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Master thesis

Vermi-biochar as alternative to peat as growing substrate for greenhouse vegetables

En blanding av vermikompost og biokull som alternativ til torv som vekstmedium for grønnsaker i veksthus

Master in Sustainable Agriculture

2018

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List of abbrevations

CEC: Cation Exchange Capacity
CH_4: Methane
CO_2: Carbon dioxide
D: Day
E: Evening
EBC: European Biochar Certificate
EC: Electrical Conductivity
GHG: Greenhouse Gases
K: Potassium
M: Morning
mS: Millisiemens
Mt: Megatonnes

N: Nitrogen
N_2O: Nitrous Oxide
ns: not significant
OM: Organic Matter
P: phosphorus
PAH: Polycyclic Aromatic Hydrocarbon
sd: Standard deviation
se: Standard error
SPAD: Soil Plant Analysis Development
v/v: volume/volume
w/w : weight/weight
WHC: Water Holding Capacity

English Summary (abstract)

Biochar is a novel soil amendment technique with a potential of sequestering atmospheric carbon into soil with an increase in certain soil quality parameters essential for crop production. Intense use of peat as growing media, especially in horticulture, has led to a huge exploitation of stable carbon from wetland mosses into the atmosphere accelerating climate change. Certainly, there is a need for sustainable alternatives. Series of research on using coconut fiber or other composts have been conducted for testing peat alternatives. The results, however have not always been positive, mainly due to water and nutrient mobility and stability issues. My study examined biochar prepared from a mixed woodstock of ash (*Fraxinus excelsior* L.), beech (*Fagus sylvatica* L.) and oak (*Quercus robur* L.) prepared at 500 - 550 °C in a slow pyrolysis reactor on a vegetable farm in Åsgårdstrand, Vestfold. An initial experiment was made to examine the effect of biochar on germination and in this trial onion (*Allium cepa* L.) was selected due to its sensitivity at an early stage. These initial results showed that biochar, if diluted, would not harm the crop establishment. A new experiment was then conducted to test if biochar mixed with vermicompost (vermibiochar) in a 1 : 2 ration (w/w) could replace, at least some of the peat used in greenhouse production of vegetables. This vermibiochar was then mixed with a commercial peat soil in different volumetric ratios 40 : 60, 60 : 40, 70 : 30, 80 : 20, 100 : 0 respectively, and with 100 % of the commercial peat soil as a control. Vermibiochar has a slightly alkaline nature and contains high levels of macro- and micro-nutrients. Red Cherriette radish (*Raphanus sativus* L. var. *sativus*) was selected for the experiment, as this was a priority crop for the collaborating farmer. Germination rate, radish root and shoot weight, number of marketable leaves and total biomass production were examined. The results showed that vermibiochar rates from 40 to 70 % in the peat mix, led to a significant increase in radish root weight and total biomass production compared to peat soil alone. As there was no significant differences in root weight and total biomass production between a growth substrate based on vermibiochar and substrate based on peat, one could argue that vermibiochar could replace 100 % of the peat used in greenhouse production of radish. Most likely, the same will be true for other crops raised in peat-based soils. Further research is needed to verify if this would also be the case for other peat-based horticultural productions.

Key words: Biochar, vermicompost, organic matter, nutrients, peat, growing media

Norwegian Summary

Biokull representerer en ny jordforbedringsteknikk med potensiale å overføre karbon fra luft til jord og samtidig bidra til bedring av flere av de jordegenskaper som er viktige for plantevekst. Torv som vekstmedium brukes i stor utstrekning, særlig innenfor hagebruket, og har bidratt til at karbon bundet i organisk materiale i myrer i økende gras blir overført til atmosfæren og på den måten bidrar til klimaendring. Det er behov for alternativer til torv. En rekke forsøk på å bruke kokosnøtt-fiber eller andre organiske vekstmedia istedenfor torv har blitt gjennomført, men de viser ikke alltid like gode resultat, særlig på grun av forhold knyttet til vann og næringsstoffhsholdningen. Et arbeid ble satt i gang med bruk av biokull fra flis fra ask (*Fraxinus excelsior* L.), bjørk (*Fagus sylvatica* L.) and eil (*Quercus robur* L.) produsert i en pyrolyse reaktor ved temperaturer rundt 500 - 550 °C. Et første forsøk ble gjennomført for å teste effekten av biokull på spiring og vekstetablering. Løk (*Allium cepa* L.) ble her valgt, dette siden arten er særlig følsom på et tidlig stadium. Resultatene viste at biokull dersom det blir fortynnet, ikke skadet etableringen av løkplantene. Et neste forsøk ble deretter gjennomført for å teste om et vekstmedium laget av en blanding av vermikompost og biokull i et 2 : 1 forhold kunne ertatte noe av all torven som blir brukt. Dette vermi-biokullet ble så blandet med en komersiell torvjord i ulike forhold (regnet på volumbasis), fra 40 : 60, 60 : 40, 70 : 30, 80 : 20, 100 : 0 og med 100 % av den komersielle torvjorden som kontroll. Vermi-biokullet var noe alkalisk og inneholdt høye verdier av så vel makro som mikronæringsstoff. Rød Cherriette reddik (*Raphanus sativus* L. var. *sativus*) ble valgt som testplante siden dette er en viktig grøde for bonden som det ble samarbeidet med. Spireprosent, vekt av reddiken, bladvekt, antall salgbare blad, samt total biomasseproduksjon ble undersøkt. Resultatene viste at å blande 40 – 70 % vermi-biokull i torvjorda ga en statisisk sikker økning i så vel reddik-vekt som i total biomasseproduksjon sammenlignet med torvjorden alene. Da det ikke kunne påvises sikre forskjeller i produsert biomasse og vekt på reddikene kan det argumenteres for at vermi-biokull i prinsipp kunne erstatte 100 % av all torv som blir brukt i veksthusproduksjoner av reddik. Det samme vil sannsynligvis også være tilfelle for andre vekstslag dyrket i torvbaserte jordblandinger. Videre forskning er nødvendig for å bekrefte om dette også er tilfelle for andre torvbaserte hagebruksproduksjoner.

Nøkkelord: Biokull, vermicompost, organisk materiale, næringsstoff, torv, vekstmedium

1 Introduction

1.1 Background

Growing substrate, also termed growing media, has been used for a long time, especially for raising plants and in greenhouse production of vegetables and ornamental plants (Schmilewski, 2007). In regard to soil-based growing systems, peat is cost-effective and highly reliable (Bragg, 1990; Grafiadellis, Mattas, Maloupa, Tzouramani, & Galanopoulos, 2000). Readily available and considerable cheap resource has led to huge exploitation of peat, leading for researchers, politicians, and stakeholders to find alternatives to reduce the intense pressure on its usage. The enormous peat extraction has led to an accelerated release of stable carbon into the atmosphere, contributing to climate change (Alexander, Bragg, Meade, Padelopoulos, & Watts, 2008). Indeed, there is a need to search for another cost-effective, productive and eco-friendly sustainable growth substrate that could replace peat. Furthermore, peat extraction from wetlands has risen the question to conserve the ecosystem in a process of heading towards sustainability. On a global scale, there is an estimated coverage of 400 million ha of peatlands. At the same time, the global peat usage for horticultural purposes has increased to nearly 11 million metric tons per annum (Strack, 2008). As we understand, a major global carbon sinks is being used as growing media contributing to climate change. On the other hand, peat is used due to its high porous nature, low bulk density, low microbial activity, low salt content, increased water holding capacity (WHC), high cation exchange capacity (CEC) and other attributable nutrient supplement for the plant along with its lower decomposition rate. Therefore, for decades peat has been the major growing medium throughout the world.

1.2 Peat extraction and emissions

Disturbance of peat land bogs for its use results in carbon imbalance and emissions of CO_2, CH_4, and N_2O. Prior to peat extraction, raised bogs and fens are drained to facilitate the aeration that meets the requirements to be used as growing media. Over the years, more than 10 million ha of peatlands have been drained in Russia and the Nordic countries (Norway, Sweden, and Finland), facilitating soil aeration and oxidation, causing hard tough surface, increasing the decomposition rates leading to emissions of CO_2, N_2O (Strack 2008).

Peatland used for cultivation in Norway is around 63,000 ha a year, with an annual loss of 1.8 - 2 million ton of CO_2, resembling about 4 % of the total CO_2 emissions from Norway (Grønlund, Hauge, Hovde, & Rasse, 2008). However, excluding cultivated land use (unmanaged, foresty drained, agriculture, abandoned), peat constitute for 15.2 % of total emissions (Joosten, 2015). Emissions are related to the disturbance of peatlands through removing peat bogs, draining, exposing to an aerobic environment. Despite this, as long as it remains in the natural state, decomposition rate is slow and the emission is lower (Cleary, Roulet, & Moore, 2005).

Another way that peat is used, and what this thesis is addressing, is the use as growth substrate in plant nurseries or other horticultural productions. The peat used for such a purpose is produced in wetlands through partly decomposed material under limited oxygen supply. Climatic conditions prevalence, the degree of decomposition along with plant species determine peat characteristics and qualities (Handreck, Black, & Black, 2002). Mostly peat from sphagnum mosses are highly porous, with a good water holding capacity and cation exchange capacity compared to other materials used. Low pH of such peat mosses is favourable for the acid loving plants, however, the low pH can be adjusted with lime or biochar to use for other plants. Along with fertilizers, this can produce a growing media adapted to any plant species. With these attributes, around 90 % of all growing media based enterprises in Europe are peat dependent (Kern et al., 2017). Being a non-renewable resource with a long generation time (Kern et al., 2017) and a high CO_2 emission potential, restriction on using peat as growing media has been initiated by the European Commission (Lehmann & Joseph, 2015). This has however not yet been implemented fully.

The use of peat and its effects, both on emissions and on degradation of wetland ecosystems, are having enormous ecological impacts. This has risen the need to find alternative and more sustainable growing medias (Barber, 1993). Nevertheless, a lot of research and practices has been undertaken in using coconut fiber, perlite, rice hulls, barks, and other composted solid materials as potent growing media alternative to peat (Abad, Noguera, & Burés, 2001; Fascella, 2015). So far, they have not been compatible for peat substitute. A synergetic effect of peat and compost has been observed, with peat supplying better aeration and water holding capacity and compost enhancing the fertilizing capacity of the substrate. Some of the tested alternatives had inconsistency in nutrient mobilization, stability, and other chemical properties, and were not stable enough to substitute peat completely (Schmilewski, 2008).

