochar (derived from timber), and compost. Total volume of substrate, increase in water retention and size in relationship to the catchment area of 100m^2 is also presented.

Soil-mix 1 consists of 90% sand, 0% loam, 7% biochar, and 3%compost. This soil-mix was designed for maximum hydraulic conductivity to be able to handle large flows. This resulted in a total volume of substrate needed to theoretically treat 75% of zinc runoff of 8.2m^3. This soil-mix gave a 4% increase in water retention and the size of the flow-through planter in relationship to the catchment area is 16% with a 500mm soil depth.

Soil-mix 2 consists of 70% sand, 10% loam, 10% biochar and, 10%compost. This recipe is designed to be similar to the soils used in the industry for bioretention (Stromberg 2010). This resulted in a total volume of substrate needed to theoretically treat 75% of zinc runoff of 6.7m^3. This soil-mix gave a 6% increase in water retention and the size of the flow-through planter in relationship to the catchment area is 13% with a 500mm soil depth.

Soil-mix 3 consists of 50% sand, 10% loam, 30% biochar and, 10%compost. This soil-mix was designed for a realistic mixture for bioretention in flow-through planters. This resulted in a total volume of substrate needed to theoretically treat 75% of zinc runoff of 4.9m^3. This soil-mix gave a 19% increase in water retention and the size of the flow-through planter in relationship to the catchment area is 10% with a 500mm soil depth.

Soil-mix 4 consists of 20% sand, 5% loam, 50% biochar and, 25%compost. The last soil-mix is designed to offer maximized CEC to volume ration. This resulted in a total volume of substrate needed to theoretically treat 75% of zinc runoff of 2.1m^3. This soil-mix gave a 32% increase in water retention and the size of the flow-through planter in relationship to the catchment area is 4% with a 500mm soil depth.

5 DISCUSSION

The attempt to model a flow-through planter treating runoff from a zinc roof has led to several interesting insights on which factors are important to consider in the implementation of biochar in bioretention. However, there are many factors that have not been taken into account and many assumptions have been made, to simplify and to be able to calculate the treatment effect. The following discussion takes this into account and compares the results to create a better understanding of the topic.

BENEFITS AND DISADVANTAGES OF SUBSTRATES

The results from the model clearly show the importance and impact of a high CEC in the substrate for an efficient Zn removal from stormwater. Soil with a high CEC increases the performance of the bioretention systems, thereby removing a higher amount of pollutants with less substrate. The six different substrates: sand, loam, charcoal, biochar from timber, designer biochar, and compost, all contribute differently to the treatment efficiency. It is apparent that all substrates, except sand, have a large impact on Zn removal. However, the different substrates possess other important functions that when combined can enhance each other to create an optimal soil mix. An optimal soil mix is arguably a mixture of different substrates to draw the positive effects from each and to minimize their negative effects.

Two mineral substrates have been part of the model, sand and loam. Sand has the positive characteristics that it is stable and its performance is sustained over time. It does not age or change properties as much as other substrates; it is not easily weathered into smaller particles. On the other hand, it has a very low CEC, 5meq/100g, and will therefore not contribute much to pollution treatment or plant habitat. Loam provides a better plant habitat and provides a slightly higher CEC of 15meq/100g (Jurries 2003). Further, loam consisting of a mixture of sand, silt, and clay can potentially become heavily compacted; therefore the ratio of loam should be kept low.

Like loam, compost also has the positive effect that it provides plants with nutrients and creates a good habitat for plant roots and microorganisms (Stromberg 2010). It is, however, largely altered by decomposition as shown by Hadas and Portnoy (1997) and will therefore age. A study issued by CalTrans and performed by Claassen and Young (2010) look at compost and leaching (see Stromberg 2010). They suggest that metal, carbon, and phosphorus leaching losses are initially high, but decline as the compost ages; as well, concentrations of potassium and nitrate increase slightly (Claassen & Young 2010; see Stromberg 2010). This means that adding compost to a bioretention systems will lead to leaching of certain nutrients that will then enter waterways. Biochar, on the other hand, sustains its positive effects over a much longer time; yet, it is also prone to aging due to mechanical breakdown (Sohi et al. 2009). Sohi et al. (2009) also show that CEC in biochar increases over time. This aspect is interesting in an agricultural context where biochar stays in the soil for a long time, but in bioretention applications this may not be of importance due to the relative short lifecycle (20 years) of bioretention systems due to clogging.

