LAMK Lahden ammattikorkeakoulu
Lahti University of Applied Sciences

EVALUATION ON THE QUALITY OF GREEN ROOF RUN OFF BASED ON NUTRIENTS

Case Study Jokimaa, Lahti

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MOHAMMADI, RUBABA: Arviointi vihreä kattojen valumia laatuun perustuvat ravinteet Tapaustutkimus Jokimaan, Lahti
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TIIVISTELMÄ

Kaupunkiasumisen viherkatot ovat yksi innovatiivisimmista ratkaisuista, joiden avulla voidaan lieventää ilmastonmuutoksen aiheuttamia ympäristöongelmia. Viherkatot vähentävät pintavalumia, parantavat ilmanlaatua sekä vähentävät kaupunkien lämpösaarekkeiden vaikutuksia. Viherkattojärjestelmän vaikutuksesta valumien laatuun käydään kuitenkin keskustelua. Tämän tutkimuksen päätarkoitus oli tutkia viherkaton vaikutusta suotoveden ravinteisiin. Tutkittujen koeviherkattojen koostumus sisältää enimmäkseen kierrätettyä, murskattua tiiliseosta sekä vähäisen osuuden kompostia, kuorihaketta ja turvetta. Kaksi suunniteltua kasvillisuustyyppiä muodostuivat esikasvatetusta sedum-niittymatoista tai istutuksista, jotka kasvatettiin siementen ja pistokkaiden avulla. Lisäksi kenttäkokeessa tutkittiin biohiilellä tehtyjen parannusten potentiaalia suotoveden ravinteiden vähentämiseksi erilaisilla viherkattojen kasvillisuuskoostumuksilla.

Veden laadun mittaustulokset osoittivat, että viherkatot vapauttivat merkitsevästi korkeampia ravinnepitoisuuksia kuin kontrollikatot, joissa ei ollut kasvillisuutta eikä kasvualustaa. Näin ollen valumamäärän väheneminen ei vähentänyt ravinnemassan aiheuttamaa kuormitusta . Voimakas sade näytti huuhtovan pois ravinteet , eikä ajan kuluminen parantanut viherkaton valuman laatua. Biohiili ei kyennyt vähentämään ravinnepitoisuutta ensimmäisenä vuotena, mutta järjestelmien kehittymisen myötä ravinnepäästöjen tilanne parani.

Yhteenvetona voidaan suositella kokonaisvaltaista tutkimusta, jossa arvioidaan optimaalista lannoitteen ja kompostin suhdetta ravinnekoostumusten perusteella ja eri kasvien ravinnevaatimuksia. Lisätutkimuksia tarvitaan, jotta voidaan kehittää paras mahdollinen, optimaalisesti toimiva viherkattoratkaisu , jossa suotoveden ravinnepitoisuus ei ole liian suuri.

Asiasanat: viherkatto, ravinne, biohiili, kasvillisuustyyppi

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ABSTRACT

The urban green roof is one of the innovative solutions to mitigate climate change via reducing surface runoff, improving air quality, and reducing the effects of urban heat islands. However, a debate exists over the role of green roof systems in runoff quality. The major purpose of this study was to investigate the impact of green roofs on nutrients leachate in the runoff. The growing media of the experimental green roofs in case study consisted mostly of recycled, crushed brick mixture and a small portion of compost, crushed bark, and peat. Two types of designed vegetation consisted of pre-grown sedum-meadow mats or planting with seeds and plug plants. Furthermore, the potential of biochar amendment to decrease nutrients leachate was studied for different vegetation establishment methods in a field experiment.

The water quality results showed that the green roofs released significantly higher concentrations of nutrients than the bare control roofs without substrate and vegetation. Green roofs reduced runoff volume but did not mitigate the nutrients mass load. The extreme rain in August 2014 seemed to wash out the nutrients and increasing the duration time did not improve the quality of green roof runoff. Biochar was not able to decrease nutrients concentration during the first year, but it started to improve nutrients discharge when the systems had matured.

Overall, a holistic study of optimum fertilizer or compost amendment based on their nutrients composition and different plants requirements for nutrients is recommended. More investigation is needed to find optimal solutions on how to construct green roofs that do not leach more nutrients.

Keywords: green roof, nutrients, biochar, vegetation type

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ABBREVIATIONS

TN	Total Nitrogen
TP	Total Phosphorous
DOC	Dissolved organic compound
TKN	Total Kejeldal Nitrogen
ADWP	Antecedent dry weather period
Cu	Copper
Pb	Lead

1 INTRODUCTION

Increasing population in cities and growth of urbanization has to expand impermeable areas, deforestation and a dramatic loss of green areas. Chaos urbanization has numerous environmental problems such as climate change, extreme rainfall in some regions, in contrast with water famine in other districts, and urban heat island effects (Gill, Handley, Ennos & Pauleit 2007,115-131). Furthermore, an increase of impervious areas due to urbanization increases the volume of urban stormwater runoff that is higher than municipal storm water transmission canals capacity. On the other hand, groundwater tables are declining due to a loss of discharging and infiltration water by ground; that is a potential threat in the future, especially in semi-arid and arid regions. Additionally, groundwater quality is being deteriorated due to decrease the permeable soil areas by industrial and human activities, even though the soil treats the pollutants and act as a filter for water pass through it. As well as the human need to green spaces as a place for rest and recreation.

Innovative green building techniques involving the creation of green infrastructure can be used as tools to mitigate these increasing challenges and can be actively encouraged within urban planning strategies. Green roofs are a type of green infrastructure that can also be classified as a green building technique since they are manmade and developed as a part of a building structure. A green roof is one of the innovative, promising solutions to mitigate urbanization challenges and benefits to the public and the environment (Razzaghmanesh, Beecham & Kazemi 2014, 651-659).

Nevertheless, many studies propose that green roofs sequester nutrients while several other studies have shown that the green roof growing media serves as a nutrients source in runoff and expose adverse effect on receiving water resources. Nitrogen compounds accelerate eutrophication in water resources causing health problem for public and equations. Phosphorous is another major nutrient which causes eutrophication. The desired soil amendment that prevents nutrients leaching into a runoff would be effective. One soil amendment that may be able to solve this problem in green roof soil is biochar (Beck, Johnson & Spolek 2011, 1-8).

Therefore, the main goal of this study is to evaluate the impact of green roofs on the quality of runoff focusing on these essential nutrients in pilot green roofs in field conditions.

2 LITERATURE REVIEW

2.1 The definition and structure of green roof

Green roof or garden roof is a roof of a building that is covered with plants. This lightweight roofing engineered system is designed to plant growth, as well as protect the roof and creating more green space for better quality of urban life.

Green roofs usually consist of a waterproof membrane, root barrier, drainage layer, filter fabric, growing media, and vegetation layer (Fig.1). It is extremely important to choose proper green roof materials for longer durability and sustainable design.

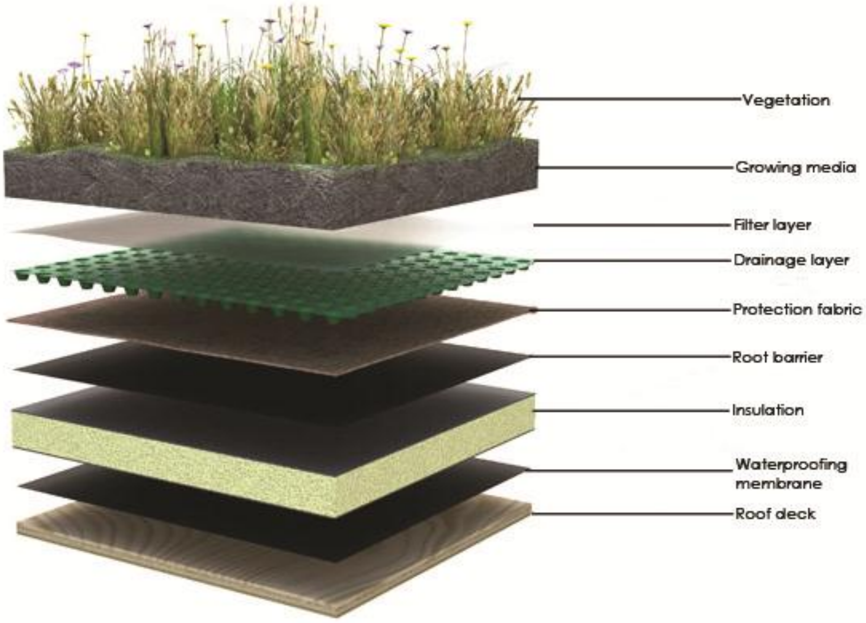

Figure1. Schematic of the green roof structure (Soco construction 2013.)

The base layer is the waterproofing layer which is made of an elastic or thermoplastic material. It should be non-biodegradable and adequately elastic to withstand pressure, retaining water in a heavy rainstorm and should be impervious to root entrance and acid leachate. (Conservation technology 2008.)

The second layer is a root barrier layer, which protects of under layer from root penetration. Root influence and leaks can harm the roof membrane. The root barrier materials should be flexible and resistance to cracking and perforation. The earlier material was polyethylene consisting of two more multifilament grid layers, but nowadays RBM 400 and Blackline 500 are common. (Lange , Puffenberger, Bollineni & Wei 2008.)

The next layer is the drainage layer that is necessary for the roofs with slope angle less than 10°. Roofs with steeper angles can drain naturally due to gravity. It should be highly resistant to retain rainwater and provide humidity back to the substrate during drought periods and provide more space for root growth.

Granular drainage layers were common drainage layer in the past, whereas nowadays different light substances like permeable, plastics or polystyrene and recycled construction materials are used as a drainage layer. (Dabbaghian 2014.)

The fourth layer is a filter layer which is prepared of permeable substance to prevents soil particles of the growing medium and plant entering lower layers. In most green roofs a semipermeable propylene fabric is utilized. (Dabbaghian 2014.)

The top layer is the soil, growing medium or the substrate layer. It must be light to prevent high pressure on the roof and should provide an adjusted equilibrium between water retention and drainage. The substrate must consist of approximately 75%-80% of inorganic and 20%-25% of organic compost.

Different materials have been utilized as a substrate, such as crushed brick, mineral aggregates, compost, coir and clay soil and other additives, such as crumb rubber, paper ash, clay and sewage sludge. However, more research should be done for applying recyclable materials and sludge regards their potential negative impacts on the environment. For instance, if applied sludge was not sanitary and contains more organic material, it starts to decompose and harms humans and the environment.