Table 1.1 Peat land areas of world (Source: World Energy Council, 2013)

Region	Peatland Area (km^2)
Central and North America	1,762,267
Asia	1,490,361
Europe	525,668
South America	130,800
Africa	56,165
Antarctica, Oceania, Pacific	8,048
Total	3,973,309

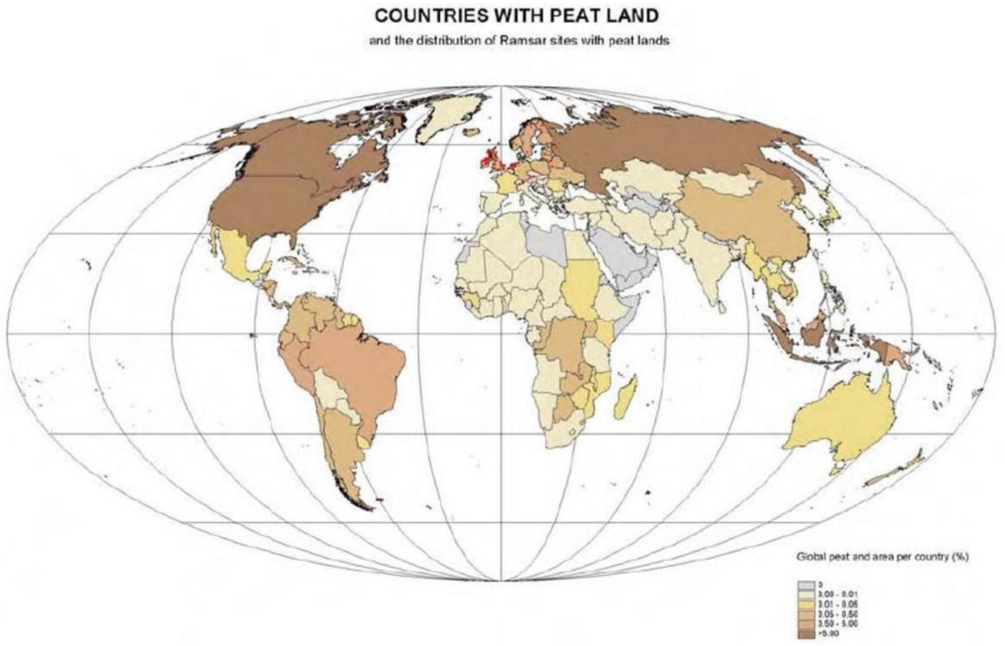

Figure 1.1 Peat land area in different countries (Source: Wetlands International, 2000)

Peat with its low global land-coverage, constituting of only 3 %, has a huge carbon stock compared to for example the forest area of the world (Barthelmes, Couwenberg, Risager, Tegetmeyer, & Joosten, 2015). Nearly 15 % of global peatland has already been drained, and has resulted to a huge CO_2 emissions; annually around 5 % of the global CO_2 emissions (Joosten, 2009). The study has shown to drain nearly half of peatland area available in Nordic and Baltic countries, in a loss of 80 Mt of CO_2 per annum or an amount equivalent to 25 % of the total CO_2 emissions from these countries (Barthelmes et al., 2015). In Europe, Iceland (230.4 Mt CO_2 yr^{-1}) and Latvia (182 Mt CO_2 yr^{-1}) are the two major CO_2 emitters from peat drainage (excl. cultivated land use) followed by Lithuania, Estonia, and Finland (Barthelmes et al., 2015). According to the same author, Norway and Sweden are the least peat drained country in Europe where in this region almost 60 % of the total available are already drained, however, contribute 15.2 % and 23.1 % of its total CO_2 emissions from peat use, respectively. Meanwhile, it has been estimated that CO_2 emissions from peatland use is higher in Southeast Asia than from other regions, making a release of up to 2 billion tons of CO_2 every year from peatland use, drainage and plantations equivalent to 30 % of the global emissions from fossil sources (Hooijer, Silvius, Wösten, & Page, 2006; Joosten, 2015; World Energy Council, 2013).

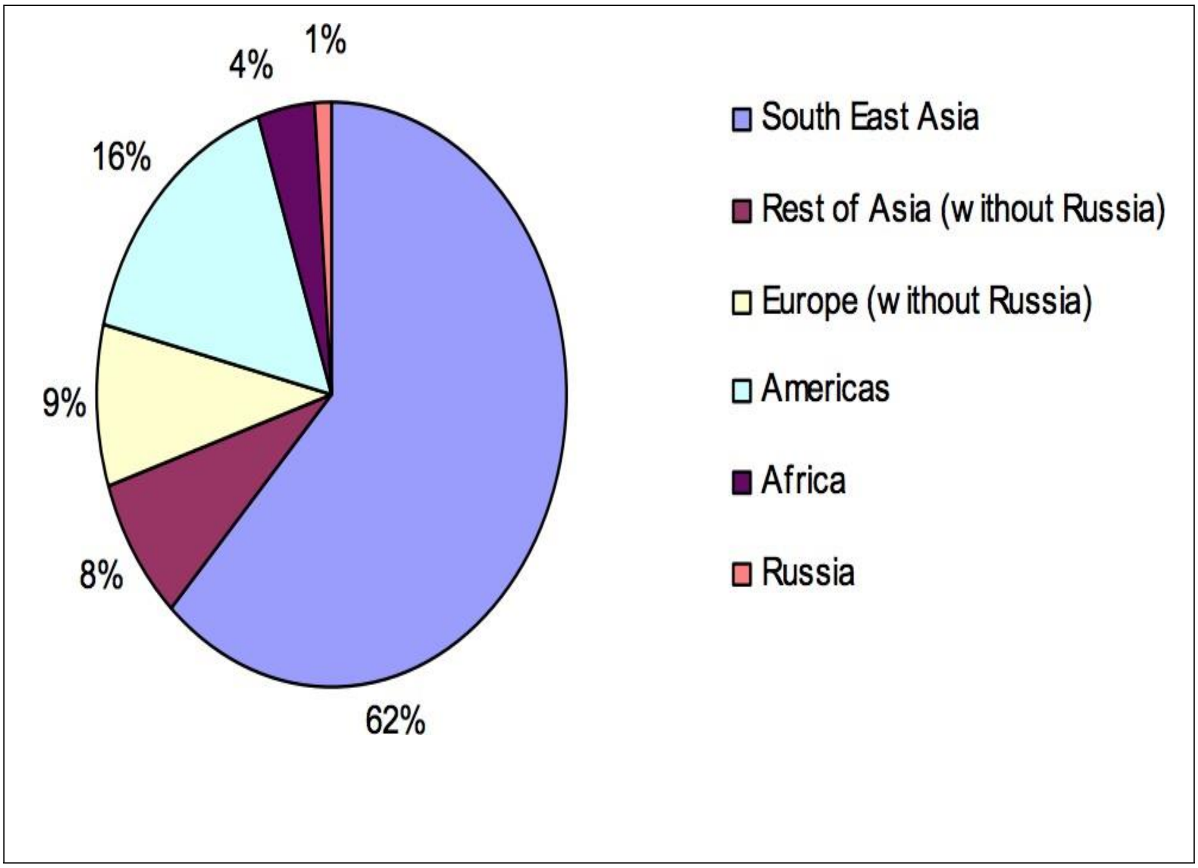

Figure 1.2 CO_2 emissions from drainage and decomposition of peat land in different regions Source: (Silvius & Kaat, 2006).

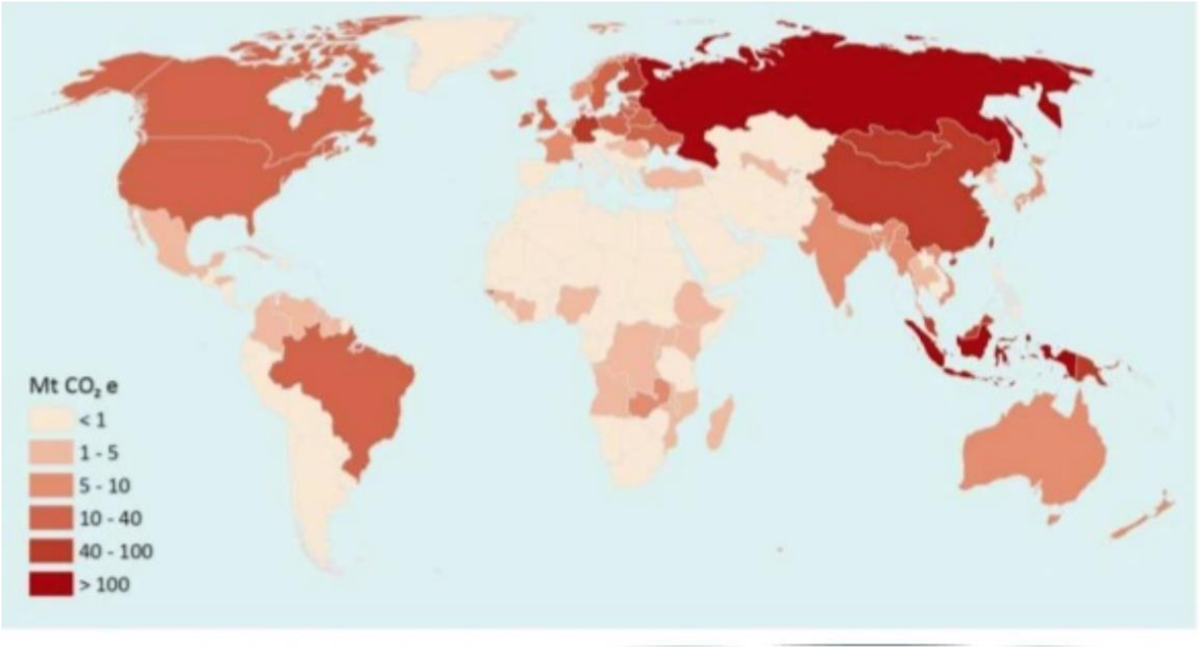

Figure 1.3 Peat land emissions of the world (Source: UNFCCC Nordic Pavillion, 2015)

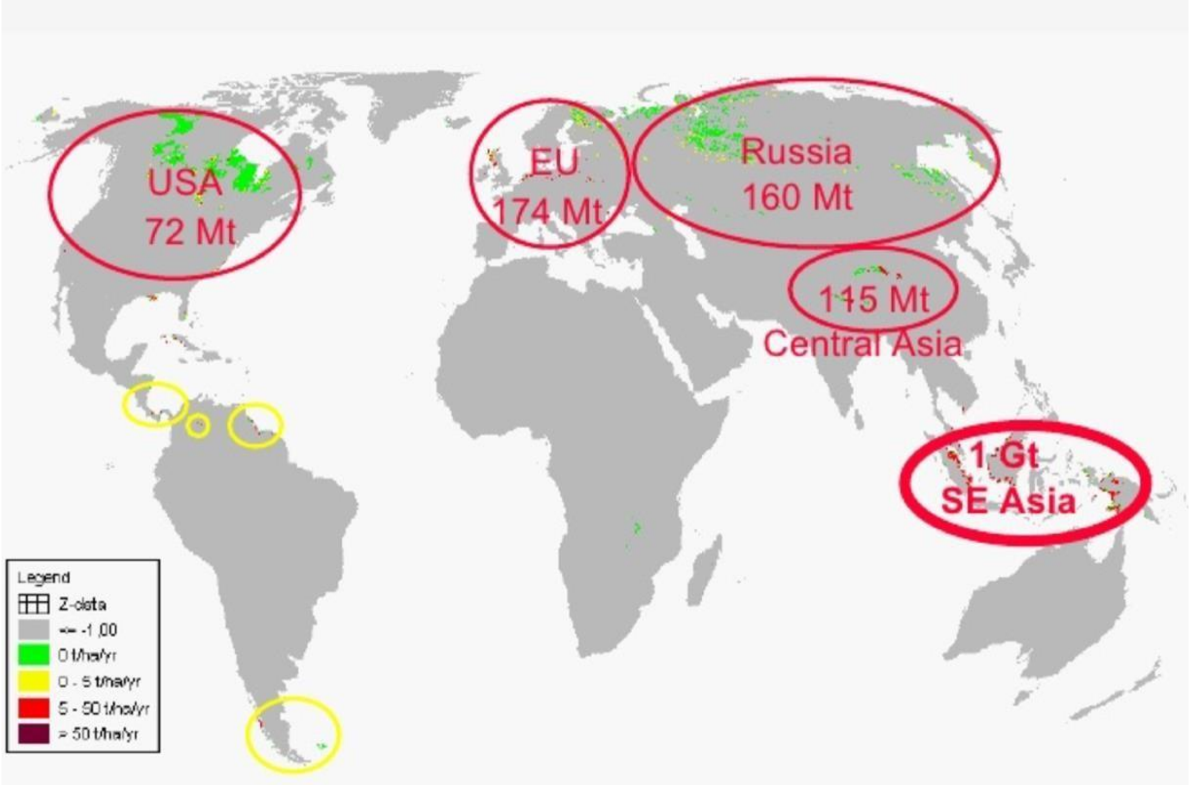

Figure 1.4 CO_2 *emissions from peat usage from different continents and regions (Source: Wetlands International, 2015)*

In Southeast Asia, Indonesia accompanies for 58 % of the national emissions only from peatland extraction. Continuous clearing of peatlands for palm plantations has led to huge emissions (Oleszczuk, Regina, Szajdak, Höper, & Maryganova, 2008).