Clogging poses a threat to the performance of bioretention systems (Le Coustumer et al. 2012). To maintain the hydraulic conductivity of the filter media and to limit sediment entering the bioretention system, the layout and design are significant (Le Coustumer, Fletcher, Deletic, Barraud & Poelsma 2012). Sediment is unlikely to be a problem in the scenario described in this study. A roof is the catchment area for the flow-through planter. Roofs can be considered cleaner than streets, therefore the problem with sediment clogging is relatively small. However, the mechanical weathering of biochar may cause clogging. As biochar weathers it can migrate and fill the pores of the sand and potentially lower the performance of the flow-through planter during its lifecycle.

It can been seen from the benefits and disadvantages presented above, that all four soil-mixes (fig. 5) have positive and negative impacts on: stormwater pollution treatment, stability over time, and plant habitat. Soil-mix 1 is perhaps the most stable mix and is designed thereafter. It mainly consists of sand and will therefore require a very large volume due to the low CEC. It will also provide a poor plant habitat. The 7% content of biochar will provide a 4% increase in water content. Soil-mix 2 is designed to resemble bioretention soils and has a slightly lower sand content of 70% and then an equal share of 10% of loam, biochar, and compost, this provides a stable soil that will not age drastically. It does provide a similar increase in water holding capacity as soil-mix 1 but will, due to the higher content of compost, provide a better plant habitat. Soil-mix 3 is an attempt to design an optimal soil for flow-through planters treating pollution from zinc roofs. It has even lower sand content of

50% and will therefore not be very stable over time. It has a high biochar content of 30% and can thus treat pollution more effectively and has a high increase in water holding capacity of 19% as compared to pure sand. Lastly, soil-mix 4 has the highest biochar content, half the volume and only 25% sand. This substrate is able to treat zinc pollutants in stormwater with a very small volume and a catchment- to bioretention area of 4%, which is close to the numbers discussed by EPA (1999) where a bioretention size of 5-7% is discussed as optimal. This allows the flow-through planter to be fitted into a small space and still efficiently treat stormwater pollutants. However, soil-mix 4 is prone to aging and clogging and will consequently not perform optimally after some time. It also has a very high increase in water holding capacity of 32%, which provides a poor plant habitat due to a large pore volume occupied by water creating anaerobic conditions.

LIFECYCLE OF BIORETENTION

As discussed earlier, when considering the lifecycle of a flow-through planter the topic of carbon sequestration is significant. The lifecycle of a flow-through planter is very short in comparison to the time perspective when discussing carbon sequestration, which varies 100-5000 years (Major et al. 2010) to as little as 8 years (Gurwick et al. 2013). How these environmental benefits apply to biochar in bioretention is uncertain. However, sequestrated carbon could potentially be transferred to another location after its use as bioremediation media; continuing the sequestration. Then additional emissions from handling and transportation would have to be added to the greenhouse gas budget. Major et al. (2010) discuss the possibility of climate change mitigation through large-scale carbon sequestration. However, it is doubtful if the relatively small amount of biochar in flow-through planters or other bioretention systems would have much of an impact on climate change mitigation. After this study I believe that carbon sequestration is an insubstantial argument for its application but could be seen as a small benefit in addition to others.

WATER HOLDING CAPACITY

Water holding capacity is important for plant growth and both biochar and compost can improve this capacity (Beck, Johnson & Spolek 2011; Stromberg 2010). Beck, Johnson and Spolek (2011) demonstrated that 7% biochar in a green roof substrate gave an increase of 4.4% in water holding capacity. Compost has a similar effect (Aggelides & Londra 2000). Aggelides and Londra (2000) point out that the increase in water holding capacity was greater in a loamy soil than in a clay soil when adding compost. I would argue that an increase in water holding capacity would be even more significant in a sandy soil, which is used in bioretention systems, due to the even larger quantity of macro pores (Eriksson 2011). Increase in water content in a bioretention soil must be balanced to a hydraulic calculation because when pores are filled with water the total air filled pores will be lower. This means that the total volume of bioretention facility has to be increased to make up for this loss in air filled volume to accommodate large volumes and intensities of stormwater.