Vegetation is a fundamental element in a green roof. It can influence the runoff quantity by decreasing runoff via better evapotranspiration and uptaking water by zone root. Plant types for green roofs should be adapted to local climate conditions and can tolerate antecedent and high temperature, freezing, and the wind. (Dabbaghian 2014.)

2.2 Types of green roof

Green roofs are classified into two categories: extensive and intensive. Extensive roofs are characterized by light substrate depth of less than 15 cm. Moreover, due to shallowness depths , plants are often limited to grasses and plants such as sedums, grass, and moss that can tolerate extreme weather conditions, high winds, and drought. The advantages of an extensive roofing system are that they are lighter due to less growing media and they need a lower capital operation and maintenance costs than intensive green roofs.

Intensive roofs have substrate depths greater than 15 cm to support larger and more varied vegetation, including small trees and shrubs. Hence, the structure should support the heavier weight, which necessitates higher capital operation and maintenance costs.These roofs are more accessible for recreation, agriculture, and public use. So it demands more irrigation, maintenance, and expertise than extensive green roofs.

2.3 Benefits of green roofs

Green roofs or vegetated rooftops reduce storm water significantly due to vapor-transpiration through plants as well as storing some of the precipitation in the substrate. Furthermore, a green roof distributes the runoff over a longer period and likewise expand the flood peak duration because of the slow release of water that is accumulated in the substrate layer and reduce sewage overflows. (Mentens, Raes & Hermy 2006, 217-226 ; Gibler 2015; Kok , Sidek, Chow, Abidin, Basri & Hayder 2015, 1-7; Lee, Lee & Han 2015, Glass., 2007; Teemusk & Mander 2007, Czemil Berndtsson 2010)

Retaining runoff depends on many factors such as weather conditions (length of proceeding dry period, air temperature, wind conditions, humidity), characteristics of rain event (intensity and duration), green roof features (roof slope, green roof soil composition, thickness, moisture and depth, number of layers and materials component), and type of vegetation. (Villarreal & Bentsen 2005, Teemusk & Mander 2007, Czemil Berndtsson 2010, 351–360.)

Green roofs may also reduce the heat island effect and improve building insulation and energy efficiency. Green roofs increase evapotranspiration through plants leaves, trap an air layer within the plants that causes preventing of summer heat reaching the construction surface; or in winter, the interior heat is prevented from escaping. (Takebayashi & Moriyama 2007, 2971-9; Santamouris 2012, 682–703; Banting, Doshi, Li & Mission 2005; Townshed 2007; Glass 2007.)

Green roof plants use carbon dioxide for their respiration and release oxygen and filter out fine air particles while the air passes over the plants (Green roofs for healthy cities 2016). Murphy (2015) believed that green roofs remove up to 73 kg of atmospheric pollutants annually. Soft surfaces, such as grass or green roof reduce noise by decreasing frequencies and stopping reflecting (Townshed 2007; Van Renterghem & Booteldooren 2009, 1081–1087).

The green roofs are often established for aesthetic reasons. In populated urban areas with limited available lands, flat roofs play a significant role in providing recreational space for healthy living of urban dwellers. (Townshed 2007; Teemusk & Mander 2007, 271–277.) Finally, green roofs improve urban biodiversity and create habitat for plants and animals

(Brenneisen 2003; Lee, Lee & Han 2015, 171-176; Madre, Vergnes, Machon & Clergeau 2014, 100–107).

The investigations clearly demonstrated that green roofs neutralized acid rain to stabilize the pH of the runoff, Indicate that a green roof can be a good BMP best management practice for mitigating acid rain runoff in urban areas (Gong, Wu, Peng, Zhao & Wang 2014, 1205-1210; Beecham & Razzaghmanesh 2015, 370 -384 ; Bliss, Neufeld & Ries 2009, 407- 417 ; Aitkenhead-Peterson, Dvorak, Voider & Stanley 2011, 17–33 ; Czemil Berndtsson 2010, 351–360; Chen 2013, 51–58 ; Teemusk & Mander 2011, 3699–3713 ; Vijayaraghavan & Jushi 2012, 1337– 1345; lang 2010; Berghage, Beattie, Jarrett, Thuring & Razaei 2009).

2.4 Challenges of green roofs

From the perspective of construction, there are some barriers which are preventing the green roof industry are becoming more widespread. High installation and maintenance cost, lack of knowledge and awareness, lack of accessible roof and technical issues are the most common obstacles to green roof application. For instance, the extra load of the soil needs extra structure materials and costs to withstand extra pressure. Furthermore, green roofs should be attractive like parks to the public, and it demands a much deeper substrate and the complex irrigation systems. On the other hand, more care is needed in intensive green roofs as the native plants cannot tolerate the extreme conditions of a rooftop. (Sihau 2008.)

2.5 Nutrients

2.5.1 Nitrogen

Nitrogen is a vital nutrient for plant growth. Nitrogen is added to ground as fertilizer or arises naturally in the soil as organic forms from decomposing plant and animal residues. Soil bacteria convert nitrogen to nitrate by nitrification, that is a desirable form for plants to absorb. However, nitrate

is a hydrophile ion that moves with water through the soil profile easily. In the case of excessive rainfall or over- irrigation, nitrate will be leached from the root zone to groundwater from any soil. Denitrification can be a major mechanism of NO_3^-N loss when soils are saturated with water for 2 or 3 days. (Lamb, Fernandez & Kaiser 2014.)
Excess nitrogen in the aquatic system contributes to the growth of algae and other aquatic plants and eutrophication. Furthermore, the massive growth of algae causes taste and odor problems in drinking waters and the dissolved oxygen depletion causes harm to the aquatic organisms, clogs water intakes, drains, and pipes. (Vijayaraghavan & Jushi 2012, 1337–1345).

The Environmental Protection Agency of USA (USEPA) considers 10 mg/L standard as the maximum contaminant level (MCL) for nitrate-nitrogen and 1 mg/L for nitrite-nitrogen in order to control inputs of nutrients from point sources into aquatic systems (Oram 2016) . Furthermore, European Union considered 2-10 mg/L as a limit value for total nitrogen to control eutrophication of surface water (Oenema 2016). In this study, the value of 10 mg/L is considered as a guideline limit for green roofs outflow in order to a better understanding of likely potential impacts of the green roof on water reservoirs.

2.5.2 Phosphorus

Phosphorus is the another essential macronutrient for stimulating plants growth. TP is the sum of three major forms: organic P, fixed mineral P, and orthophosphate (OP). Phosphorus is one of the three nutrients added to soils in fertilizers. Precipitation washes out phosphates from farm soils into watercourses. Excess phosphate cause rapid growth of algae, and aquatic plants that deplete dissolved oxygen. In contrast to nitrogen; phosphate is retained in the ground by biological activities, absorption, and mineralization.

The initial phosphate in fertilizers and manure is moderately soluble and available for the plant. Nonetheless, various reactions begin to change phosphate to be minus soluble and less accessible in exposure with the soil. Factors such as soil pH, moisture content, temperature, and the available minerals in the soil affect the rate of solving phosphate. The dissolving of the fertilizer occurs when it is in contact with soil moisture, that increases the soluble phosphate in the soil solution around the fertilizer particle and causes short and slow movement of the dissolved phosphate and react with minerals present in the soil. This movement can increase by rainfall or irrigation. The principal mechanism for phosphate ions reacts contain adsorbing to soil particles or combining with minerals in the soil (Calcium (Ca), Magnesium (Mg), Aluminum (Al), and Iron (Fe)) and developing solid complexes. The high quantity of phosphate in soils results in phosphate increase in soil solutions. This will generally result in minor, then potentially significant rises in the aggregates of phosphate in water. (Busman, Lamb, Randall, Rehm & Schmitt 2009.)

The USEPA recommend 0.1 mg/L TP for streams which discharge into reservoirs to control eutrophication (Oram 2016). The European Union propose 0.1- 0.4 mg/L TP for surface water quality standards (Buijs 2016). The UK considers 0.03 mg/L for high and 0.5 mg/L for the poor ecological status of rivers. Denmark considers phosphorus standard (0.3 mg/l) to all point source discharges and does not have any standard for phosphorus in rivers. (A revised approach to setting Water Framework Directive phosphorus standards 2012.) The value of 0.1 mg/L TP is considered as a guideline limit for green roof discharge in this study. However, these standard concentration limits are not essential indicators for nutrients management in water supplies.

2.6 Biochar

While plants demand nutrients for better growth, higher nitrogen and phosphorus concentrations have repeatedly been observed in runoff from green roofs that confirm the high quantity of nutrients wash out from the soil before up taking by roots. So it is necessary to find out a desirable soil amendment that prepares essential nutrients available for plants and prevent nutrients dissolving in the runoff. Amendment of biochar to retain nutrients would be a promising solution as a soil additive for growing green roofs.

Biochar is a carbon-rich coproduct derived from the pyrolyzing of biomass under high-temperature, low oxygen conditions for biofuel production. Pyrolysis means chemical degradation of an organic substance by heating in anaerobic condition. The four different types of pyrolysis consist of fast, intermediate, slow pyrolysis and gasification. Slow pyrolysis is defined as “carbonization” due to producing a high quantity of carbonaceous material and in the gasification process, a large proportion of syngas is produced. (Verheijen, Jeffery, Bastos, Van der Velde & Diafas 2009.) At temperatures of between 250-1000ºC, biomass (wood, straw, manure) produce a different portion of syngas, bio-oil, and biochar. Slow pyrolysis (below 400ºC for 30 minutes to several hours) produce more biochar (35%) than fast pyrolysis.(Ahmad, Rajapaksha, Eun Lim, Zhang, Bolan, Mohan, Vithanage, Lee & Sik Ok 2014, 19–33.)

Biochar is similar to other charcoals, however, in general biochar is produced by dry carbonization or pyrolysis and gasification of biomass, whereas the hydrochar is generated as a slurry in water by hydrothermal carbonization of biomass under pressure. Furthermore, biochar is consumed as a rectifier or fertilizer while charcoal is used for other forms of consumptions. (Biederman & Stanley Harpole 2013, 202–214.)

Biochar contains high organic carbon that led to being as a soil conditioner to improve the physicochemical and biological performance of soils. Biochar contains highly condensed aromatic structures that resist decomposition into the ground and thus can effectively sequester a portion of the applied carbon for decades or hundreds of years. (Biederman & Stanley Harpole 2013, 202–214.) It is worth noting that sorption of organic contaminants by biochars is more favored than that of inorganic contaminants.