Despite many challenges, biochar could be a potential component in a new growth substrate that could play a significant role in maintaining an eco-friendly and sustainable production (Farrell & Jones, 2010). In the past few years, biochar produced through the high temperature treatment of organic wastes and woodstocks under oxygen-deficient conditions has been used in agriculture and had achieved significant results (Jeffery, Verheijen, van der Velde, & Bastos, 2011). Biochar from the organic wastes leads to highly porous and stable char with other chemical and nutrient attributes than char made from woodstocks. Biochar has the ability to store carbon in its structure for a very long time and has thus a potential to contribute to carbon capturing and resuced CO_2 emissions. Biochar with its carbon capture ability and clean energy generated during the production process (through pyrolysis and gasification) has a potentiality to reduce 1.8 gigatonnes/year (1.8 billion metric tons) offsetting 12 % of global greenhouse gas emissions equivalent to 15.4 billion metric tons of GHG's that human adds every year (Woolf, Amonette, Street-Perrott, Lehmann, & Joseph, 2010). Meanwhile, there is a limited number of studies on biochar as a component of alternative growing substrates.

In order to cope with increasing demands of peat use and rising environmental drawbacks, a need for the best alternative sustainable growing substrate has been essential avoiding the use of these non- renewable resources, which can be tackled through biochar having at least some of the peat-addressing properties.

1.3 Biochar: peat addressing properties

Indigenous people living in the Amazon Basin of Brazil were found to create the high fertile black soil, about thousands of years ago so-called as Terra preta. Studies have shown that burning of the residues from their kitchen and other organic wastes has to lead to dark black carbon content in soil, resulting for the high carbon containing black soil, which we called as biochar or black gold today (American Chemical Society, 2008 ; "Using Charcoal to Make Soil Into Black Gold", 2018). Today, these soils are considered as very fertile, with high nutrient values and a good economic return for the farmers.

Biochar is a charcoal involving heating of organic matters under limited oxygen conditions with a process called pyrolysis. The significance of pyrolysis is that the carbon and nitrogen present in the organic matters are volatilized, resulting a solid by-product, the so-called biochar. Biochar has an increased number of aromatic carbon rings, making it recalcitrant to decomposition (Kimetu & Lehmann, 2010). The feedstock used and the pyrolysis operating conditions leads to varying in physical and chemical properties of biochar (Hossain, Strezov, Chan, Ziolkowski, & Nelson, 2011; Kloss et al., 2012). The temperature in the biochar production process determines some of its agronomic value. Volatization of organic matter and nutrients will occur at increased temperatures. This will result in a less porous char, less suitable as a soil amendment (Downie, Crosky, & Munroe, 2009; Gaskin, Steiner, Harris, Das, & Bibens, 2008). The alkaline nature of biochar can be used for acidic soils, neutralizing or increasing the pH and allowing essential nutrients to be more available for plant uptake. Adsorption ability of heavy metals like lead, zinc, copper, and cadmium into its pores adds up the additional benefits of the biochar (Ali et al., 2017). Prior to use, characterization of the biochar is essential. Biochar is normally considered as a soil improver, increasing the carbon content and fertility of the soil. Thus, biochar can enhance the quality of low fertile soil. For some, biochar is regarded as a benchmark for coping food security challenges through increasing soil quality and crop productivity, and total soil carbon content (Biederman & Harpole, 2013). Some studies have recognized that biochar can be an effective component in a soil-less growth substrate (Lehmann & Joseph, 2015). This due to its high surface area, porous nature, structural stability and recalcitrant nature. Positive yield results from adding biochar to the soil has been obtained in crops as diverse as corn, tomatoes and radish (Chan, Van Zwieten, Meszaros, Downie, & Joseph, 2008; Hossain, Strezov, Chan, & Nelson, 2010; Major, Lehmann, Rondon, & Goodale, 2010). This has embraced the potential to test biochar in growth substrates as an alternative to non-renewable resources like peat. Certainly biochar may play a role in reducing the emissions compared to peat substrate (Kammann, Glaser, & Schmidt, 2016). Application of biochar would potentially enhance the performance of the crop due to its use as fertilizer additive or being treated with other organic amendments like compost, increasing the nutrient availability, soil organic carbon content and other physical and chemical properties of the growth substrate (Agegnehu, Srivastava, & Bird, 2017). There are evidence to believe that biochar mixed with vermicompost can further enhances soil properties, reduce disease borne pathogens and increases crop productivity (Shoaf, 2014).

However, negative impacts of biochar on plant growth has been reported due to its high pH and dose used with content of potential toxic compounds (Clough, Condron, Kammann, & Müller, 2013). There is a need to considered such properties, both in the feedstock used and the production process, including any pre-and post-treatments (Jaiswal, Frenkel, Elad, Lew, & Graber, 2015). The attributes of the biochar are dependent on both the feedstock and the production process. Synergetic effects have been found on mixing biochar with compost, reducing potential harmful effects and making nutrient more available and the char more stable (Busch & Glaser, 2015). Significant positive results in plant growth have been achieved, as well as enhanced soil physical and chemical properties, such as pH, EC, WHC, and nutrient availability making it promising as a substrate for plants (Doan, Henry-des-Tureaux, Rumpel, Janeau, & Jouquet, 2015). Mixing biochar with compost (vermicompost) results in dual benefits from both for plants. Even activated char gets more nourished or charged than normal char, enhancing better fertility and plant growth, with increasing soil organic matter content, even reducing nutrient leaching potential. The potential of using biochar as an additive or alternative to peat is greatest if mixing it with soil or compost (Steiner & Harttung, 2014). Recent studies were done using pure biochar, without any activation or organic amended found not enough potential to reduce the peat use (Steiner & Harttung, 2014).

2 Objectives

The main aim of the study was to find ways to replace at least some of the peat used as growth substrate in agriculture. The following three objectives were included:

1. Investigate physical and chemical properties, as well as potential phytotoxic effects, of biochar produced on a vegetable farm in Vestfold, Norway.
2. Determine how the current biochar mixed with vermicompost (vermi-biochar) could replace peat as a growth substrate for radish produced in greenhouses at the farm.
3. Fine-tune the proportions of vermi-compost and peat to optimalize the greenhouse production.

The main hypothesis was that activated biochar could increase germination, plant growth, marketable yield, and overall biomass production compared to peat used alone.

3 Methodology

3.1 Biochar Production and properties

Biochar was produced in a B300 pyrolyser (Biochar Energy Systems P/L., Bendigo, Australia) from a mixed woodstock of asch (*Fraxinus excelsior*), beech (*Fagus sylvatica*) and oak (*Quercus robur*) at a temperature of 500 - 550 °C at Skjærgarden farm, Vestfold, Norway (59°N, 10°E).

3.2 Experimental Framework

3.2.1 Phytotoxic bioassay

The biochar produced was used to determine phytotoxic effect by conducting germination trial in soil less petri-dish bioassay using a sensitive species; *Allium cepa* L. Prior to use, biochar was first dried at 40 °C (for two days). A bioassay was then made using five dilution schemes with distilled water from 1 : 5 to 1 : 25, and further two biochar-digestate ratio schemes for 1 : 30 along with tap water as a control (Table 3.1). The final readings were ended after 15 days with germination rate, root and shoot weights and lengths (Table 4.4, Figure 6.1, Figure 6.2). 5ml of each solution was used in each petri-dish having two 85 mm filter paper (Whatman ^{TM}, China) with 10 seeds used per replication having total eight treatments and four replications per treatment. Image J software (http://imagej.net/) was used to determine root and shoot length.

Table 3.1 Composition of biochar, digestate and distilled water used in Allium cepa

Treatment	Biochar (g)	Digestate (ml)	Water (ml)
Tap water(Control)	0		300
Biochar:Water,BC:H20 (1:5)	60		300
Biochar:Water,BC:H20 (1:10)	30		300
Biochar:Water, BC:H20 (1:15)	20		300
Biochar:Water, BC:H20 (1:20)	15		300
Biochar:Water,BC:H20 (1:25)	12		300
Biochar:digestate(1:2 dil)	10	150	300
Biochar:digestate (1:4 dil)	10	75	300

3.2.2 Biochar in growing substrate for greenhouse radish

Biochar was charged or activated with vermicompost in a 1 : 2 ratio (w/w) to a vermi-biochar growth substrate (Bv). An experiment was made to examine the effects of this vermi-biochar compared to peat as growth substrate. Six treatments were included; peat alone, vermi-biochar alone, and at different mixtures of vermi-biochar and peat (Table 3.2).

The peat replacement study was carried out in containerized plastic trays (Vefi 64 trays, Larvik, Norway), using a complete randomized block design with six treatments and four replications per treatment. The plant was red Cherriette radish (*Raphanus sativus* L. var. *sativus*), one of the major greenhouse crops of the farm. Seven seeds were placed in each replicate having a volume of 0.063 L each. The plastic tray was equipped with a hole for drainage. Supplement of water was given when required looking after dryness. Additional fertilizer supplement was given with Calcinite (15.5 % N) and Kristalon (9 - 5 - 25 + Mg + S + micro nutrient). Altogether 2.6 liters of Calcinite (pH 6.65, EC 0.235 mS/m) was sprayed to all the replicates throughout the experiment with 1 litre on 8 - July, 0.8 litre each on 19 July and 24 July respectively with in growing period (from July 2 - August 1). Kristalon (2.8 liters, pH 6.45, EC 0.268 mS/m) were sprinkled over the replicates with 1 liter each on 11 July & 17 July respectively and 0.8 liters on 22 July. All plastic tray were placed in a greenhouse and average temperature was recorded on a daily basis (21.55 ± 4.96 M, 22.81 ± 5.7 D, 20.01 ± 1.78 E). The number of germinated seeds were observed on a daily basis without disturbing the system.

The readings were terminated after 30 days with a final germination rate and, fresh root and shoot weights, root diameter, and brix %. Brix determines the dissolved solids, minerals and nutrient content identifying maturity of crops and proper harvesting.

Table 3.2 Composition of growing media used in the experiment

Treatment	Composition	Details
T1	P100	100 % peat soil
T2	P6Bv4	60 % peat soil + 40 % Vermi-biochar
T3	P4Bv6	40 % peat soil + 60 % Vermi-biochar
T4	P3Bv7	30 % peat soil + 70 % Vermi-biochar
T5	P2Bv8	20 % peat soil + 80 % Vermi-biochar
T6	Bv	100 % Vermi-biochar

3.3 Statistical analysis

R studio software (https://www.rstudio.com/) and Ms-Excel was used for statistical analysis. Two-way variance analysis (ANOVA) was used for significance tests. Tukey's HSD test were used to determine the difference among treatments at a 95 % significance level.