ZINC IS TOXIC FOR PLANTS

Phyto-toxic Zn accumulates over time in soil (Beesley et al. 2011). Vyslouilová, Tlustos, Száková and Pavlíková (2003) study what results this has on vegetation, by looking at heavy metal uptake in Willow, *Salix ssp*. The research indicated that

Willow has the potential for Zn uptake, but that its growth is stunted by an increased Zn concentration (Vyslouilová et al. 2003). The same study also shows that arsenic (As) and cadmium (Cd) accumulates with a higher Zn content in the soil (Vyslouilová et al. 2003). These insights give a new dimension to the problem. When selecting plant species for this situation there are several factors to take into consideration. First, will the plants survive the increasingly phyto-toxic environment? If so, species with physical properties that can handle such harsh habitat should be selected. Second, if Zn could be accumulated in plant tissue – thus lowering the pollution levels in soil and 'freeing up space' for new cations – the lifecycle of the bioretention could be prolonged or the size could be decreased. The above ground biomass may also be harvested to remove the Zn from the system. The affects of vegetation are, however, disregarded from in the model.

METHOD DISCUSSION

To answer the thesis questions and sub-questions the methods used are: literature review, interview, and model. This is to give a broad variety of sources and to approach the thesis questions from different angles. Source criticism and reliable literature has been used. Although most literature is peer reviewed there are a few sources where the reliability needs to be assessed. For instance the source used for cation exchange capacity is a student class lab report and has not been published nor peer reviewed. It is, however, one of the few sources found on this subject and follows trends discussed by a more reliable source, see Lehmann & Joseph (2009). As for the method of interview, only one is conducted. It would have been interesting to interview supplementary informants in the field to get a more comprehensive and diverse view of biochar implementation. The issue is that the subject is relatively new in Sweden, and there are only a few people who possess knowledge on the topic and thus provide first-hand information. Producers can be contacted but it is difficult to assess their bias.

ASSUMPTIONS AND LIMITATIONS

The zinc concentrations used are probably not 100% accurate for a Swedish situation. This is because concentrations vary due to many variables. The concentration from Nacogdoches, Texas is higher than the ones from Paris, France. The reason for this is expected to be the difference in climate (Popova, Sokolova, Raicheva & Christov 2003). Nacogdoches has a higher annual temperature than Paris and this is probably the cause for the higher Zn concentration, 12.4°C (Weatherbase, n.y.) vs 18.7°C (Weatherbase, n.y.). Alnarp has an average yearly temperature of 7°C which is considerably lower than the other two (Weatherbase, n.y.). Atmospheric SO_2 can also cause an increase in zinc concentration from the roofs where data is collected (Falk et al. 1998, see Gromaire et al. 2002). Sulphur concentration in rain is higher in areas with high fossil fuel emissions, such as from traffic. Texas and Paris have high emissions compared to Alnarp thus would the corrosion rate be lower in Alnarp (ICPP 2013). Additionally, the test roofs in Texas were new at the time of the field test, as opposed to the roofs in Paris that are old. This may also have affected the results from the two separate studies. However, Karlén et al. (2001) pointed out that the zinc concentrations are relatively constant over time. In the model an average is used to account for this. Additionally, it is assumed that the bioretention system is able to receive water all year round.

Whereas in reality, there would be a time in winter when the substrate is frozen and stormwater would not be able to percolate and the purification would then be zero.

In the model it is assumed that 75% of the water passes through the substrate. Without doing a complimentary hydraulic calculation it is uncertain if this number is accurate. Some water will evaporate directly off the roof. Some runoff will, during intense storms with high flows, be forced into an overflow structure in the flow-through planter thus diverting polluted water from the treatment system (fig. 2). The model for treatment should therefore be combined with a hydraulic calculation to determine the intensities and volumes of roof runoff, to be able to adjust the size of the system to avoid diversion. Diversion of stormwater should be avoided for maximum treatment but in a live scenario this is probably not possible.

Water holding capacity has been modeled using the data presented by Beck, Johnson and Spolek (2011). It is not presented if water holding capacity is linear to applied weight of biochar, and therefore may not be extrapolated from the results. Additionally, it is uncertain if the data can be applied to types of bioretention systems other than green-roofs. In the model the water holding capacity of compost is disregarded from the calculation, although it would affect the result positively (Stromberg 2010).

Another limitation in the model is that it is assumed that no other cations apart from Zn^{2+} will enter the substrate. For a more accurate result from the model other pollutants such as ammonium needs to be taken into account. , Atmospheric ammonium NH_4^+ deposition is substantial with 15 kg/ha or 1.5 g/m^2 annually (Hansen, Karlsson, Ferm, Karlsson, Bennet, Granat, Kronnäs, Brömssen, Engardt, Akselsson, Simpson, Hellsten & Svensson 2013). Comparing this to the annual zinc runoff of 6.9 g/m^2 shows that NH_4^+ effect on the model needs to be considered. The NH_4^+ loads are 22% of the Zn loads. Since Alnarp is situated close to the ocean the effects of wind transported chlorine would possibly be changing the outcome of the model as well (Spicer, Chapman, Finlayson-Pitts, Plastridge, Hubbe, Fast & Berkowitz 1998).