The high stability of biochar due to the extensive structure of aromatic carbons cause modification of soil's water holding capacity through its macroporous nature (Yao, Gao, Zhang, Inyang & Zimmerman 2012, 1467–1471.) Biochar can sequester up to 2.2 billion tons of carbon every year by 2050. Furthermore, syngas and pyrolysis oils from biochar production can be a good alternative to fossil fuels. By using the biochar soil does not demand fertilizer and subsequently nitrous oxide emissions from soils will be reduced.(Ernsting 2016.)

Many soils are acidic and crops generally could not absorb nutrients in the acidic soil. Since most types of biochar are alkaline, adding an alkaline biochar cause easier take-up nutrients for plants, however, this effect might not be present for a long time. (Ernsting 2016.)

2.6.1 Challenges of biochar

Traditional biochar processing produces small airborne black carbon particles which have 500-800 times the negative impact of global warming than carbon dioxide, they can absorb short energy wave from the sun rather than reflect it back into space. Furthermore, small black carbon particles are deposited on snow and ice, they cause or speed up melting and thus cause further warming. Therefore, particles need to be very small and biochar should produce in equipped and well-designed machines, not a traditional process that farmers apply it. (Ernsting 2016.)

Furthermore, depending on the pyrolysis temperature and the initial feedstock there is likely to produce Polycyclic Aromatic Hydrocarbons (PAHs) particles which are carcinogenic. The another problem with wood biochar is that it demands significant amounts of wood or other biomass, therefore, extensive application of wood biochar would destroy forests. (Ernsting 2016.)

2.7 Historical Background

Nearly all the studies on green roof runoff quality detected nutrients in the runoff, but the results vary significantly. Some study results with similar conditions are as follow:

Aitkenhead-Peterson, Dvorak, Voider & Stanley (2011, 17–33) reported a larger amount of nitrate nitrogen (NO_3–N 2.1 mg/l) in the runoff than in precipitation (0.2 mg/l). Czemil Berndtsson, Bengtsson & Jinno (2009, 369–380) studied runoff quality from an intensive green roof in Japan and extensive green roof in Sweden. The substrate depth of intensive green roof was 40 cm of perlite that is made of artificial inorganic lightweight soil. The extensive green roof in Sweden consisted of crushed lava, natural calcareous soil, clay and shredded peat with a depth of 3 cm. The result showed higher dissolved organic carbon and potassium in both roofs. The source of DOC was organic material from the roof soil or from the vegetation decomposition. Results indicated that nitrate nitrogen and ammonium nitrogen decreased in both extensive and intensive vegetated roofs. However, the intensive vegetated roof reduced TN and TP in contrast to the extensive roof.

In another study by Gregoire & Clausen (2011, 963–969) runoff quantity and quality from a 248 m^2 extensive green roof and a control were compared in Connecticut. The growth media component consisted of 75% lightweight expanded shale, 15% composted biosolids and 10% perlite. Each bed was planted with a mixture of 10 sedums and 12 plugs species. TP and PO_4–P mean released from green roof runoff higher than in precipitation, but lower than the control roof. However, the green roof behaved as a sink for NH_3–N, Zn, and Pb. It also reduced the mass export of TN, TKN, NO_3, and NO_2–N because of 51.4% reduction in stormwater runoff. The growing media and slow release fertilizer were probable sources of P and Cu in green roof runoff in this study.

Wang, Zhao & Peng (2013, 2691–2697) evaluated the effect of different factors on nutrients leaching in green roof runoff via artificial rains. The results represented that green roof was a source of total phosphorus, but a sink for most of the nutrients pollutants. The results also revealed that substrates applied in the green roof and substrates depth effected on the concentration of these nutrients pollutants in the runoff. The role of plant density and drainage systems were not so significant.

Harper, Limmer, Showalter & Burken (2015, 127-133) conducted nine-month field green roof pilot study to evaluate runoff quantity and quality with two different media (Arkalyte mix and GAF’s GardenscapesTM). Different type of sedum was used in this experiment. In initiate stage , total phosphorus >30 mg-P/L and total nitrogen concentrations >60 mg-N/L were observed in green roof runoff. GAF had much higher TP concentrations in runoff, and concentrations decreased over nine months media type hence age factor were considered as the largest influences on nutrients loading from the green roof .

Beecham & Razzaghmanesh (2015, 370 - 384) studied factors affecting the quality and quantity of effluent green roof on sixteen low-maintenance and unfertilized intensive and extensive green roof beds. The first two factors of slope (1 and 25) and depth (100 mm and 300 mm) were randomized to the growing media (organic mix, Brick mix, and Scoria mix). The third factor was plant type , which was based on three plant species named Brachyscome Multifedia (Cut - leaved Daisy), Chrysocephalum Apiculatum (Everlasting Yellow Buttons), and Disphyma Crassifolium. 6 roofs were designed as intensive and 6 as extensive and 4 roofs were considered as a control roof without vegetation. From the results green roofs generally acted as a source of nutrient pollutants in this study but the nutrients leachate was lower than non-vegetated beds which emphasize on the vegetation role in improving pollutant removal in green roof systems. Among vegetated beds, the intensive green roofs discharged nutrients less than the extensive beds while in the non-vegetated beds, the extensive beds performed better than intensive systems. In addition, growing media with the less organic matter contained better water quality.

In Vijayaraghavan & Jushi (2012, 1337– 1345) experiment, two types of substrates were used , the first media included white peat, black peat, and clay. The second substrate consisted of natural inorganic volcanic material, compost, organic and inorganic fertilizers, sedum Mexicanum was selected. Results showed over 40 mg/L phosphate concentrations; however, nitrogen concentrations were not significantly greater than the control. Type of growth media affected strongly by the concentration of chemical components in the green roof runoff.

Beck, Johnson & Spolek (2011, 1-8) evaluated changes of adding 7% biochar in extensive green roof runoff quality and quantity. Growing media contained a mix of gravel, sand, silt, clay, as well as specially screened pumice, fiber life compost, and paper fiber. Sedum and regress were planted on the roofs. The biochar consisted of 70.0% agricultural char and 30.0% manufactured waste char of passenger car tires. Trays with biochar amendment showed increases in water retention and significant decreases in the total nitrogen, nitrate, total phosphorus, phosphate, and organic carbon concentration. In terms of vegetation type, sedum retained phosphate and total phosphorus from both biochar and non-biochar treatments.

3 RESEARCH OBJECTIVES

The objectives of this study that are derived from the former studies and study context in chapter 2 to achieve the aim of this study consist of:

to determine the effect of green roofs ageing on the concentration of nutrients in the runoff (phosphorus and nitrogen); to determine the impact of differently designed vegetation type on nutrients leaching; to evaluate the effect of climate and rainfall intensity on nutrients releasing in the runoff ; to evaluate the effect of biochar amendment on nutrients discharging from green roof.

The data used in this study has been collected by Kirsi Kuoppamäki and her colleagues that are working on a series of experiments, carried out under the Fifth Dimension-green roofs in urban Areas-research program in the University of Helsinki.

4 MATERIALS AND METHODS

The study area of this research from Helsinki university was located at Jokimaa research station in Lahti City, Southern Finland. The experiment was conducted in 25 green roof beds of size 1×2×1.5 meters each were made of plywood with the slope adjusted to 4^o or 1:14. The experiment was established in early July 2013.

The effect of biochar (present or absent), and the effect of two vegetation structure methods: pre-grown mats, plug plants and sowing were considered as two main factor design in a random plot design, each with 5 replicates. In addition to twenty vegetated beds, there were five non-vegetated beds without substrate, biochar or other green roof layers.

Experimental green roofs (Fig. 2) consist of some layers. Each bed bottom and inner wall were covered with an HD polyethylene roofing membrane, the second layer was 25 mm drainage layer made of a molded polystyrene (Nophadrain; Veg Tech AB 2014) in the form of egg shell-like plastic , the next layer was10 mm thick water holding fabric (“VT-filt”: Weight 1280 g/m^2, water storage capacity 8 l/m^2; Veg Tech AB 2014), the fallowing layer was the substrate layer, and finally the plants were placed. Substrate major constituents included crushed, recycled brick (85%), compost (5%), peat (5%) and crushed bark (5%).

For pre-grown mats with biochar, a 50 mm substrate layer was added and then a 10 mm thick layer of biochar (equal to 4 kg/m^2) were spread (Fig.3). For non-biochar pregrown 60 mm substrate layer was added. Finally, 40 mm thick green roof vegetation mat was applied for both plots. These readymade mats were produced by VegTech in Sweden and imported to Finland by Envire VRJ Group Ltd. The mats consist of dense vegetation of mosses, *Sedum* spp., herbs, and grasses. For plug plant plots, a substrate layer was added to the depth of 100 mm. Then eight plug plants of different species (per plot) and seeds were sown. The plug plant species were *Campanula rotundifolia*, *Centaurea jacea*, *Fragaria vesca*, *Knautia arvensis*, *Lotus corniculatus*, *Pilosella officinarum*, *Veronica spicata* and

Viola canina. The seed mixture sown included *Antennaria dioica*, *Allium schoenoprasum*, *Dianthus deltoids*, *Galium verum*, *Leucanthemum vulgare*, *Sedum acre*, *S. telephium*, *Thymus serpyllum*, and *Viola tricolor*.

Biochar was produced from birch (*Betula* spp.) were pyrolyzed for 2 hours at the range of temperature from 380-420^o C and had BET specific surface area of 7 m^2 /g, the bulk density of 389 g/l and pH 7.6. Runoff was collected from green roofs to three drainage holes at the lower edge of the green roof box connecting a gutter that is attached the rain gauge and a funnel to a 25 L container (Fig. 2 & 4).

The containers were emptied and the water volume measured after precipitation events. 200 ml water samples were taken for analyses at 3-4 month intervals; totally six samples were collected whole experiments. The first water sample was collected one month after plant establishment when sufficient volume of runoff collected from the container. One ECRN-100 rain gauge was installed next to the green roof treatments to measure precipitation. Furthermore, a local weather station collected data on precipitation events, wind velocity, and air temperature.

4-1 Laboratory analysis

For all nutrients experiments analysis in the case study, Ascorbic acid and molybdate reagent (ISO 6878:2004) were added to phosphorous samples and then were measured by a spectrophotometer. To determine total nitrogen High-Performance Liquid Chromatography (HPLC) instrument with 0.04M sodium chloride (NaCl) as an eluent (ISO 29441:2010) were applied.