4 Results and discussion

4.1 Properties and characteristics of biochar and vermi-biochar

Produced biochar from slow pyrolysis reactor (at 500 - 550 °C) was mixed uniformly and choose randomly for chemical analysis, which was done later in lab of Eurofins Umwelt Ost GmbH (Bobritzsch-Hilbersdorf, Germany). pH content, heavy metals, Polycyclic Aromatic Hydrocarbon (PAH), nutrient content of biochar and bio-digestate were measured. PAH content in biochar was compared with European Biochar Certificate (EBC) regulations Versions 6.3 E (http://www.european-biochar.org) which sets two grade, premium as (< 4 mg kg^{-1}) and basic (< 12 mg kg^{-1}).

The produced biochar has higher pH (9.5) with higher values for other properties having EC 68.5 mS/m and ash content of 48.3 %. Adding biochar having higher pH and EC can be a subject of risk causing the nutrient imbalances, alkali stress, precipitating the metal ions affecting the germination of seedlings (Beesley, Moreno-Jimenez, Fellet, Carrijo, & Sizmur, 2015; Shi, 1997; Shi & Yin, 1993).

Heavy metals were noticed in the feedstock used and also in biochar produced. The total PAH of biochar (10 mg kg^{-1}) was below the EBC regulations for Basic grade but higher than premium quality biochar (Table 4.1). Pyrolysis reactors might have added the heavy metals causing the differences between feedstock used and biochar produced.

Pure alkaline biochar was amended with vermicompost (having neutral pH) to make nutrient enriched vermi-biochar (Bv) which lowers the pH to 8.79 mS/m, having a significant difference to P100, P6Bv4 and P4Bv6. Detailed overview of physical and chemical properties of vermibiochar and peat mixed substrate is explained in below section.

Table 4.1 Chemical properties of the produced biochar (pure biochar, not diluted) and the woodchips used in the production. The EU requirements for basic and premium biochar are included.

Parameters	Biochar	Woodchips.	Requirements	
			EU basic	EU premium
pH in CaCl$_2$.	9.5	-		
Total C (%)	57.1 [A]	48.9		
Hydrogen (%)	0.5	5.6		
Fe$_2$O$_3$ (%)	4.3	3.8		
CaO (%)	5.3	11.1		
K$_2$O (%)	3.9	5.6		
MgO (%)	1.6	2.8		
Na$_2$O (%)	3.1	3.1		
Total N (%)	0.14	0.18		
Sulfur (%)	0.05	0.07		
Ash content, 815°C (%)	46.8	2		
Pb (mg kg^{-1})	8	<2	<150	<120
Cd (mg kg^{-1})	<0.2	0.3	<1.5	<1.0
Cu (mg kg^{-1})	17	2	<100	<100
Cr (mg kg^{-1})	27	9	<90	<80
Hg (mg kg^{-1})	<0.07	<0.07	<1.0	<1.0
Ni (mg kg^{-1})	13	5	<50	<30
Zn (mg kg^{-1})	98	33	<400	<400
As (mg kg^{-1})	-	-	<13	<13
Mn (mg kg^{-1})	667	67		
Total PAHs (mg kg^{-1})	10	-	<12	<4

[A] measured in biochar >600 µm

Table 4.2 Electrical conductivity (EC) and pH of the included growing substrates.

Treatments	EC (mS/m)	pH
Bv	85.1±15.24 a	8.79±0.03 a
P100	45.4±3.9 f	8.01±0.18 ab
P2Bv8	30.4±0.4 c	8.47±0.08 a
P3Bv7	38.2±4.8 d	8.83±0.28 a
P6Bv4	45.6±4.5 f	8.37±0.099 ac
P4Bv6	61.3±6.5 e	8.06±0.035 ab
Vermicompost	57 ± 0 h	7.5 ± 0 b

Values are means ± sd, followed by the different letter in any column are significantly different at the 0.05 level using Tukey's HSD test.

Our results shows a significant increase in the EC of substrates (from 45.6 to 61.3 mS/m) when vermi-biochar is used at 40 % to 60 % and finally to 85.1 mS/m when 100 % vermi-biochar is used, comparative to lower 45.4 mS/m on only peat usage (Table 4.2). In addition, EC of mixed substrate was increased at rates of 40 %, 60 % and 100 % vermi-biochar having lowest for 80 % vermi-biochar used. Increased EC of pure biochar (68.5 mS/m) amended with higher EC of vermicompost leads to increased EC of vermi-biochar (Bv). By contrast, reduction of

EC in higher does of biochar used, as in our study with P2Bv8 and P3Bv7 was similar to the finding of (Steiner & Harttung, 2014). Subsequent results were also for pH, lower being for peat and increase with increasing biochar concentration (40 % vermibiochar, 70 % vermibiochar , 100 % vermibiochar). Neutral pH of vermicompost mixed to pure biochar, prior to its use reduced the actual pH of biochar or balance the pH of resulting vermi-biochar required for radish production. Significant difference in pH was prevalent among the peat and peat enriched biochar substrates except for P4Bv6. Increasing rates of vermi-biochar (70 - 100 %) tend to increase the alkaline nature of substrates.

Table 4.3 Organic components of the substrates.

Treat-ments	Dry matter (%)	Water content (%)	Organic matter (%)	Ignition loss (IOM) (%)	Total C (%)	Total N (%)	C/N relation
Bv	96.3±0a	3.7±0a	40.1±2.3a	59.9±2.3a	48.0±3.5a	0.77±0.09b	62.5±3.7b
P100	90.4±0.2b	9.6±0.2b	19.8±0.8b	80.2±0.8b	42.8±0.42b	1.00±0.01a	42.7±0.9a
P3Bv7	94.7±0.1c	5.3±0.1c	32.1±0.5c	67.9±0.5c	48.9±1.76 c	0.81±0.06b	60.6±3.2b

Values are means ± sd, followed by the different letter in any column are significantly different at the 0.05 level using Tukey's HSD test.

The water content in the vermi-biochar and peat mixture (here represented with 30 % peat and 70 % vermibiochar; P3Bv7) was 5.3 % (v/v), which was significantly higher than in vermi-biochar alone but lower than in peat alone, showing that this mixture has lower water holding capacity than peat. Organic matter (OM) content in vermi-biochar is significantly higher followed by vermi-biochar peat mix (P3Bv7) and peat. Addition of biochar and vermicompost (here having 22.2 % OM) tends to boost up the organic matter content, resulting more in the biochar-peat mixed substrate than peat alone (Alvarez, Pasian, Lal, López, & Fernández). Peat has also an optimal C : N ratio (42.7 : 1) equivalent to (Dumroese et al., 2011). However, substitutes 70 % peat use (Table 4.3) by biochar mix having 60.6 : 1 (C : N). Higher C : N ratio can lead to nitrogen immobilization and less available to plant, however, can be adjusted by additional nitrogen to meet the requirement for microbes, allowing other additional nitrogen to get access to plants (as in our case), which has also been reported in conifer seedlings (Dumroese, 2009; Handreck, 1993). Among the treatment used pH, C % and C : N ratio were lower in peat soil. Vermi-biochar has higher carbon %, C : N ratio than 100 % peat soil. Overall, vermi-biochar peat mixture (P3Bv7) has higher pH, C %, C : N ratio, OM content than peat having no any significant difference to vermi-biochar. This can be helpful for selecting fine-tuning of biochar and peat mix, considering the factors for increasing yield and also reducing the CO_2 emissions discarding peat usage.

4.2 Germination and Early seedling growth

4.2.1 Growth Response to Onions

Overall, there were no any negative impacts from the biochar on the germination of *Allium cepa*. Instead, biochar increases the emergence of seedlings in start than control, followed by a decline. However, could settle having germination rate 90 - 93% in biochar amended treatment compared to 98 % for tap water, with no any significant differences. In addition, the bio-digestate retard the germination significantly having lowest with higher concentration used. Ammonium toxicity and salt stress from the increased digestate might lead to such effects. Increased concentration of biochar use retard root and shoot growth considering the dilution of char is essential prior to its use.

Table 4.4 Germination, Root length, Shoot length, Root fresh weight and Shoot fresh weight of Allium cepa.

Treatment	Germ-ination (%)	Root length (mm)	Shoot length (mm)	Root weight (g)	Shoot weight (g)
Tap water	98 ± 5	27 ± 7	65 ± 10	1.86±0.04	2.05±0.05
Biochar: Water (1:5)	90 ± 12	6 ± 1	15 ± 7	1.80±0.03	1.82±0.02
Biochar: Water (1:10)	93 ± 10	13 ± 3	49 ± 10	1.81±0.02	1.97±0.03
Biochar: Water (1:15)	93 ± 10	16 ± 4	51 ± 5	1.84±0.02	1.97±0.03
Biochar: Water (1:20)	90 ± 8	22 ± 5	52 ± 15	1.83±0.02	2.00±0.04
Biochar: Water (1:25)	90 ± 8	18 ± 7	52 ± 11	1.84±0.02	2.00±0.04
Digestate + Biochar (1:2)	70 ± 16	6 ± 2	17 ± 7	1.79±0.04	1.81±0.05
Digestate + Biochar (1:4)	80 ± 8	17 ± 6	46 ± 6	1.82±0.02	1.97±0.03
p-Value (ANOVA)	$P<0.05$	$P<0.001$	$P<0.001$	$P<0.05$	$P<0.001$

Values are means ± sd, significant different are labelled by asterisk in Figure 6.2.

Biochar containing phytotoxic substances which are soluble in water or PAH compounds having toxic effects might have reduced the root and shoot length which was opposite to study done on leached biochar increasing such growth parameters (Rogovska, Laird, Cruse, Trabue, & Heaton, 2012). Our study reflects biochar diluted with water at a rate of 1 : 20 or 1 : 25 had a good result (increased root , shoot length and weight) with no negative effect on germination and early seedling growth compared to water (control). Meanwhile, the toxic nature of the biochar and digestate need to be better examined before being mixed into seedling growth media.

4.2.2 Growth Response to Red Cherriette Radish

Despite, P4Bv6 has slower start with 10.7 %, lower than Bv in the beginning (6-July), both achieved 100 % germination level on 10 July. Overall, 100 % peat substrate enhance early seedling growth at start with 75 % compared to other substrates, leading to 96.4 % on 10 July and at the end (similar to P6Bv4 and P3Bv7). P2Bv8 has same start as 100 % peat, ended with final germination of 92.8 % being lowest among other substrates with no any significant difference (Table 4.5).

Table 4.5 Germination percentage of substrates.

Treatments	Germination %
P100	96.4±7.1 a
P6Bv4	96.4±7.14 a
P4Bv6	100±0.0 a
P3Bv7	96.4±7.1 a
P2Bv8	92.8±8.2 a
Bv	100±0.0 a

Values are means ± sd, followed by the different letter in column are significantly different at the 0.05 level using Tukey's HSD test.

Germination percentage for all substrates was greater than 90 % depicting increased germination index having no phytotoxic effects for plants (Emino & Warman, 2004; Zucconi, Monaco, Forte, & Bertoldi, 1985) and to our study was higher for peat enriched vermi-biochar (P4Bv6) and vermi-biochar (Bv) than peat alone.