6 CONCLUSION

Generally, Bioretention BMPs are modeled with hydraulics in focus to be able to handle estimated stormwater flows. This research has brought more insight into how bioretention BMPs could be modeled with another approach; the approach of qualitative treatment and pollutants removal in stormwater. Sizing through treatment should however, be combined with a hydraulics calculation.

This study has shown that biochar is a viable option as soil amendment for bioretention soils. Biochar brings many positive aspects similar to the ones of compost, but in a more stable form, which allows the substrate to be stable over time. The positive aspects are firstly a high CEC – that possibly increase over time – that allows a smaller total volume of substrate to be used. Biochar also increases the water holding capacity of soil, which is positive for the vegetation used in bioretention systems. This is to create a better plant habitat in order to give the vegetation the possibility of increased phytoremediation and microorganisms to populate the soil. Lastly, biochar brings the positive aspect of carbon sequestration. This has however, been understood as an insubstantial argument for its application in bioretention systems due to the small quantities used. A problem with biochar implementation concluded from this study is the lack in supply. This lack in constant supply is harmful to its implementation, as production methods develop with char in focus, there will probably be a greater supply.

Findings from this research show that biochar is an interesting alternative for increasing bioretention efficiency. For flow-through planter applications, treating runoff from zinc roofing, a soil-mix consisting of 50% sand, 10% loam, 30% biochar, and 10% compost is considered to be the optimal soil-mix. This soil will theoretically treat the runoff if the area of the flow-through planter is 10% of the catchment area with a 500mm soil depth. Additionally it will provide a 19% increase in water holding capacity improving plant habitat. It is also reasonable stable over time.

By implementing biochar into bioretention systems its positive aspects could be utilized to produce a more efficient substrate for treatment of cations in stormwater. This will allow bioretention systems to be refined and discharged water will be less polluted. This means waterways will be healthier and other ecosystem services enhanced, allowing us to mitigate the damages done to the environment.

FURTHER RESEARCH

The outcome of this study is theoretical. It would be interesting to compare the results from this study to a field test. Zinc roofs could be set up and runoff could be conveyed into different substrates matching the ones in the model of this paper. Effluent pollutant loads could be measured to see how well the different substrates perform in pollution removal. This field of research would be very valuable in the work towards a more effective stormwater treatment.

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Personal Communication

Embrén, B., 140213. Biochar as soil amendment in the City of Stockholm.

Fransson, A-M., 140318. Biochar for increased in plant growth

APPENDICES

Kg of substrate needed to treat runoff from 1m^2 zinc roof

	Unit	Sand	Loam	Charcoal	Biochar Timber	Biochar Designer	Compost	Comment
Runoff Zinc Zn	**g/l**	**0,0098**	**0,0098**	**0,0098**	**0,0098**	**0,0098**	**0,0098**	Average of Texas and Paris
Molar mass Zn	**g/mol**	**65,409**	**65,409**	**65,409**	**65,409**	**65,409**	**65,409**	
Mol Zn in solution from roof	mmol/l	0,150	0,150	0,150	0,150	0,150	0,150	
Volume per year for 1m2 roof	**l/y**	**700,0**	**700,0**	**700,0**	**700,0**	**700,0**	**700,0**	Yearly Precipitation in Alnarp
Mol per year	mmol/year	104,814	104,814	104,814	104,814	104,814	104,814	
Amount passing through	**%**	**75%**	**75%**	**75%**	**75%**	**75%**	**75%**	Assumed
Adjusted mole per Year	mmol/year	78,611	78,611	78,611	78,611	78,611	78,611	
Charge of pollutant ion	**e**	**2,0**	**2,0**	**2,0**	**2,0**	**2,0**	**2,0**	Zn2+
Adjusted value due to charge	meq/year	157,221	157,221	157,221	157,221	157,221	157,221	meq=mmol
CEC of substrate	**meq/100g**	**5,0**	**15,0**	**25,98**	**60,00**	**138,50**	**300,0**	
Yearly Zn treatment	g/year	5,142	5,142	5,142	5,142	5,142	5,142	
w/w	%	3,14	1,05	0,61	0,26	0,11	0,05	
Weight of substrate needed	kg/year	3,144	1,048	0,605	0,262	0,114	0,052	per m2 roof
Bold = input values								

Volume (m^3) of soil-mix needed to treat runoff from 100 m^2 zinc roof for 20 years.