Figure 2. The experimental setup of green roofs and control roofs connecting from a gutter to which is attached the rain gauge and a funnel to a 25 L container

Figure 3. A cross section of substrate layers of pre-grown biochar amendment green roof. The planted green roofs had a similar structure except for the 4 cm pre-grown layer that was replaced by substrate, plug plants and seeds (Kuoppamäki & Lehvävirta 2016, 39-48)

Figure 4. The experimental setup of green roofs at Jokimaa research station, Lahti

5 RESULTS

Nitrogen leaching from non-vegetated roofs was low and did not vary during the study period from August 2013 until November 2014 (Fig. 5). However, more fluctuation was seen in runoff from planted green roof. A high peak of nitrogen was seen in August 2014 in planted green roofs, while leaching from pre-grown green roofs rose slightly. The extreme rainfall occurred in August both 2013 and 2014, while the mildest event took place in November 2013 (Table 1), when the majority of runoff originated from the melting ice in the substrate. Therefore, based on data, runoff from the experimental green roofs contained higher TN concentrations compared to the roofs without vegetation. For emphasis, a guideline limit line of nutrients is drawn in all graphs to compare with the quality of green roofs discharge. The concentrations above the guideline limit reflect the probable threat of eutrophication in water resources. Also, pre-grown green roofs contained lessTN than planted roof in August 2014 rain storm.

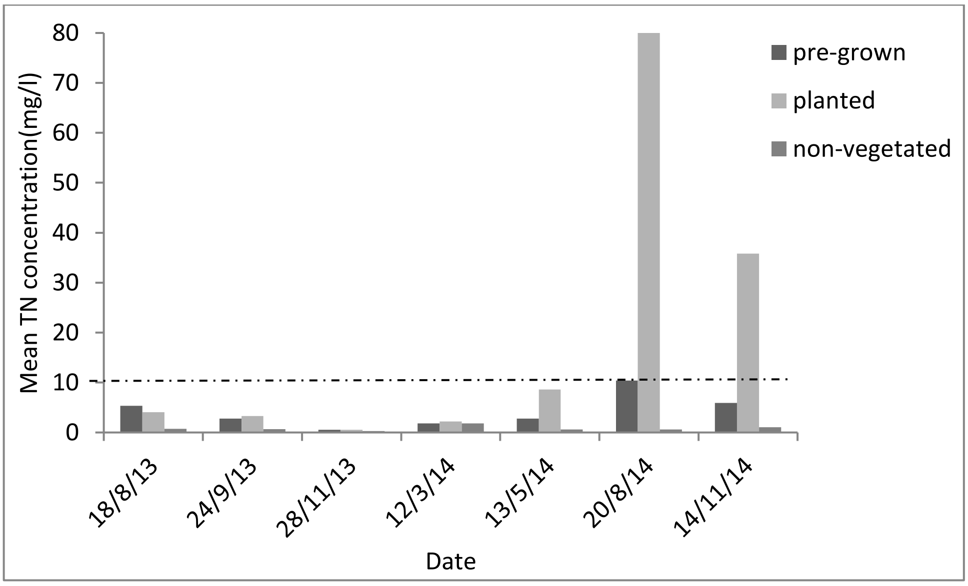

Figure5. The average (±SE) concentration of total nitrogen in the runoff from pre-grown, planted and non-vegetated roof during the study period from August 2013 until November 2014.

Table1- Basic information about the precipitation, the interval of antecedent dry weather period (ADWP), mean air temperature, rainfall volume (with maximum rain intensity) and the mean (±SD) amount of runoff. ADWP and rainfall intensity were determined only for precipitation, not for snowfall or melting events (Kuoppamaki & Lehvävirta 2016, 39-48)

Date	15.8. 2013	24.9 2013	28.11 2013	12.3. 2014	13.5. 2014	20.8. 2014
ADWP, days	1.5	0.5	-------	-------	2	1.5
Mean temperature ranges(c^{o})	(11.4-20.8)	(6.2-15.7)	(-1.0-6.5)	(-5.9-7.6)	(6.8-14.3)	(6.4-22.2)
Rainfall, mm (max intensity mm/20 min)	81.4(3.9)	17.7(2.4)	0.4(-)	17.5(-)	14.2(2.0)	31.2(3.8)
Runoff(SE), mm						
Planted	34.6(2.9)	2.3(0.6)	1.4(0.3)	8.2(3.3)	4.9(0.2)	6.4(0.2)
Planted + Biochar	33.3(17.0)	1.7(0.7)	1.2(0.2)	11.5(4.4)	3.3(0.4)	3.3(0.4)
Pre grown	47.2(9.5)	10.4(1.2)	3.2(0.5)	9.3(2.3)	4.7(0.2)	2.2(0.3)
Pregrown + Biochar	30.4(15.6)	7.4(4.1)	2.3(0.6)	9.4(2.3)	4.6(0.3)	1.4(0.2)

As is shown by the figure 6 the total phosphorous concentration fluctuated slightly in all green roofs during the research period, however, a peak was observed in August 2014 that plunged to less than 0.1 mg/l during three months. Overall, the total phosphorus concentrations were higher in runoff from the experimental green roofs than from the non-vegetated control roofs. Furthermore, planted green roofs showed better performance in higher rainfall than the pre-grown roofs. Runoff contained less nutrients at freeze-thaw events (November) compared to rain events during the growing season 2014, but slightly increased with the starting of snow melting.

It is evident that TN leaching was less in non-vegetated roofs comparing the other green roofs (Fig. 8). However, TN concentration did not exceed the guideline limits. It seemed that the N levels fluctuated in all three types of roof. However, the trends were almost similar among them, and the most less leaching was seen in November 2013. Amending of biochar was not noticeable until Jun 2014, but after that when the systems became less than one year old it started to retain nitrogen, apparently.

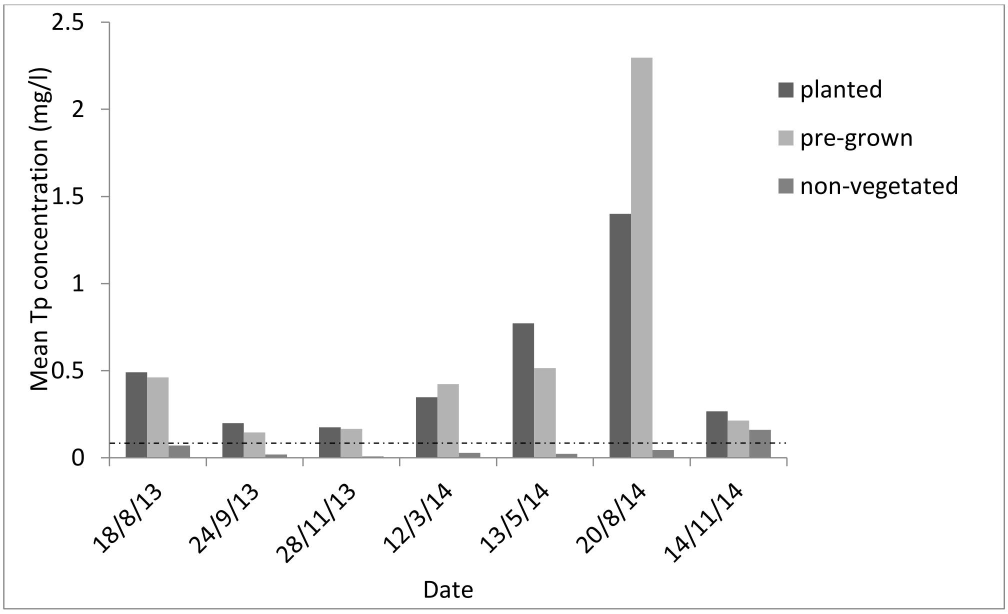

Figure 6. The average (±SE) concentration of total phosphorus in the runoff from pre-grown, planted and non-vegetated roofs during the study period from August 2013 until November 2014.

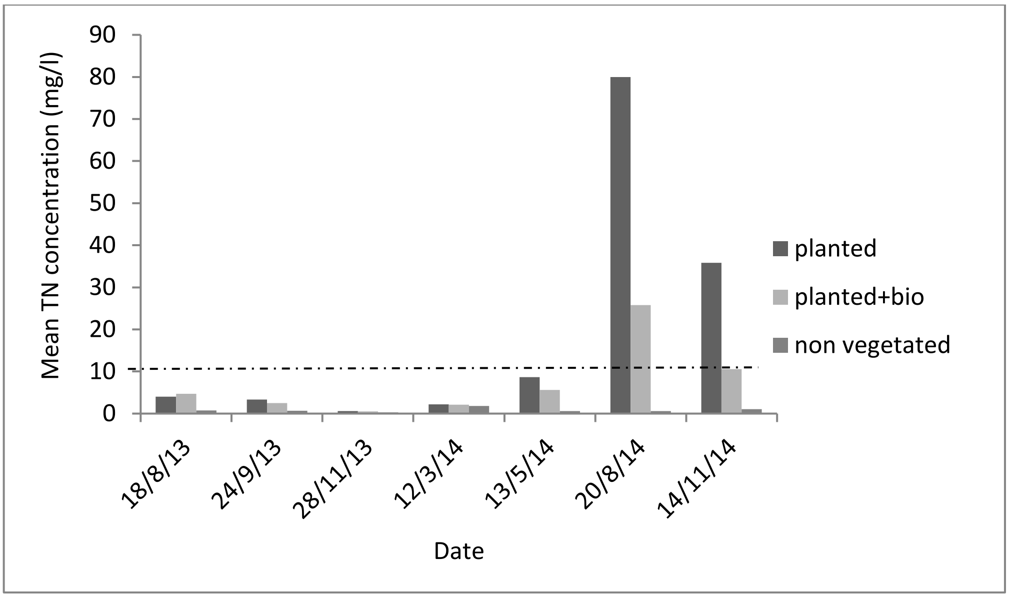

Figure 7. The average (±SE) concentration of total nitrogen in runoff from planted green roofs in biochar treatments and non-vegetated roofs during the study period from August 2013 until November 2014.