The significant difference between the substrates was seen in height measured on 15 July and 18 July. P6Bv4 has highest plants, measured to 6.5 cm on 15 July, which was significantly differing from Bv to 5.4 cm tall. The same trend was seen on 18 July, but no differences were seen from 21 July onwards (Table 4.6).

Table 4.6 Height of Radish plants measured at different time interval.

Treatments	Height (cm) – Date (15 July)	Height (cm)- Date (18 July)	Height (cm)- Date (21 July)	Height (cm)- Date (25 July)	Height (cm)-Date (28 July)
P100	6.4±0.46 a	8.8±0.95 b	10.2±1.12a	11.2±1.04a	11.8±.1.17a
P6Bv4	6.5±0.52 a	9.5±0.97 a	11±0.81 a	12.08±0.64 a	12.8±0.87a
P4Bv6	6.2±0.39 a	9.05±0.48 b	10.9±0.47a	12.1±0.74 a	12.8±0.51a
P3Bv7	5.9±0.65 b	8.4±0.75 b	10.2±0.8 a	11.5±0.84 a	12.5±1.13a
P2Bv8	5.8±0.37 b	8.4±1.21 b	10.4±1.29a	11.9±1.37 a	12.6±1.43a
Bv	5.4±0.34 b	8.1±0.19 b	10.2±0.24a	11.7±0.52 a	12.6±0.92 a
p-value	$p<0.001$	$p<0.05$	ns	ns	ns

Values are means ± se, followed by the different letter in any column are significantly different at the 0.05 level using Tukey's HSD test.

4.3 Radish Growth, Yield, and Quality

The response of biochar on the yield of radish differs as per rates of char used. The fresh root weight was significantly higher in P3Bv7 compared to the peat (Table 4.7). Among the fresh vermi-biochar and other vermi-biochar peat mix, there were no any significant differences in fresh root weight. Biochar content in growing substrates influences leaf chlorophyll content resembling higher SPAD indexes in 60 - 80 % biochar mix (v/v) compared to peat (Emino & Warman, 2004) symbolizing greenness, efficient photosynthetic activity resulting in the increased yield, same as to 70 % char in our study. In our amended substrates, Vermi-biochar peat mix (P3Bv7) has 29.31 % higher fresh root weight followed by P2Bv8 (28.88 %), P4Bv6 (25.92 %), P6Bv4 (23.69 %) and Bv (23.07 %) in addition to peat.

In regard to total biomass (root and shoot weights), peat soil has lowest weight (18.07 gm) and highest for P3Bv7 with 24.7 gm. Relative to peat soil, a vermibiochar substrate (Bv) was significantly higher with 21.91 %. In our study, increased biomass in P3Bv7 (26.69 %) to peat was slightly higher than 22 % in the study done by (Tian et al., 2012) who used biochar - peat (50 % - 50 %) for the growth of *Calathea rotundifola* 'Fasciata'. These enhanced growth parameters among the substrates used are possibly due to nutrient release from the carbonized, porous vermibiochar (Laird, 2008; Lehmann et al., 2003).

Overall water holding capacity, WHC of P100 was higher with 80.58 % followed by P6Bv4 (75.8 %), P4Bv6 (67.68 %), P3Bv7 (66.55 %), P2Bv8 (62.85 %). Bv had lower WHC with 53.61 %. Hydrophysical properties from vermibiochar and peat mixed substrate (Table 4.8) having increased nutrient retention properties (Table 4.3, Table 4.9), radish plant performed best in the vermibiochar and mixed substrate than peat alone.

Table 4.7 Effects of different substrates on selected growth parameters of the radish.

Treatment	Fresh Shoot Weight (gm)	Fresh Root Weight (gm)	Total Biomass (gm)	Brix %	Marketable leaves number	Root Diameter (cm)
P100	3.9±0.2 a	14.1±0.8 b	18.07 ±0.9 b	4.7±0.4 a	6.3±0.07 a	2.67±0.12 a
P6Bv4	4.7±0.3 a	18.6±0.9 a	23.3 ±1.1 a	4.1±0.08 a	6.6±0.2a	3.15±0.06 a
P4Bv6	4.6±0.2 a	19.2±0.7 a	23.8 ±0.8 a	4.8±0.6 a	6.5±0.09 a	3.16±0.09 a
P3Bv7	4.6±0.4 a	20.1±1.9 a	24.7 ±2.3 a	5 ± 0 a	6.3±0.2 a	3.18±0.12 a
P2Bv8	4.3±0.5 a	19.9±1.6 a	24.2 ±2 a	4.05±0.2 a	6.4±0.2a	3.19±0.09 a
Bv	4.6±0.1 a	18.5±0.7 a	23.1 ±0.6 a	4.71±0.7 a	6.61±0.2a	3.15±0.04 a
p-value (ANOVA)	ns	p<0.05	p<0.05	ns	ns	ns

Values are means ± se, followed by the different letter in any column are significantly different at the 0.05 level using Tukey's HSD test.

Table 4.8 Particle Size Analysis of growing substrates (all values are in % retained in each sieve size category).

Sieve Size (mm)	B100 (%)	P6Bv4 (%)	P2Bv8 (%)	P100 (%)	P3Bv7 (%)	P4Bv6 (%)
5	10	5.88	8.69	7.69	4.54	8.89
4	2	5.88	4.34	7.69	4.54	2.22
2	10	17.64	8.69	30.76	18.18	8.88
0.5-2	60	52.94	39.13	46.15	50	44.44
<0.5	18	17.64	39.13	7.69	22.72	35.55

The overall percentage of the finer particle (< 0.5, 0.5 – 2, 2 mm) was greater in biochar mixed peat enriched substrates P3Bv7, P4Bv6, P6Bv4, B100, P2Bv8. In addition, the percentage of coarse particles (> 2 mm) was higher in P100. The higher percentage of soil particles retained in a sieve of size (< 0.5, 0.5 – 2, 2 mm) pinpoints the possibility of vermi-biochar and peat mixed substrate as a potent growing media in horticulture with increased root weights (Jayasinghe, 2012).

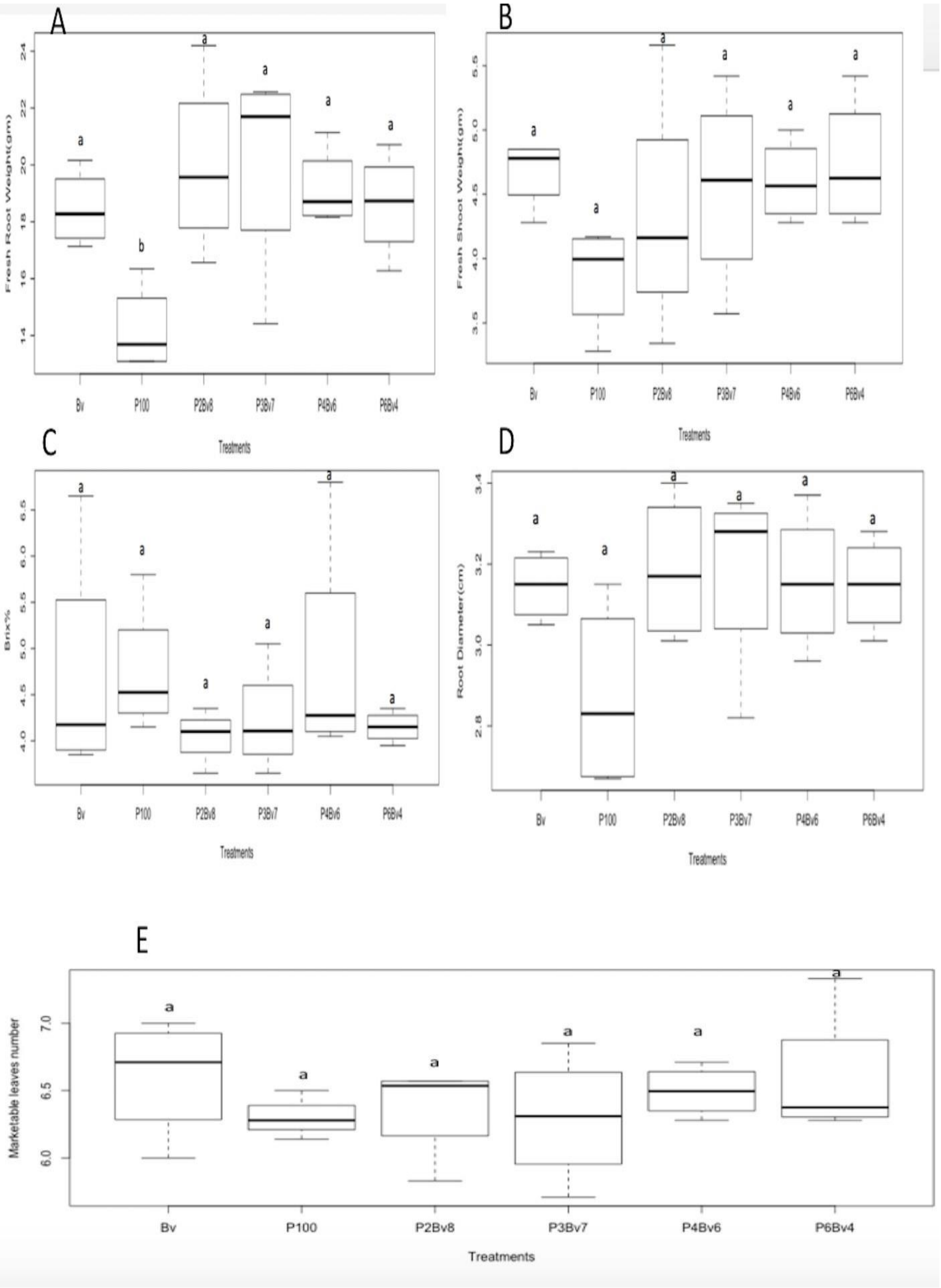

Figure 4.1 (A) Fresh root weight (gm) vs Treatments, (B) Fresh Shoot Weight (gm) Vs Treatments, (C) Brix % Vs Treatments, (D) Root Diameter (cm)Vs Treatments, (E) Marketable leaves number Vs Treatments.

Table 4.9 Elemental composition of substrates analyzed through inductively coupled plasma mass spectrometry (ICP-MS).

Elements	Bv	P100	P3Bv7	P -value
P (mg kg^{-1})	1513.3±17.6 a	511±35.7 b	1269.7±34.9 c	P<0.01(**)
K (mg kg^{-1})	5498.3±178.2 b	3290.7±97.4 a	5066.7±101.6 b	P<0.001(***)
Ca (mg kg^{-1})	10441.7±99.1 a	26073.7±427.1 b	15628±262.3 c	P<0.001(***)
Mg (mg kg^{-1})	25603.3±844.6 b	20192±798.8 a	20273±217.5 a	P<0.01(**)
Al (mg kg^{-1})	12781.7±495.4 b	8589.3±211 a	12088±255.3 b	P<0.001(***)
Ba (mg kg^{-1})	167.7±6 b	89.4±4.2 a	165.2±6.5 b	P<0.001(***)
Fe (mg kg^{-1})	12866.3±488.7 b	8598.3±188.7 a	13760±297 b	P<0.001(***)
Na (mg kg^{-1})	2195.3±35.6 b	3532.3±110 a	3264±96.8 a	P<0.001(***)
Pb (mg kg^{-1})	9±0.5 b	15.7±0.9 a	8.3±0.2 b	P<0.001(***)
Zn (mg kg^{-1})	109.8±1.5 a	26.2±0.5 b	85.7±0.3 c	P<0.001(***)
Mn (mg kg^{-1})	425±14.2 a	173.3±4.9 b	405±9.3 a	P<0.001(***)
Cd (mg kg^{-1})	0.63±0.03 b	0.4±0.00 a	0.53±0.03 b	P<0.05(*)
Cr (mg kg^{-1})	44.27±4.64 b	127.93±12.57 a	271.00±28.97 c	P<0.05(*)
Ni (mg kg^{-1})	28.33±2.99 b	85.23±8.21 a	178.5±19.35 c	P<0.05(*)
As (mg kg^{-1})	0.7±7.9E-17 a	0.73±3.3E-02 a	0.7±7.9E-17 a	ns

Values are means ± se, values in any row followed by the different letter are significantly different at the 0.05 level using Tukey's HSD test.