	Unit	**Sand**	**Loam**	**Charcoal**	**Biochar Timber**	**Biochar Designer**	**Compost**	**Comment**
Weight of substrate needed	kg/year	**3,144**	**1,048**	**0,605**	**0,262**	**0,114**	**0,052**	
Bulk density	**kg/l**	**1,440**	**1,600**	**0,240**	**0,500**	**0,500**	**0,480**	
Volume	dm^3	4,528	1,677	0,145	0,131	0,057	0,025	
Lifecycle	**years**	**20**	**20**	**20**	**20**	**20**	**20**	Assuming a 20 lifecycle
Total volume	m^3	0,0906	0,0335	0,0029	0,0026	0,0011	0,0005	
Size of roof	**m^2**	**100**	**100**	**100**	**100**	**100**	**100**	
Soil-mix 1		**Sand 90%**	**Loam 0%**	**Charcoal**	**Biochar 7%**	**Biochar Designer**	**Compost 3%**	**Comment**
Volume for 100m2 roof	m^3	9,056	3,354	0,290	0,262	0,114	0,050	
Amount in soil mix	**%**	**90%**	**0%**		**7%**		**3%**	100%
Adjusted volume	m^3	8,150	0,000		0,018		0,002	
Total volume	m^3						**8,2**	
Increase in WHC per % of BC	%						0,63	
Increase in water hold capacity	%						**4%**	Water holding capacity
Relation to watershed	%						16%	Assuming 500mm deep
Soil-mix 2		**Sand 70%**	**Loam 10%**	**Charcoal**	**Biochar 10%**	**Biochar Designer**	**Compost 10%**	**Comment**
Volume for 100m2 roof	m^3	9,056	3,354	0,290	0,262	0,114	0,050	
Amount in soil mix	**%**	**70%**	**10%**		**10%**		**10%**	100%
Adjusted volume	m^3	6,339	0,335		0,026		0,005	
Total volume	m^3						**6,7**	
Increase in WHC per % of BC	%						0,63	
Increase in water hold capacity	%						**6%**	Water holding capacity
Relation to watershed	%						13%	Assuming 500mm deep
Soil-mix 3		**Sand 50%**	**Loam 10%**	**Charcoal**	**Biochar 30%**	**Biochar Designer**	**Compost 10%**	**Comment**
Volume for 100m2 roof	m^3	9,056	3,354	0,290	0,262	0,114	0,050	
Amount in soil mix	**%**	**50%**	**10%**		**30%**		**10%**	100%
Adjusted volume	m^3	4,528	0,335		0,079		0,005	
Total volume	m^3						**4,9**	

Increase in WHC per % of BC	%						0,63	
Increase in water hold capacity	%						**19%**	Water holding capacity
Relation to watershed	%						10%	Assuming 500mm deep
Soil-mix 4		**Sand 20%**	**Loam 5%**	**Charcoal**	**Biochar 50%**	**Biochar Designer**	**Compost 25%**	**Comment**
Volume for 100m2 roof	m^3	9,056	3,354	0,290	0,262	0,114	0,050	
Amount in soil mix	**%**	**20%**	**5%**		**50%**		**25%**	100%
Adjusted volume	m^3	1,811	0,168		0,131		0,013	
Total volume	m^3						**2,1**	
Increase in WHC per % of BC	%						0,63	
Increase in water hold capacity	%						**32%**	Water holding capacity
Relation to watershed	%						4,2%	Assuming 500mm deep
Bold = input values								

Qualitative Interview Questions
Björn Embrén, Tree Specialist at the City of Stockholm 14/2/14

- **Could you tell me briefly about the projects where you use biochar?**
  Kan du berätta kortfattat om dina projekt där du använder biokol?

- **What advantages do you see with biochar?**
  Vad ser du för fördelar med biokol?

- **What disdvantages do you see with biochar?**
  Vad ser du för nackdelar med biokol?

- **How do you see biochar being used in the future?**
  Hur ser du på framtida användning av biokol?

- **Have you had any thought on implementing biochar for stormwater?**
  Har du haft några tankar på att använda biokol i dagvattensammanhang?

- **Do you see any issues with the combination biochar and stormwater?**
  Ser du något problem med kombinationen biokol och dagvatten?