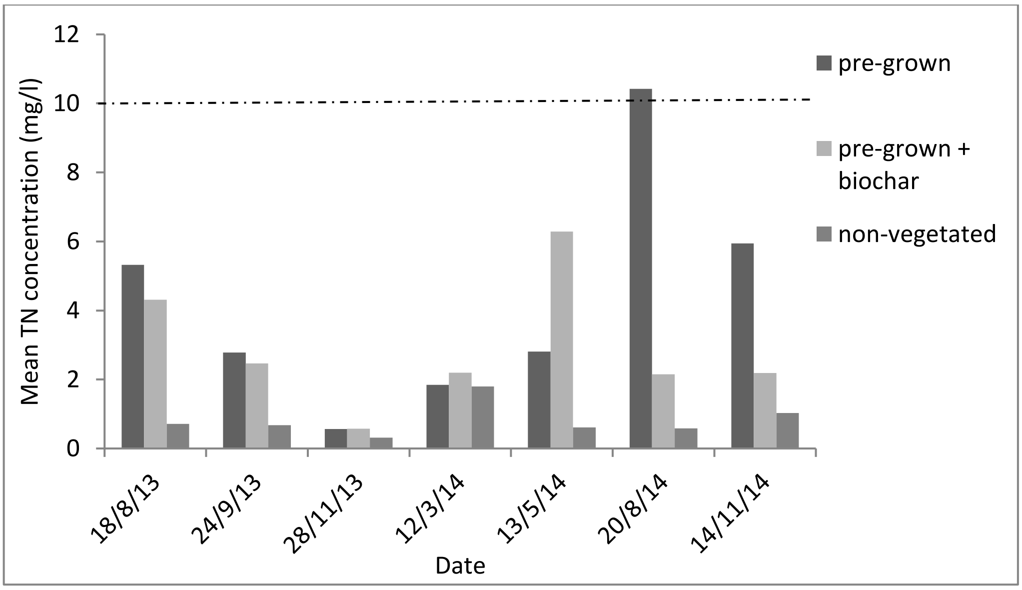

Figure 8. The average (±SE) concentration of total nitrogen in runoff from pregrown green roofs with and without biochar amendment and non-vegetated roofs during the study period from August 2013 until November 2014.

The biochar-amended soil did not result significantly in decreasing TP concentration levels in the rainfall runoff (Fig. 9). However, with the high amount of nutrients in the runoff in August 2014, biochar had a clearly reducing impact on the concentrations of both TN and TP in all experiments.

A more drastic change was seen in the pregrown green roof as it leaped from 0.4 in May to 2.4 mg/l in August 2014 (Fig. 10). By observing the graph, it can be seen that green roofs contained more phosphorous that it fluctuated during the time while non-vegetated roofs did not show phosphorous leaching. Amending biochar did not improve the leaching of phosphorous at first. Though; it started to decrease phosphorous leaching vastly since August 2014.

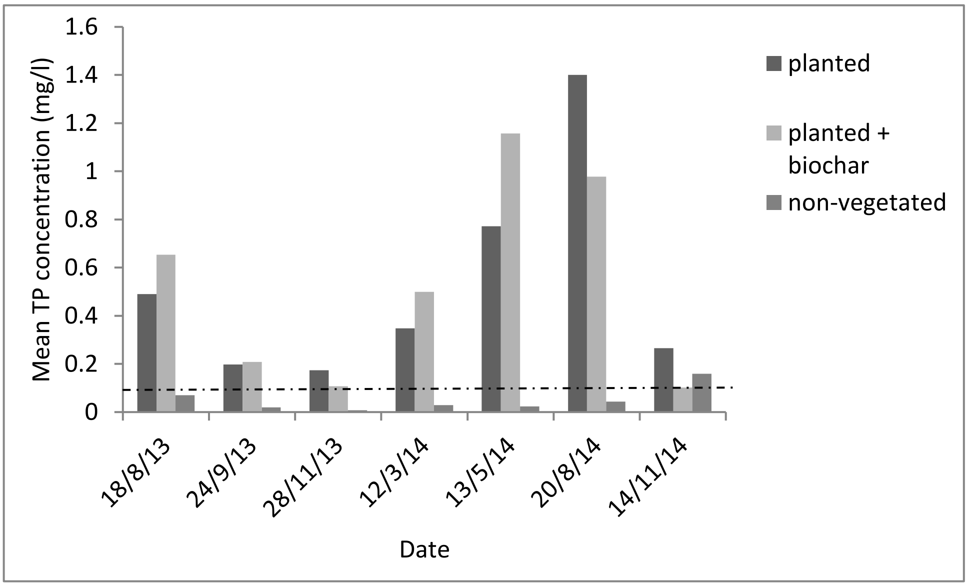

Figure 9. The average (±SE) concentration of total Phosphorous in runoff from pre-grown green roofs in the biochar treatments and non-vegetated roofs during the study period from August 2013 until November 2014.

Few conclusions can be made from the concentration data alone because different volumes of runoff drained from each roof. For example, While the concentration of TN may have been lower in green roof runoff, more mass of TN would have been present in the runoff from the green roof. Therefore, the volume of runoff was necessary to determine the mass loadings. Therefore, mass load per unit of green roofs area were considered as well. When considering impacts to water bodies downstream, concentrations are much less important than loading. So, the mass loading is investigated as well.

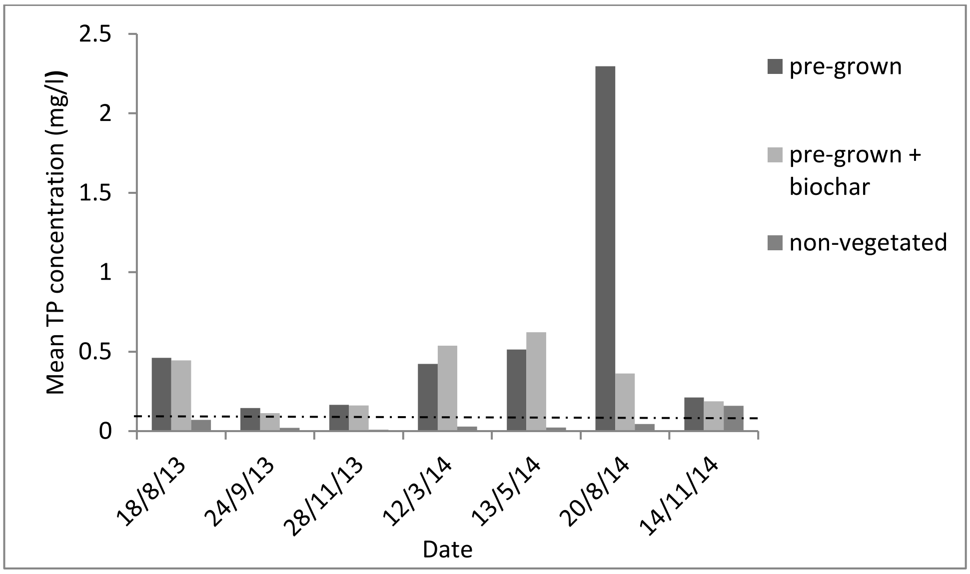

Figure 10. The average (±SE) concentration of total Phosphorous in runoff from pregrown green roofs in the two biochar treatments and non-vegetated roofs during the study period from August 2013 until November 2014.

For these experiments, TP and TN concentrations and loading in runoff still elevated more than one year after construction. Since the green roofs discharged higher concentrations of the nutrients, reduction in runoff volume did not similarly mitigate the nutrients load. The mass loads from non-vegetated roofs were lower than green roofs (Fig. 11&12) except in two lighter rainfall events that lower nutrients load occurred due to lower runoff from the green roofs.

Application of biochar decreased nutrients loading in the first year slightly with some exceptions. However, it reduced both peak concentration and loading in green roofs significantly. Furthermore, biochar reduced TN load more in the planted green roofs than in the pre-grown ones, However it is interaction with initial high N load in planted green roofs without biochar. Biochar positive effect on TP load decreasing was almost similar in planted and pre-grown green roofs. (Due to a high mass load of TN in August 2014 in planted green roof (518) it cannot be seen in real quantity in the Fig. 11).

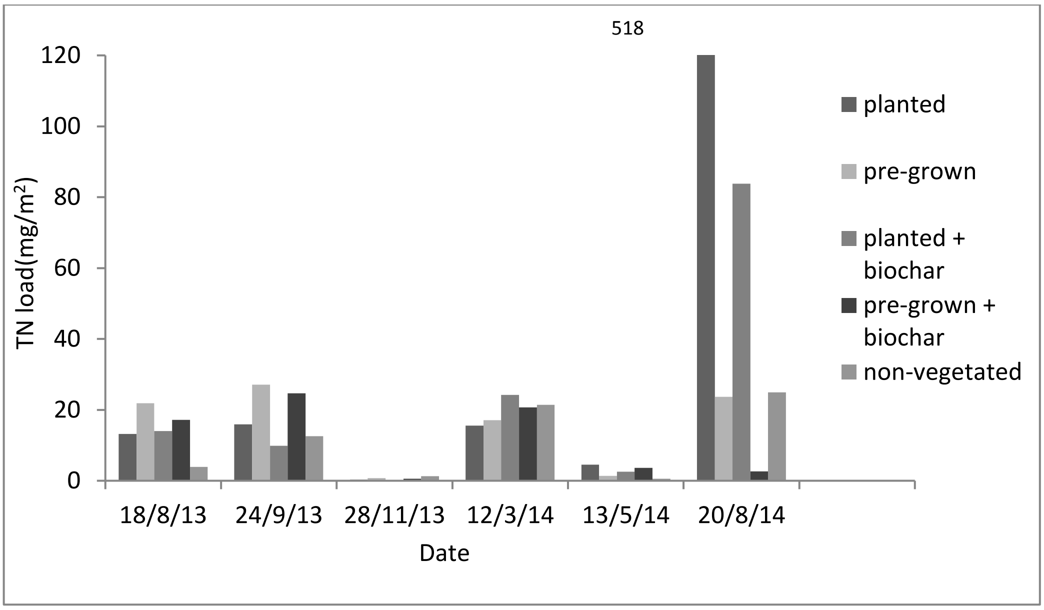

Figure 11. TN load in runoff from all green roof treatments and non-vegetated roof during a year of study

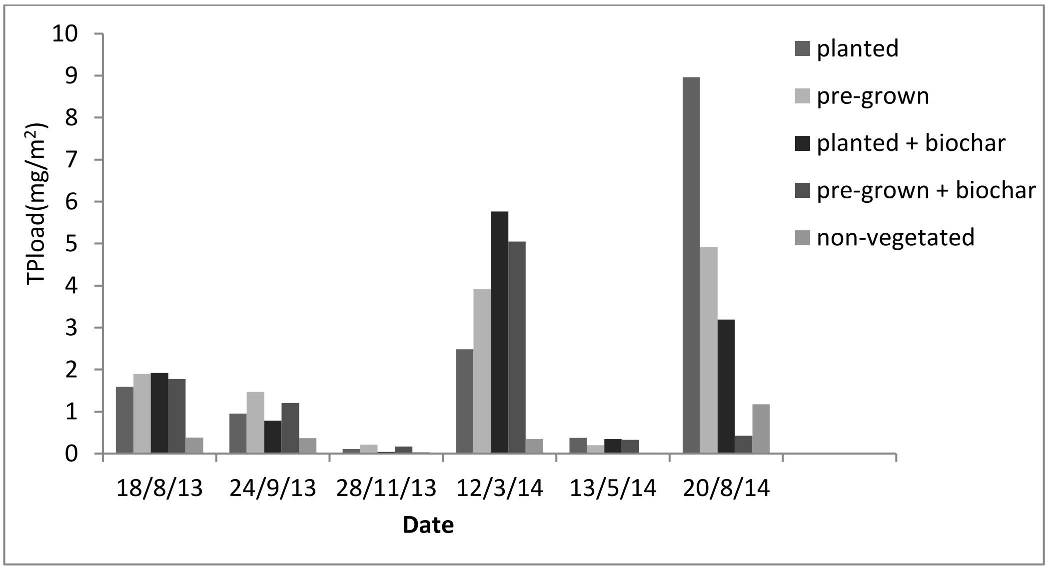

Figure 12. TP load in runoff from all green roof treatments and non-vegetated roof during a year of study