The contents of mineral element were clearly affected by the type of growth substrate. The contents of P, K, Mg, Al, Ba, Fe, and Zn were significantly higher in vermi-biochar and vermi-biochar enriched peat compared to peat alone. On the other hand, concentration of Mn present in Bv and P3Bv7 was in phytotoxic range (Römheld, V., H. Marschner 1991). Regarding lead toxicity, P100 soil has highest concentration, while other elements are in normal range having no negating effect on plant growth. Thus, peat soil may have higher lead toxicity problem than vermi-viochar substrates. The results indicate that lead adsorption seems to be higher in Bv and P3Bv7 compared to peat alone, which may reduce the toxicity level in these substrates. By contrast, Na and Ca content was significantly higher in peat substrate compared to Bv and P3Bv7, reduced with an increase in biochar concentration in mixed substrate. In addition, the concentration of heavy metals (Zn, Pb, Cd, Cr, Ni, As) present in vermibiochar are in the standard of premium graded biochar, except Cr and Ni for peat enriched subrate, P3Bv7 (Table 4.1, Table 4.9). This shows our vermibiochar meets the requirement of premium grade biochar as per EBC standard (Version 6.3 E).

Despite of slightly lower water holding capacity of biochar and biochar peat mix substrates (compared to peat soil alone), these substrates have enough essential nutrients to secure a proper plant uptake and growth (Table 4.7, Table 4.9, Figure 4.1). In this case, the research of Graber et al. (2010) concluded that biochar might increase the soil microbial activity or any additional fertilizer added under fertigation regime during crop cycle, continuously supply the nutrients enough for any growing media essential for plant growth and also be acceptable as horticulture substrates (Wright, Jackson, Barnes, & Browder, 2009). Biochar also has the potential to adsorb NH^{4+} and NO^{3-} and this could decrease the availability of N and also limit the root uptake of this and another nutrient. Additional fertilizer application may be needed (Xiang et al., 2017). Thus, biochar is supposed to increase the root growth under fertigation regime to crop. A meta-analysis done by Xiang, Deng, Duan, & Guo (2017) discussed about biochar increasing the root biomass by its nutrient supplement ability, however, its effect on different elements availability varies. Particularly, biochar increases the soil phosphorus increasing root biomass, which was analogous to our study as phosphorus content was higher in our vermi-biochar samples with an increase in fresh root weight. In addition, increase in soil pH through biochar application enhance the availability of immobile nutrients like P and K to plants, increasing biomass (Eissenstat, 1992). Nabavinia, Emami, Astaraee, & Lakzian (2015) further adds, biochar (8.58 pH , 92 mS/m) from tannery wastes leads to increase in plant available nutrients, N, P resulting the increased fresh root weight and plant biomass as to our study in radish. In addition, Van Zwieten et al. (2007) suggests on using biochar having alkaline pH and increased phosphorus concentration, responsible for increasing dry matter content of substrates and yield.

Elemental composition and nutrient uptake properties of vermi-biochar, peat, and vermi-biochar mixtures has lead to a difference in radish yield. Increased availability of phosphorus in Bv and P3Bv7 by 66.22 % and 59.85 % compared to peat might have boosted the plant growth. Studies have shown that increased root biomass can be related to availability of P (Havlin, Tisdale, Nelson, & Beaton, 2016). In addition, biochar is supposed to hold more P than peat, reducing the leaching potential and making it more available to plant growth (Manolikaki, Mangolis, & Diamadopoulos, 2016; Owen, Warren, Bilderback, & Albano, 2008). Furthermore, increased shoot biomass in peat amended vermi-biochar substrates could also be related to significant increase in potassium availability compared to peat alone (Headlee, Brewer, & Hall, 2014).

4.4 Biochar rates and Yield Variability

Our study showed that vermibiochar used in a ratio of 75 % was optimal and this could be due to vermi-biochar positive effects on maintaining EC, pH, and plant nutrients. Meanwhile, promising results have been reported under lower doses of biochar; below 50 % v/v basis (Fascella, 2015). A study done by Dumroese et al. (2011) showed that biochar mixed with peat in a ratio of 25 % (v/v) was optimal as an alternative substrate. Also, the research of Blok et al. (2017), showed no negative or phytotoxic effects in Gerbera plants on using a biochar-peat mix of 20 % - 80 % (v/v) and the mix did, in this case, have the same physical, chemical and nutrient properties as standard peat substrate.

In a 2010 article, Jayasinghe, Arachchi, & Tokashiki discussed that biochar mixed with peat could enhance the porosity and water holding capacity of the substrate. Perhaps this could explain the increased fresh root and shoot weights observed in our study.

Higher pH and EC of soil sample also signifies its nutrient supplement ability influencing the yield parameters, as documented in our study as well as in other studies (Jayasinghe et al., 2010). In the cultivation guide "Radish Commercial and Specialty Crop Guides" (n.d.), a pH of 6 - 6.8 is recommended for optimum radish growth. As to our study, pH of all substrates was above this ideal range, but still not too high for proper plant growth. The EC was also not too high to cause problems. This counts for all substrates except for vermi-biochar used alone without mixing it with peat. The EC was reduced to 85.1 mS/m after the fertigation practice during growth period and harvesting. In general, ideal pH and EC enhance the availabilities of macro and micronutrients (Pill, Tilmon, & Taylor, 1995) which is driven by biochar having large negative charged surface area essential for plant availability (Glaser et al., 2002; Laird, 2008). Fresh biochar produced at 500 - 550 °C had in our case a pH of 9.5. Addition of vermicompost reduced the pH compared to pure biochar, and mixing enough peat with the vermibiochar reduced the pH further, and down to a level not higher than causing problems for plant growth. Alkaline conditions were obtained in the mix if vermicompost was at the higher concentration (70 % vermibiochar = pH 8.8) compared to lower concentration (60 % vermibiochar = pH 8.1). Despite the high pH, root weight and plant growth were not negatively affected. In addition, study carried out by Margenot et al. (2018) on using softwood biochar with a pH of 10.9, showed that biochar increased both biomass production and germination under the given fertigation regimes.

In our study, organic matter content was increased from 19.8 % in the peat-based growth substrate to 32.13 % in P3Bv7 and 40.08 % in Bv. In general, it is documented that increasing the rates of biochar in a growth substrate will increase the organic matter content of substrates and that adding vermicompost would further increase the content (Alvarez, Pasian et al.). Furthermore, as we have seen, biochar improve the content of P, K, Fe and other nutrients as well as the EC and pH, increasing the nutrient availability of the substrate (Abdul & Abdul, 2017). Studies report on increasing the phosphorus and potassium content of mixed substrate when biochar is used as a substitute for peat in a perlite or vermiculite mixture, considering a good source of nutrient supplement for increased root and shoot production (Altland & Locke, 2013; Headlee et al., 2014). Our study demonstrated that vermibiochar mixed with peat at a ratio of 40 - 80 % did not pose any negative effects on plant growth. Rather it had positive effects on fresh root weight along with other yield parameters (fresh shoot weight, root diameter, brix % and marketable leaves number) compared to peat, symbolizing a novel potent and viable option in using vermibiochar at these rates substituting peat as growing media. Significant increase in elements like P, K, Mg, Al, Ba, Fe, Na, Zn along with reducing the toxic concentration of Pb pinpoints the capability of vermibiochar to bind essential nutrient to its surfaces and increase the possibility to use vermibiochar as additional nutrient supplement and fertilizers (Hagemann et al., 2017; Lehmann & Joseph, 2015). Furthermore, its re-using ability (Abubakari, 2016) for additional crop production in the greenhouse also fulfills the criteria of effective soil less substrate for horticulture.

Results from biochar research pinpoint the importance of the feedstock and pyrolysis conditions (Glaser, Lehmann, & Zech, 2002). Regarding tested plant, different plant species is also of importance (Zaller, 2007). Overall, vermibiochar used in our study (P4Bv6, P6Bv4, and Bv) had higher pH and EC with increased root and shoot biomass considered to have potential to replace the peat in a soilless substrate. This is in consonance with previous study (Vaughn, Kenar, Thompson, & Peterson, 2013). Furthermore, the recommendation from Lehmann & Joseph (2015) on using biochar in a higher dose to substitute more of the peat has been verified by our results.

5 Conclusion

The alkaline nature of pure biochar implies a risk of alkali stress and nutrient imbalances. Our study demonstrated negative effects on germination in the bioassay on of *Allium cepa*. Dilution reduced the problem. In regard to organic amendment like bio-digestate, higher doses lead to increased availability of nutrient, ammonium toxicity causing negative effects. Prior to use, concern towards the nutrient and toxic nature of organic amendments is essential avoiding negating effects.

Our greenhouse study shows the possibility of using alkaline vermibiochar (8.79) at higher rates capable of substituting 100 % of peat as growing substrate. In addition, having no any significant difference in root weights with in growing medium (vermi-biochar and peat mixed vermibiochar, except for peat), shows the possibility of using a slightly more alkaline substrate (8.83) with no negating effects. Significantly increased organic matter content and nutrient retention properties of vermi-biochar and peat enhanced vermi-biochar substrate, along with concentration of heavy metals present in range as of premium grade biochar, explains the feasibility of using vermibiochar and peat enriched substrate to replace peat moss as growing media for greenhouse production. Furthermore, under the same fertigation regime to all treatments applied, increased availability of nutrients on vermibiochar and char mixed substrates, shows that organic amendment of biochar prior to its use is essential (in this case with vermicompost), which could have an impact on its nutrient supplement properties.

In our bioassay, biochar has a potential to promote early plant growth, heights, germination based on rates of its use, having no any significant differences at the end. In addition, produced biochar can be post treated with different organic amendment ratio (in our case with vermicompost in 1:2 ratio), using at the varying rates to understand nature of elemental composition and toxic compounds present in resulting activated biochar. To conclude, vermi-biochar and peat enriched biochar substrate having higher fine particle size, increased organic matter content, increased EC and higher carbon content acts as a source of various nutrients (P, K, Fe, Zn, Mg) typifying positive growth and yield in radish, pinpointing a strong potentiality to use as horticulture substrate alternative to peat. Variation in pH with its rates used might limit its application. However, our results resembling the positive effects on radish growth and yield parameters, application rates can be further studied to avoid any negative or variating effects. Furthermore, different feedstock and operating conditions should also be assessed to examine the biochar properties capable of addressing the plant growth and yield parameters of different crops too.