6 DISCUSSION

6.1 The effect of green roofs on nutrients in runoff

Monitoring of the experimental roof plots in Lahti showed nutrients discharging from green roofs in terms of concentration and mass loading were higher than non-vegetated roofs as the survey by Kuoppamaki & Lehvävirta (2016, 39-48) in Helsinki area indicates on more nutrients leaching from green roofs. Malcolm, Reese, Schaus, Ozmon & Tran (2014, 705–712) achieved same results . The green roofs in their experiment discharged 10 to 180 times higher concentrations of the TP compared the gravel roof , that indicates the reduction in runoff volume did not mitigate the nutrients load. In only one of the analyzed storms, the 99.8% of the reduction in runoff volume resulted in a lower load from the green roofs. Application of Alum as a solution to decrease nutrients leaching caused 22% reduction of TP.

Elevated concentrations of nutrients pollutants, particularly phosphorus leaching from green roofs conveyed in numerous studies (Czemil Berndtsson 2010, 351–360; Li & Babcock., 2014; Vijayaraghavan & Jushi 2012, 1337– 1345 ; Teemusk & Mander 2007, 271–277 ; Monterusso, Rowe, Rugh, & Russell 2004, 369–376 ; Hathaway, Hunt & Jennings 2008, 37-44; Culligan, Carson, Gaffin, Gibson, Hakimdavar, Hsueh, Hunter, Marasco, & McGillis 2014; Berghage, Beattie, Jarrett, Thuring & Razaei 2009; Kok , Sidek, Chow, Abidin, Basri & Hayder 2015, 1-7; Aitkenhead-Peterson, Dvorak, Voider & Stanley 2011, 17–33; Glass & Johnson., 2008).

The majority of the measured concentrations of phosphate phosphorus of green roofs in this thesis were higher than non-vegetated roofs and were above USEPA’s recommended limit of 0.1 mg/l to avoid accelerated eutrophication in freshwater. It seems phosphors is more limited substance for discharging in water bodies. Besides, most of substrate layer and media contain more phosphorous. However, in most cases, nitrogen concentrations were not so higher (from 0.4 mg/N to <20 mg/N;

excluding the exceptionally high levels from some of the experimental roofs in 2014) than non-vegetated roofs. Furthermore, they were below the US Environmental Protection Agency (USEPA)'s and European Union's recommended standard of 10 mg/l in freshwater.

Though, it seems that the annual mass (mg) of nutrients release of a green roof is less than control roof nutrients leaching because of green roofs discharge less water quantity per annum (Li & Babcock., 2014). It is estimated that 600 kg of Total P, 7000 kg of NH_4^+ and 150, 000 kilograms of NO_3^- could save from releasing into the sewer system or local water bodies via green roof applying in NYC case study. These values are not concerning than annual nutrients discharges from sewage treatment plants (Oberndorfer, Lundholm, Bass, Coffman, Doshi, Dunnett, Gaffin, Kohler, Liu & Rowe 2007, 823–833; Culligan, Carson, Gaffin, Gibson, Hakimdavar, Hsueh, Hunter, Marasco, & McGillis 2014). Moreover, the concentrations are the same with planted landscape run off at ground level (Berghage, Beattie, Jarrett, Thuring & Razaei 2009).

A corresponding study by Beecham & Razzaghmanesh (2015, 370 - 384) investigated runoff volume and quality of sixteen low-maintenance, and unfertilized intensive and extensive green roofs in an arid climate. They found a greater concentration of nitrate and ammonia in green roofs than in the inflow stormwater. It can be concluded that the higher organic component of the substrate generated higher nutrients concentration. Vijayaraghavan & Jushi (2012, 1337– 1345) found higher levels of nitrate in green roof runoff (0.28 – 0.8 mg/L) than in control roof runoff (0.19 – 0.4 mg/L), but the levels they found were low because fertilizer was not used.

The most factors potentially influencing leaching of nutrients from green roofs can be fertilizers or compost that is used in soil or substrate as a nutrients supplier for the plant (Czemil Berndtsson 2010, 351–360). The other important factors consist of: thickness of the substrate layer and its composition, vegetation properties, drainage and roof material, age of the roof, its maintenance , type of the surrounding area, local pollution sources , atmospheric deposition dynamics of precipitation, physicochemical properties of pollutants (Czemil Berndtsson 2010, 351–360; Alsup, Ebbs & Retzlaff 2010, 91–111 ; Wang, Zhao, & Peng 2013, 2691–2697; Speak, Rothwell, Lindley, & Smith 2014, 33-43 ; Ahmed 2011, Vijayaraghavan & Joshi 2014, 121-129 ; Rowe 2011, 2100-2110; Teemusk & Mander 2007, 271–277; Emilsson, Berndtsson, Mattson, & Rolf 2007, 260–271) .

Vegetation in urban areas due to more surface area act as a filter to trap fine air particles as the air passes over the plants, the particles settling on plant surfaces are washed into the soil by rain. During dry periods, some of the dissolved components can combine to the substrate or the solid substance of the drainage layer while pollutant components during rainfall events can be leached and transported by the subsurface outflow (Alsup, Ebbs, Battaglia & Retzlaff 2011, 1709–1717; Gnecco, Palla, Lanza & La Barbera 2013, 4715–4730).

Nitrate concentrations were found to be higher in runoff from a sedum roofs in comparison to herbaceous perennials, and in runoff from shallower substrates (Monterusso, Rowe, Rugh, & Russell 2004, 369–376). Nitrate nitrogen leached more than ammonium nitrogen during moderate rain events. However, during heavy precipitation events and melting of snow, ammonium can exceed nitrate in green roof runoff. (Teemusk & Mander 2007, 271–277 , Teemusk & Mander 2011, 3699–3713.)

When comparing the release of nitrate concentrations in Robinson (2012) study, all three media (commercial, compost, bio solids) contained higher nitrate in the runoff than the amount was reported in the literature, but only the runoff from commercial media had higher nitrate concentration than drinking water quality standard. When comparing the total phosphorus concentration results discharging from green roofs , all three media (commercial, compost, and bio solids mix) released greater phosphorus concentration than water quality criteria and most green roof water quality reports.

For the non-vegetated groups, extensive roofs recorded higher ammonia concentrations than intensive roofs which could be due to the lower volume of growing media and probably less reaction time for nitrification to nitrite and nitrate or changing substrate moisture and temperature (Beecham & Razzaghmanesh 2015, 370 - 384). The results of mass and concentration of nitrate in black EPDM membrane (control) roofs, modular green roof, and built-in-place (BIP) green roof runoff were similar. However, mean nitrate mass in the runoff from the green roof systems were higher than from the control roofs and that the mass of the planted BIP systems were statistically more than the seedless structures. The average nitrate mass of the BIP's runoff declined as depth increased. (Morgan, Cooper& Retzlaff 2015, 98-112.) Studies in Charlotte, North Carolina found that atmospheric deposition accounted for 10-65% of runoff pollutant loadings for phosphorus and total suspended solids, 30-50% of runoff pollutant loadings for copper and lead, and 70-100% of runoff pollutant loadings for nitrogen. (Moran, Hunt & Jennings 2003, 1-10.)

Therefore, some main factors were investigated in our experiment field as follows.

6.2 The effect of climate

Like naturally vegetated ecosystems, green roof ecosystems might show seasonal fluctuations in runoff water chemistry due to variation in plant productivity, microbial activity, temperature or other light-dependent processes (Buffam, Mitchell & Durtsche 2016, 506–514).

The highest rainfall events occurred in August 2013 and 2014, It seems that rain washed out nutrients in the green roof in August 2014. However, nutrient leaching was less in August 2013 despite about two-fold more rainfall compared to August 2014. It might be related to higher rainfall and runoff in August 2013. Therefore, the concentration of nutrients in runoff and the amount and intensity of the rain events might be connected to each other.

Less amount of nutrients were seen in the runoff in winter, but it slightly increased when the ice melting started. The precipitation quantity in 12.3.2014 and 24.9.2013 was almost equal. However, the higher temperature in September 2013 caused more evapotranspiration and less runoff. The TP and TN concentrations were less due to less effluent in September 2013.

Teemusk & Mander (2007, 271–277) found that in the case of a moderate runoff, the substrate layer of the green roof retained phosphorus well, but in the event of the heavy rainstorm, phosphorus and phosphate were washed out. The results of the melting water of the green roof were intermediate.

Ammonium nitrogen is positively charged and tends to be attracted to soil particles. Nitrate nitrogen is negatively charged and is repelled by negatively charged soil particles. Therefore, nitrate nitrogen is more subject to leaching than ammonium nitrogen during moderate rain events. But during heavy rainstorm and snow melting, ammonium can exceed nitrate in green roof runoff (Teemusk & Mander 2007, 271–277). Most nitrogen compounds shows up in the runoff in the forms of ammonium nitrogen and nitrate nitrogen. These inorganic forms of nitrogen are soluble and easily mobile in water (Hudak 2000, 37-47; Zawaideh & Zang 1998, 107-115; Ward, Dekok, Levallois, Brender, Gulis, Nolan & Van Derslice 2005, 1607-161). Plants normally use nitrogen in only the ammonium and nitrate forms.

It is expected that precipitation retention will be higher in summer months because evapotranspiration rates are higher and will allow sufficient time for the moisture content of the soil media to be reduced before the next rain event. However, as it can be perceived from the table 1 rain intensity was higher during both August months, that caused more runoff and washing out of nutrients .