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References

Abad, M., Noguera, P., & Burés, S. (2001). National inventory of organic wastes for use as growing media for ornamental potted plant production: case study in Spain. *Bioresource technology, 77*(2), 197-200.

Abdul, R., & Abdul, R. (2017). The Effect of Biochar Application on Nutrient Availability of Soil Planted with MR219. *J Microb Biochem Technol, 9*, 583-586.

Abubakari, A.-H. (2016). *Standardisation of organic materials as amendment for soil and soilless media in urban horticultural production systems.*

Agegnehu, G., Srivastava, A., & Bird, M. I. (2017). The role of biochar and biochar-compost in improving soil quality and crop performance: a review. *Applied soil ecology, 119*, 156-170.

Alexander, P., Bragg, N., Meade, R., Padelopoulos, G., & Watts, O. (2008). Peat in horticulture and conservation: the UK response to a changing world. *Mires & Peat, 3*.

Ali, A., Guo, D., Zhang, Y., Sun, X., Jiang, S., Guo, Z., . . . Zhang, Z. (2017). Using bamboo biochar with compost for the stabilization and phytotoxicity reduction of heavy metals in mine-contaminated soils of China. *Scientific reports, 7*(1), 2690.

Altland, J. E., & Locke, J. C. (2013). Effect of biochar type on macronutrient retention and release from soilless substrate. *HortScience, 48*(11), 1397-1402.

Alvarez, J. M., Pasian, C., Lal, R., López, R., & Fernández, M. PHYSIOLOGICAL PLANT ANSWER WHEN BIOCHAR AND VERMICOMPOST ARE USED AS PEAT REPLACEMENT FOR ORNAMENTAL-PLANT PRODUCTION.

American Chemical Society. (2008, April 15). Ancient Method, 'Black Gold Agriculture' May Revolutionize Farming, Curb Global Warming. *ScienceDaily*. Retrieved April 20, 2018 from www.sciencedaily.com/releases/2008/04/080410153658.htm

Barber, K. E. (1993). Peatlands as scientific archives of past biodiversity. *Biodiversity & Conservation, 2*(5), 474-489.

Barthelmes, A., Couwenberg, J., Risager, M., Tegetmeyer, C., & Joosten, H. (2015). *Peatlands and Climate in a Ramsar Context: A Nordic-Baltic Perspective* (Vol. 2015544): Nordic Council of Ministers.

Beesley, L., Moreno-Jimenez, E., Fellet, G., Carrijo, L., & Sizmur, T. (2015). Biochar and heavy metals.

Biederman, L. A., & Harpole, W. S. (2013). Biochar and its effects on plant productivity and nutrient cycling: a meta‐analysis. *GCB bioenergy, 5*(2), 202-214.

Blok, C., van der Salm, C., Hofland-Zijlstra, J., Streminska, M., Eveleens, B., Regelink, I., . . . Visser, R. (2017). Biochar for horticultural rooting media improvement: evaluation of biochar from gasification and slow pyrolysis. *Agronomy, 7*(1), 6.

Bragg, N. (1990). A review of peat reserves and peat usage in horticulture and alternative materials. *Horticultural Development Council, Petersfield, Hampshire, UK*.

Busch, D., & Glaser, B. (2015). Stability of co‐composted hydrochar and biochar under field conditions in a temperate soil. *Soil use and management, 31*(2), 251-258.

Chan, K., Van Zwieten, L., Meszaros, I., Downie, A., & Joseph, S. (2008). Using poultry litter biochars as soil amendments. *Soil Research, 46*(5), 437-444.

Cleary, J., Roulet, N. T., & Moore, T. R. (2005). Greenhouse gas emissions from Canadian peat extraction, 1990–2000: A life-cycle analysis. *AMBIO: A Journal of the Human Environment, 34*(6), 456-461.

Clough, T. J., Condron, L. M., Kammann, C., & Müller, C. (2013). A review of biochar and soil nitrogen dynamics. *Agronomy, 3*(2), 275-293.

Doan, T. T., Henry-des-Tureaux, T., Rumpel, C., Janeau, J.-L., & Jouquet, P. (2015). Impact of compost, vermicompost and biochar on soil fertility, maize yield and soil erosion in

Northern Vietnam: a three year mesocosm experiment. *Science of the Total Environment, 514*, 147-154.

Downie, A., Crosky, A., & Munroe, P. (2009). Physical Propierties of Biochar, Biochar for Environmental Management: Science and Technology, edited by J. *Lehmann and S. Joseph, Earthscan Ltd., London*.

Dumroese, R. K. (2009). Comparing Growth of Ponderosa Pine in Two Growing Media. *In: Dumroese, RK; Riley, LE, tech. coords. National Proceedings: Forest and Conservation Nursery Associations-2008. Proc. RMRS-P-58. Fort Collins, CO: US Department of Agriculture, Forest Service, Rocky Mountain Research Station. p. 32-34*.

Dumroese, R. K., Heiskanen, J., Englund, K., & Tervahauta, A. (2011). Pelleted biochar: Chemical and physical properties show potential use as a substrate in container nurseries. *Biomass and Bioenergy, 35*(5), 2018-2027.

Eissenstat, D. M. (1992). Costs and benefits of constructing roots of small diameter. *Journal of plant nutrition, 15*(6-7), 763-782.

Emino, E. R., & Warman, P. R. (2004). Biological assay for compost quality. *Compost Science & Utilization, 12*(4), 342-348.

Farrell, M., & Jones, D. (2010). Food waste composting: Its use as a peat replacement. *Waste management, 30*(8-9), 1495-1501.

Fascella, G. (2015). Growing substrates alternative to peat for ornamental plants. In *Soilless culture-Use of substrates for the production of quality horticultural crops*: InTech.

Gaskin, J., Steiner, C., Harris, K., Das, K., & Bibens, B. (2008). Effect of low-temperature pyrolysis conditions on biochar for agricultural use. *Transactions of the ASABE, 51*(6), 2061-2069.

Glaser, B., Lehmann, J., Steiner, C., Nehls, T., Yousaf, M., & Zech, W. (2002). Potential of pyrolyzed organic matter in soil amelioration. Paper presented at the 12th ISCO Conference'. Beijing.

Glaser, B., Lehmann, J., & Zech, W. (2002). Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal–a review. *Biology and fertility of soils, 35*(4), 219-230.

Graber, E. R., Harel, Y. M., Kolton, M., Cytryn, E., Silber, A., David, D. R., . . . Elad, Y. (2010). Biochar impact on development and productivity of pepper and tomato grown in fertigated soilless media. *Plant and soil, 337*(1-2), 481-496.

Grafiadellis, I., Mattas, K., Maloupa, E., Tzouramani, I., & Galanopoulos, K. (2000). An economic analysis of soilless culture in gerbera production. *HortScience, 35*(2), 300-303.

Grønlund, A., Hauge, A., Hovde, A., & Rasse, D. P. (2008). Carbon loss estimates from cultivated peat soils in Norway: a comparison of three methods. *Nutrient Cycling in Agroecosystems, 81*(2), 157-167.

Hagemann, N., Joseph, S., Schmidt, H.-P., Kammann, C. I., Harter, J., Borch, T., . . . Elliott, K. W. (2017). Organic coating on biochar explains its nutrient retention and stimulation of soil fertility. *Nature communications, 8*(1), 1089.

Handreck, K. A. (1993). Use of the nitrogen drawdown index to predict fertilizer nitrogen requirements in soilless potting media. *Communications in soil science and plant analysis, 24*(17-18), 2137-2151.

Handreck, K. A., Black, N. D., & Black, N. (2002). *Growing media for ornamental plants and turf*: UNSW press.

Havlin, J. L., Tisdale, S. L., Nelson, W. L., & Beaton, J. D. (2016). *Soil fertility and fertilizers*: Pearson Education India.

Headlee, W. L., Brewer, C. E., & Hall, R. B. (2014). Biochar as a substitute for vermiculite in potting mix for hybrid poplar. *Bioenergy Research, 7*(1), 120-131.

Hooijer, A., Silvius, M., Wösten, H., & Page, S. (2006). PEAT-CO2, Assessment of CO2 emissions from drained peatlands in SE Asia, Delft Hydraulics report Q3943/2006, 36p. In.

Hossain, M. K., Strezov, V., Chan, K. Y., & Nelson, P. F. (2010). Agronomic properties of wastewater sludge biochar and bioavailability of metals in production of cherry tomato (Lycopersicon esculentum). *Chemosphere, 78*(9), 1167-1171.

Hossain, M. K., Strezov, V., Chan, K. Y., Ziolkowski, A., & Nelson, P. F. (2011). Influence of pyrolysis temperature on production and nutrient properties of wastewater sludge biochar. *Journal of Environmental Management, 92*(1), 223-228.

Jaiswal, A. K., Frenkel, O., Elad, Y., Lew, B., & Graber, E. R. (2015). Non-monotonic influence of biochar dose on bean seedling growth and susceptibility to Rhizoctonia solani: the "Shifted R max-Effect". *Plant and soil, 395*(1-2), 125-140.

Jayasinghe, G. (2012). Sugarcane bagasses sewage sludge compost as a plant growth substrate and an option for waste management. *Clean Technologies and Environmental Policy, 14*(4), 625-632.

Jayasinghe, G., Arachchi, I. L., & Tokashiki, Y. (2010). Evaluation of containerized substrates developed from cattle manure compost and synthetic aggregates for ornamental plant production as a peat alternative. *Resources, Conservation and Recycling, 54*(12), 1412-1418.

Jeffery, S., Verheijen, F. G., van der Velde, M., & Bastos, A. C. (2011). A quantitative review of the effects of biochar application to soils on crop productivity using meta-analysis. *Agriculture, ecosystems & environment, 144*(1), 175-187.

Joosten, H. (2009). The Global Peatland CO2 Picture: peatland status and drainage related emissions in all countries of the world. *The Global Peatland CO2 Picture: peatland status and drainage related emissions in all countries of the world.*

Joosten, H. (2015). *Peatlands, climate change mitigation and biodiversity conservation: An issue brief on the importance of peatlands for carbon and biodiversity conservation and the role of drained peatlands as greenhouse gas emission hotspots* (Vol. 2015727): Nordic Council of Ministers.

Kammann, C., Glaser, B., & Schmidt, H.-P. (2016). Combining biochar and organic amendments. *Biochar in European soils and agriculture: science and practice, 1*, 136-160.

Kern, J., Tammeorg, P., Shanskiy, M., Sakrabani, R., Knicker, H., Kammann, C., . . . Tiilikkala, K. (2017). Synergistic use of peat and charred material in growing media–an option to reduce the pressure on peatlands? *Journal of Environmental Engineering and Landscape Management, 25*(2), 160-174.

Kimetu, J. M., & Lehmann, J. (2010). Stability and stabilisation of biochar and green manure in soil with different organic carbon contents. *Soil Research, 48*(7), 577-585.

Kloss, S., Zehetner, F., Dellantonio, A., Hamid, R., Ottner, F., Liedtke, V., . . . Soja, G. (2012). Characterization of slow pyrolysis biochars: effects of feedstocks and pyrolysis temperature on biochar properties. *Journal of environmental quality, 41*(4), 990-1000.

Laird, D. A. (2008). The Charcoal Vision: A Win–Win–Win Scenario for Simultaneously Producing Bioenergy, Permanently Sequestering Carbon, while Improving Soil and Water Quality All rights reserved. No part of this periodical may be reproduced or transmitted in any form or by any means, electronic or mechanical, including photocopying, recording, or any information storage and retrieval system, without permission in writing from the publisher. *Agronomy journal, 100*(1), 178-181.