Likewise, one study observed a higher level of copper and nitrate concentrations in the summer months compared to fall and winter samples

(Van Seters, Rocha, Smith, MacMillan 2009, 33–47). Neverthless, other studies have found more phosphorus leaching in snowmelt vs. rain event runoff (Gregoire & Clausen 2011, 963–969).

Buffam, Mitchell & Durtsche (2016, 506–514). analyzed water chemistry from 88 green roof runoff samples, 86 traditional roof runoff samples, and 61 precipitation samples. Results presented that inorganic nutrients, nitrate, and phosphate in green roof runoff were higher in the summer than any other season. It seemed that the green roof internal temperature dynamic plays a significant role in runoff quality. Microbial mineralization of nutrients-rich organic matter in the substrate is expected to be a source of the main variation in nutrients concentrations as well. Furthermore, organic N added as fertilization had a direct and substantial role on the NO_3^- leaching in one-year operation.

Hydrology trend is an important key for nutrients cycling within green roofs during a larger storm or melts events because hydrologic residence times is shortened once the system is saturated (Buffam & Mitchell 2015, 107-137). In another study by Kuoppamäki, Marleena, Lehvävirta, Setälä 2016, 1-9) in Lahti, the concentrations of both nutrients were lower in autumn than in summer in green roofs.

6.3 The effect of time

With regard to time and green roof age effect, most of the studies reported decreasing nutrients leaching over time (Czemil Berndtsson, Emilsson & Bengtsson 2006, 48-63; Razzaghmanesh, Beecham & Kazemi 2014, 651-659; Speak, Rothwell, Lindley, & Smith 2014, 33-43). Köhler, Schmidt, Grimme, Laar, de AssuncãoPaiva & Tavares 2002, 382–391 found that green roofs retained 67% PO_4 over three years. Teemusk & Mander (2011, 3699–3713) realized the efficiency of phosphate retention increased from 26% in the first year to 80% in the fourth year. Another study showed high nitrogen and phosphorus levels with a dramatic reduction in concentration over a few months in green roof runoff (Harper, Limmer, Showalter & Burken 2015, 127-133).

However, there was not any apparent relation between the age of surveyed green roofs and the discharge of nutrients concentrations in present study. If we compare two highest intensity in August 2013 with two-fold rainfall and August 2014, green roofs perform better in retaining nutrients in August 2013. It is similar to Moran, Hunt & Jennings (2003, 1-10) experiment results that despite decreased TN over time, TP and OP increased in runoff over time. Moran, Hunt & Jennings (2003, 1-10) believes it can be a result of saturation of soil microsites. When soils are saturated, the phosphorus anions, known as orthophosphate (OP) can become reduced and thereby released into the soil solution and can then drain out of the soil that is parallel in present experiments. Climates with frequent intense rainfalls, where evapotranspiration would be negligible, for instance in August more P and N leached from the media that remains saturated. Biochar decreased nutrient leaching because of its high absorb capacity of rainfall. Furthermore, based on green survey roofs aged between 1-6 years old in Helsinki by Kuoppamäki & Lehvävirta (2016, 39-48) age characteristics did not have significance influence on nutrients leaching.

Another possible reason for nutrients increasing is decomposition of OM and slow breakdown of nitrogen in the substrate from non-available forms to a more labile form (Czemil Berndtsson 2010, 351-360).

The colder climate in Europe causes slower microbial decomposition than in the tropics, leading to much longer residence times of organic matter and nutrients retention (Verheijen, Jeffery, Bastos, van der Velde & Diafas 2009).

6.4 The effect of designed vegetation type and substrate layer

Controlling nutrients leaching is challenging because it demands concurrent management of plant growth and nutrients discharge. In this study, the total cover of vegetation in all pre-grown green roofs was 99%, and their vegetation survived well over the experiment course, however, 50% of plug plant vegetation did not survive over the winter. Biochar amendment improved vegetation in both two types of green roofs treatment to a maximum of 10%. Grasses and herbs in green roofs suffered during the dry and hot conditions. However, vegetation in all treatments soon improved the following precipitation.

Nitrogen fixation plants include the legume family – Fabaceae such as *kudzu, clovers, soybeans, alfalfa, lupines*, that have nodules in their root systems, they producing nitrogen compounds that help the plant to grow. Once the plant is wilted, the fixed nitrogen is released to soil making it available to other plants that fertilize the soil as well. Some nitrogen fixing leguminous plants, such as *Trifoliumrepens* and *Lotus corniculatus* that were growing especially in present planted experimental green roofs, might explain the rising nitrogen concentrations in runoff during summer 2014 after a long antecedent period that affects on plants.

In the present experiment, two types of designed vegetation behave differently in nutrients leaching in higher intensity of precipitation. Furthermore, no distinct relation observed for different vegetation type and nutrients concentration. However, pre-grown vegetated roofs decreased mass nutrients load than plug plants. The concentrations of TP in meadow mats runoff contained higher TP than sedum mats in Kuoppamäki, Marleena, Lehvävirta & Setälä (2016, 1-9) study in Lahti University campus. on the other hand, nutrients concentration in runoff were minor in autumn than in summer in another study (Kuoppamäki & Lehvävirta 2016, 39-48).

Morgan, Alyaseri & Retzlaff (2011,179-193) concluded that the media cause the change in water quality more than the vegetation type. Nitrate concentrations were higher in runoff from a sedum roof than herbaceous perennials, and in runoff from shallower substrates (Monterusso, Rowe, Rugh, & Russell 2004, 369–376).

Numerous studies found a direct link between the release of nutrients and the application of fertilizers in the production process and maintenance of green roofs (Czemil Berndtsson., 2006; Rowe 2011, 2100-2110; Teemusk

& Mander 2007, 271–277; Emilsson, Berndtsson, Mattson, & Rolf 2007, 260–271. Vijayaraghavan & Jushi 2012, 1337– 1345; Kok, Sidek, Chow, Abidin, Basri & Hayder 2015, 1-7; Moran, Hunt & Jennings (2003, 1-10); Czemil Berndtsson , Bengtsson & Jinno 2009, 369-380; Moran, Hunt, & Smith 2005, 1-12). For instance, leaching of nutrients increased when fertilizers were added conventionally to the substrate to achieve dense vegetation, but not for controlled release fertilizer (CRF) or a combination of CRF and conventional fertilizer and although the levels decreased over time (Emilsson, Berndtsson, Mattson, & Rolf 2007, 260–271).

Green roof growing media are typically engineered to include nutrients to promote plant growth cause much higher levels of phosphorus, total Kjeldahl nitrogen (TKN)((Monterusso, Rowe, Rugh, & Russell 2004, 369–376). Moran, Hunt & Jennings (2003, 1-10) used different quantity of compost: 5%, 15 %, and 30%. The nutrients concentrations of nitrogen and phosphorus species were significantly less in drainage from sand and soil media with 5% compost than soil media with 15% or 30% compost.

The thick substrate has been found to released higher concentrations of phosphate and nitrogen than the thin substrate (Seidl, Gromaire, Saad & Gouvello 2013, 195-203), as a higher volume of the substrate can be expected to leach out more nutrients than lower volume.

Application of a combination of P-rich material commonly leads to substrate with about equal quantities of N and P, despite 15- fold higher plant demand for N. A homogeneous mixture of organic substance and inorganic compound added to green roof substrate without taking soil horizons in to account caused washing of organic matter from the top soil. Different plant species have different requirements for nutrients that should be mentioned. (Buffam & Mitchell 2015, 107-137.) Therefore, if fertilizer amendment was more than the plants required, nutrients leaching would increase.

6-5 The effect of biochar

In this experiment, biochar was not able to decrease nutrients concentration leaching in the first year. Even the concentration of total nutrients in the runoff from green roofs with biochar amendment were higher than the green roofs without biochar in some precipitation events. Therefore, it can be assumed that the excessive nutrients leaching originated from biochar. The performance of biochar fluctuated during the time, but it seems it started to retain nutrients after 9 months when the green roof became older. Furthermore, biochar reduced the concentration of nutrients leaching in higher rain intensity. Moreover, biochar reduced TN load more in the planted green roofs than in the pre-grown ones, however it is interaction with initial high N load in planted without biochar. Biochar positive effect on TP load decreasing was almost similar in planted and pre-grown green roofs. If the cumulative loading is assumed, biochar amendment in planted green roofs decreased 62% of TN and 78% of TP loading. Furthermore, biochar decreased 67% of TN loading and 71.31% of TP loading in pregrown green roofs runoff. From table 2, it can be observed that pregrown and planted green roofs with biochar were more efficient in reducing TN and TP load respectively. Biochar reduced TN load more than TP in the highest intensity of rainfall.
Pyrolysis circumstances (pressure, gas content, temperature, process method), feedstock features (composition, size, moisture amount and storage conditions) and production parameters describe biochar properties (Antal & Grønli 2003, 1619–1640).

Preliminary feedstock selection influences the biochar characteristics, for instance as it can be seen from Table 3 (in appendices) manure feedstocks produces biochars with higher available nutrients, on the other hand, plant-based biochars contain lower nutrients. Greater N concentrations in biochars made of manure can be associated with the high protein content in the feedstock (Ippolito, Spokas, Novak, Lentz & Cantrell 2014, 137-162 ; Yao, Gao, Zhang, Inyang & Zimmerman 2012, 1467–1471).

Table 2- Mass load of total nutrients in all green roofs treatments and non-vegetated roofs since August 2013 to December 2014

Types of the green roofs	Cumulative load of TN(mg/m^2)	Cumulative load of TP(mg/m^2)
Non-vegetated	68.5379	2.926
Planted	744.8511	15.76
pre-grown	114.80	13.41
Planted + biochar	175.9385	12.43
pre-grown + biochar	77.52	9.5638

Table 4 (in appendices) illuminates the effect of temperature, pyrolysis type or their interaction influence on nutrients availability in biochar. From the table, it shows that available P, K, Ca and Mg concentrations are greater in slow pyrolysis rather than fast pyrolysis. Increasing pyrolysis temperature cause a decrease indecomposable substances, volatile compounds and elements such as O, H, N, S and thus concentrates nutrients available in biochar(Ippolito, Spokas, Novak, Lentz & Cantrell 2014, 137-162). It appears that total N content reached a maximum level between 300 to 399^{o}C and decreased at greater temperatures (Table 4 in appendices).

Nitrogen is sensitive to heat, so biochar that is produced in high temperature consists extremely low nitrogen content and decrease available nutrients for plants. Phosphorus exists among the organic carbon in plant tissue. Organic carbon starts evaporation at 100^{o}c temperature while phosphorus volatilized at 800^{o}c. So among pyrolysis process free carbon volatile and phosphorus in the plant tissue is release (Verheijen, Jeffery, Bastos, van der Velde & Diafas 2009).Thus, phosphate leaching is seen in green roofs with biochar produced in lower temperature.

Yao, Gao, Zhang, Inyang& Zimmerman (2012, 1467–1471) evaluated sugarcane bagasse, peanut hull, Brazilian pepperwood, and bamboo biochar that pyrolyzed at 300, 450 or 600 °C in a slow process, and a hydrochar to determine their potential to remove NO_3^- from solution. It was found that biochars (bagasse, bamboo, peanut hull, and Brazilian pepperwood) which produced in 600 °C were able to remove between 0.12% to 3.7% of NO_3^- from a solution. Mizuta, Matsumoto, Hatate, Nishihara & Nakanishi (2004, 255–257) realized that bamboo biochar pyrolyzed at 900 °C could adsorb high NO_3^-.

Significant NO_3^- adsorption happened at pyrolysis temperatures ≥700 °C in Kameyama, Miyamoto, Shiono & Shinogi (2012, 1131-1137) analyses for bagasse biochar made toward five pyrolysis temperatures (400–800 °C). It is believed that adsorption of NO_3^- might attribute to base functional groups because high pH observed at high pyrolysis temperatures. Therefore, a biochar with NO_3^- adsorption capacity should be pyrolysis at a temperature of 600 °C or above.

Hardie, Oliver, Clothier, Bound, Green & Close (2015) experienced fertilizer efficiency in the Huon Valley, Tasmania. They applied 47 Mg ha^{-1} Acacia hardwood biochar on commercial apple (Malas domestic) orchard, a higher concentration of phosphorous in the leachate observed while having no significant effect on nitrate or potassium concentration in biochar application than the control.

Kuoppamäki, Marleena, Lehvävirta & Setälä (2016, 1-9) tested two different biochar products performance in a laboratory experiment on pre-grown green roofs with sedum mat produced in Sweden (product name Nordic Green Roof®Sedum matte), the origin of feedstock for both biochars were birch wood, but they were manufactured by the different company. Biochar (A) had been pyrolyzed in a continuous process at 380–420°C for 2 h. Whereas biochar B was produced in a batch retort at 450°C for a holding time of 23 h. Five replicates were performed for two biochars and the green roofs without biochar as a control. The laboratory results revealed that biochar A reduced TN and TP load by 24% and 27%, respectively. In contrast, biochar B increased TN and TP load by 5% and 21%, respectively.

Biochar can retain nutrients via several mechanisms including electrostatic adsorption and the retention of dissolved nutrients in the water; the biochar capacity depends on its large surface area and quantity of functional groups, porosity, and NO_3^- adsorption capacity, age of biochar, the quantities of consumed biochar, the rate of N loading of the assumed ecosystem, soil type and hydraulic, precipitation circumstances, plant and microbial demand N (Clough , Condron , Kammann & Müller 2013, 275-293).

High surface area and microporosity of biochar are dominant for organic adsorbent. On the other hand, ion-exchange, electrostatic attraction, and precipitation are dominant mechanisms for the remediation of inorganic contaminants by biochar. Since the sorption of organic contaminants depends mainly on surface area and pore size, biochar in general shows greater sorption capacity for organic than inorganic contaminants. (Ahmad, Rajapaksha, Eun Lim, Zhang, Bolan, Mohan, Vithanage, Lee & Sik Ok 2014, 19–33.)

Another mechanism could be nitrification of nitrate. Besides that, the C/N ratio in soil affects mineralization and immobilization of nitrogen, as greater ration increase nitrogen immobilization. Since biochar effects on nitrate leaching may improve over time, further studies need to examine nitrate leaching and biochar effects in large scale over long durations as declining washing out of nutrients by biochar application was observed in the second year of this experimental study.

Another probable reason for nutrients leaching by biochar is that the surface of biochar is often negatively charged, which causes negatively charged ions to be repulsed, but depends on both the nutrients and the biochar type (Yao, Gao, Zhang, Inyang & Zimmerman 2012, 1467–1471). Additionally, as mentioned before, nitrate and phosphate groups are negatively charged and they are hydrophilic ions, therefore they cannot compound with soil or negatively charged biochar easily (Hudak, 2000; Zawaideh & Zang, 1998; Ward et al., 2005). Therefore, some consideration should be given to chemistry of nutrients and soil and the nutrients cycle in the ecosystem.

In Yao, Gao, Zhang, Inyang & Zimmerman (2012, 1467–1471) study contrary to higher zeta potentials of the raw sugar beet tailing biochar than digested sugar beet tailing biochar, both removed low phosphate from solution. And digested sugar showed highest phosphate removal. They realized that digested sugar contained MgO on the surface that absorb phosphate. the other metal elements (Ca, K, Fe, Zn, Cu, and Al) did not show significant absorbent of biochar. Magnesium oxide is used for many purposes such as soil and groundwater remediation, water and wastewater treatment, air treatment, and waste treatment due to its acid buffering property and stabilizing dissolved heavy metals (Magnesium oxide 2016).

7 CONCLUSION

According to the main goal, this study indicated that green roofs increased the amount of nitrogen and phosphorous in runoff which is the main concern about green roofs. It seems that lots of factors might contribute to nutrients leaching such as the roof materials, fertilizers, precipitation properties, soil properties and hydrology trend, internal temperature dynamic of green roof, seasonal variation, evapotranspiration rate, chemical properties of nutrients, plant species and different requirements of the plant for nutrients and atmospheric deposition. It seems the largest challenge is the negatively charged and hydrophilic features of nutrients and the washing out of nutrients.

Furthermore, there was not any apparent relation between the age of surveyed green roofs and the nutrients concentrations in green roofs runoff.

In terms of vegetation influence on nutrients leaching, no apparent relation was observed when comparing different vegetation types and nutrients concentration. However, it seemed that pre-grown vegetated discharged lower mass nutrients load than plug plants.

As regards climate, extreme rain caused washing out of nutrients in the green this appears to be since the soil is saturated and less concentration of nutrients were released from a green roof in the freezing season.

In the experiment, it seemed that biochar was not able to decrease nutrients concentration during the first year, but it started to reduce peak concentration and cumulative loading and nutrient discharging during the second year. On the other hand, the biochar that was used in this experiment might not have been of proper quality. The pyrolysis temperature, feedstock features, and production parameters should be mentioned more for biochar efficiency on nutrients retention. Hence, amending biochar has a positive effect, but it should be optimized, and more research is needed to optimum quantity and properties of biochar to be applied and its actions in the longer term. Further study is suggested about possible positively charged additives to the biochar used in this study.

Overall, it is impossible to control all the variables, but it is suggested that green roofs at least be constructed with suitable materials and that the substrate and fertilizers be well designed to avoid excessive runoff of nutrients and other pollutants in the process. Therefore, it is suggested that more holistic investigation of green roofs should be considered over a longer period to achieve more reliable conclusions about the mechanism of water runoff from green roofs.

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APPENDICES

Table 3- Average biochar available nutrient concentrations based on feedstock sources (dry weight basis)(Ippolito, Spokas, Novak, Lentz & Cantrell 2014, 137-162)

source	NO_3 (mg kg^{-})	P	K	Ca	Mg
Com	0.85	806	11600	1280	1340
Wheat/barely	1.05	596	14000	379	112
Rice Straw/husk	--------	--------	--------	840	552
Sorghum	--------	99.5	--------	--------	-------
Soybean stover	--------	--------	--------	--------	-------
Peanut shell	--------	--------	--------	--------	-------
Pecan shell	--------	--------	--------	--------	-------
Hazelnut shell	--------	--------	899	270	28.0
Switchgrass	--------	--------	--------	--------	--------
Baggage	--------	76.0	--------	--------	--------
Coconut coir	--------	--------	--------	---------	--------
Food waste	--------	--------	13300	5060	1090
Other(grass, leaves, orange peel, other green wastes)	0.92	307	8370	680	574
Hardwoods	0.12	25.1	1620	652	116

Softwoods	---------	200	1020	684	103
Papermill waste	---------	--------	117	20800	234
Poultry manure/litter	---------	448	13800	5830	1280
Turkey manure/litter	---------	1400	----------	---------	--------
Swine manure	---------	225	----------	---------	--------
Dairy manure	---------	240	13500	7940	3170
Cattle manure	---------	320	----------	---------	--------
Biosolids/Sewage Sludge	---------	--------	---------	---------	--------

Table 4- Average biochar total nutrient concentration based on pyrolysis temperature, pyrolysis type and pyrolysis temperature by type (dry weight basis) (Ippolito, Spokas, Novak, Lentz & Cantrell.2014, 137-162)

Pyrolysis temperature	C(%)	N(%)	P (gkg^{-})	K (gkg^{-})	S (gkg^{-})	Ca (gkg^{-})	Mg (gkg^{-})	Fe (gkg^{-})	Cu (gkg^{-})
<300 ^{o}	53.6	1.25	11.4	4.90	7.05	1.10	-------	0.05	5.16
300-399	57.1	1.99	13.7	21.1	14.0	39.1	7.07	2.49	330
400-499	62.1	1.29	13.0	17.7	0.17	52.4	5.05	2.79	124
500-599	63.2	1.15	11.8	14.9	2.00	49.9	6.93	2.19	105
600-699	62.4	0.94	11.4	14.9	0.60	55.6	6.73	1.25	115
700-799	63.7	1.50	42.9	54.0	6.57	46.8	18.8	4.32	545

>800	63.2	0.84	25.4	77.2	92.0	78.4	72.6	7.93	330
Pyrolysis type									
Fast	56.2	0.74	14.8	53.2	0.33	60.5	60.6	5.75	8.52
Slow	60.2	1.44	15.4	20.8	8.97	47.8	8.65	2.67	294
Pyrolysis temp×type									
Fast, 300-499	61.0	0.92	31.5	51.2	0.23	58.0	1.79	------	-------
Fast, 500-699	51.1	0.72	0.30	3.40	0.37	3.70	1.50	1.40	17.0
Fast, 700-900	59.1	0.34	3.39	105.5	-------	92.8	120	7.93	--------
Slow, <300	53.6	1.25	11.4	4.90	7.05	1.10	--------	0.05	5.16
Slow, 300-399	60.0	1.71	11.9	17.0	13.0	43.4	6.25	2.11	289
Slow, 500-699	62.8	1.17	12.5	15.6	2.30	54.4	7.19	1.90	124
Slow, 700-900	64.2	1.53	43.7	53.2	6.57	495	20.0	4.32	509