Lehmann, J., da Silva, J. P., Steiner, C., Nehls, T., Zech, W., & Glaser, B. (2003). Nutrient availability and leaching in an archaeological Anthrosol and a Ferralsol of the Central

Amazon basin: fertilizer, manure and charcoal amendments. *Plant and soil, 249*(2), 343-357.

Lehmann, J., & Joseph, S. (2015). *Biochar for environmental management: science, technology and implementation*: Routledge.

Major, J., Lehmann, J., Rondon, M., & Goodale, C. (2010). Fate of soil‐applied black carbon: downward migration, leaching and soil respiration. *Global Change Biology, 16*(4), 1366-1379.

Manolikaki, I. I., Mangolis, A., & Diamadopoulos, E. (2016). The impact of biochars prepared from agricultural residues on phosphorus release and availability in two fertile soils. *Journal of Environmental Management, 181*, 536-543.

Margenot, A. J., Griffin, D. E., Alves, B. S., Rippner, D. A., Li, C., & Parikh, S. J. (2018). Substitution of peat moss with softwood biochar for soil-free marigold growth. *Industrial Crops and Products, 112*, 160-169.

Nabavinia, F., Emami, H., Astaraee, A., & Lakzian, A. (2015). Effect of tannery wastes and biochar on soil chemical and physicochemical properties and growth traits of radish. *International Agrophysics, 29*(3), 333-339.

Oleszczuk, R., Regina, K., Szajdak, L., Höper, H., & Maryganova, V. (2008). Impacts of agricultural utilization of peat soils on the greenhouse gas balance. *Peatlands and climate change*, 70-97.

Owen, J. S., Warren, S. L., Bilderback, T. E., & Albano, J. P. (2008). Phosphorus rate, leaching fraction, and substrate influence on influent quantity, effluent nutrient content, and response of a containerized woody ornamental crop. *HortScience, 43*(3), 906-912.

Pill, W., Tilmon, H., & Taylor, R. (1995). Nitrogen-enriched ground kenaf (Hibiscus cannabinus L.) stem core as a component of soilless growth media. *Journal of Horticultural Science, 70*(4), 673-681.

Radish Commercial and Specialty Crop Guides. Aggie-horticulture.tamu.edu. Retrieved 24 April 2018, from https://aggie-horticulture.tamu.edu/vegetable/files/2011/10/radish.pdf

Rogovska, N., Laird, D., Cruse, R., Trabue, S., & Heaton, E. (2012). Germination tests for assessing biochar quality. *Journal of environmental quality, 41*(4), 1014-1022.

Römheld, V., H. Marschner 1991. Function of Micronutrients in Plants. In *Micronutrients in Agriculture*, SSSA Book Ser. 4. SSSA, Madison, WI. p. 297-328. doi:10.2136/sssabookser4.2ed.c9

Rueden, C. T., Schindelin, J., Hiner, M. C., DeZonia, B. E., Walter, A. E., Arena, E. T., & Eliceiri, K. W. (2017). ImageJ2: ImageJ for the next generation of scientific image data. *BMC bioinformatics, 18*(1), 529.

Schmilewski, G. (2007). *Growing medium constituents used in the EU.* Paper presented at the International Symposium on Growing Media 2007 819.

Schmilewski, G. (2008). The role of peat in assuring the quality of growing media. *Mires & Peat, 3*.

Shi, D. (1997). Effects of NaCl and Na_2CO_3 on growth of Puccinellia tenuiflora and on present state of mineral elements in nutrient solution. *Acta pratacu. sin., 6,* 51-61.

Shi, D., & Yin, L. (1993). Difference between salt (NaCl) and alkaline (Na_2CO_3) stresses on. *Puccinellia tenuiflora*, 144-149.

Shoaf, N. L. (2014). *Biochar and vermicompost amendments in vegetable cropping systems: Impacts on soil quality, soil-borne pathogens and crop productivity.* Purdue University,

Silvius, M., & Kaat, A. (2006). Peatland degradation fuels climate change (Prepared for the 12th UN-FCCC Summit, Nairobi 2006). Ebe, The Netherlands: Wetlands International. Retrieved March 30, 2009. In.

Steiner, C., & Harttung, T. (2014). Biochar as a growing media additive and peat substitute. *Solid Earth, 5*(2), 995.

Strack, M. (2008). *Peatlands and climate change*: IPS, International Peat Society.

Team, R. C. (2016). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. 2014. In.

Tian, Y., Sun, X., Li, S., Wang, H., Wang, L., Cao, J., & Zhang, L. (2012). Biochar made from green waste as peat substitute in growth media for Calathea rotundifola cv. Fasciata. *Scientia horticulturae, 143*, 15-18.

UNFCCC Nordic Pavillion (2015). *UNFCCC Cop 21 Paris Peatlands and GHG emissions A global overview* [PowerPoint slides]. Retrieved from https://www.slideshare.net/NNCS_COP21/peatlands-and-ghg-emissions-peatlands-and-ghg-emissions

Using Charcoal to Make Soil Into Black Gold. (2018). *VOA*. Retrieved 24 April 2018, from https://learningenglish.voanews.com/a/a-23-2008-05-05-voa3-83135627/128136.html

Van Zwieten, L., Kimber, S., Downie, A., Chan, K., Cowie, A., Wainberg, R., & Morris, S. (2007). *Papermill char: benefits to soil health and plant production.* Paper presented at the Proceedings of the conference of the international agrichar Initiative.

Vaughn, S. F., Kenar, J. A., Thompson, A. R., & Peterson, S. C. (2013). Comparison of biochars derived from wood pellets and pelletized wheat straw as replacements for peat in potting substrates. *Industrial Crops and Products, 51*, 437-443.

Wetlands International (2000). Countries with peat lands and the distribution of Ramsar sites with peat lands [Maps]. Retrieved from https://commons.wikimedia.org/wiki/File:Countries_with_peat_land.jpg#/media/File:Countries_with_peat_land.jpg

Wetlands International (2015). *Peatlands Management and Sustainability* [PowerPoint slides]. Retrieved from https://www.slideshare.net/WetlandsInternational/peatland-management-for-sustainability.

Woolf, D., Amonette, J. E., Street-Perrott, F. A., Lehmann, J., & Joseph, S. (2010). Sustainable biochar to mitigate global climate change. *Nature communications, 1*, 56.

World Energy Council. 2013. World Energy Resources.Chapter 6

Wright, R. D., Jackson, B. E., Barnes, M. C., & Browder, J. F. (2009). The landscape performance of annual bedding plants grown in pine tree substrate. *HortTechnology, 19*(1), 78-82.

Xiang, Y., Deng, Q., Duan, H., & Guo, Y. (2017). Effects of biochar application on root traits: a meta‐analysis. *GCB bioenergy*.

Zaller, J. G. (2007). Vermicompost as a substitute for peat in potting media: Effects on germination, biomass allocation, yields and fruit quality of three tomato varieties. *Scientia horticulturae, 112*(2), 191-199.

Zucconi, F., Monaco, A., Forte, M., & Bertoldi, M. d. (1985). Phytotoxins during the stabilization of organic matter. *Composting of agricultural and other wastes/edited by JKR Gasser*.

6 Appendix

6.1 Appendix I

Germination of *Allium cepa* measured among the biochar and control treatment in bioassay

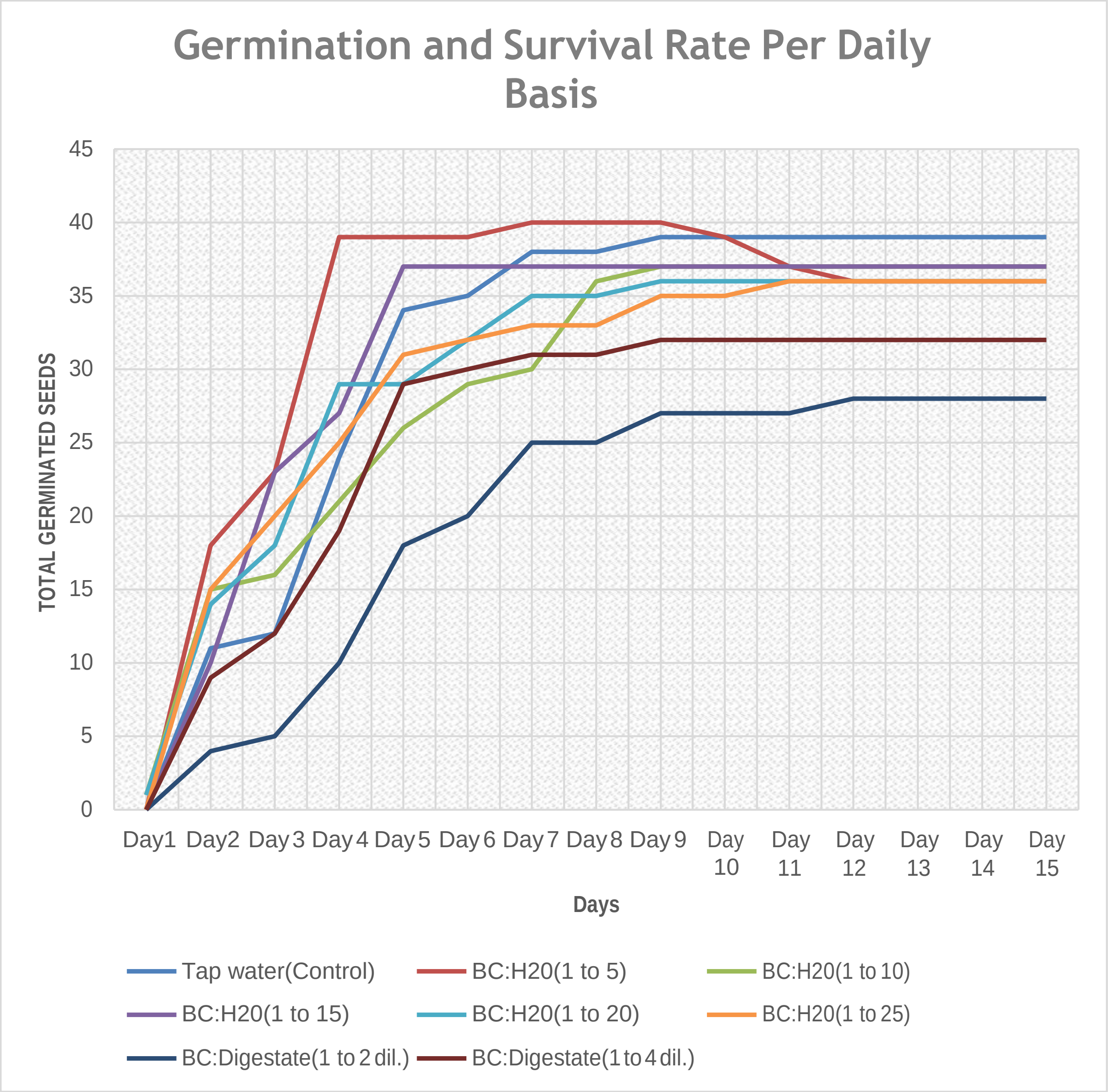

Figure 6.1 Germination of Allium cepa under control and biochar amended treatments in phytotoxic bioassay.

6.2 Appendix II

Growth parameters measured in *Allium cepa* of Phytotoxic bioassay

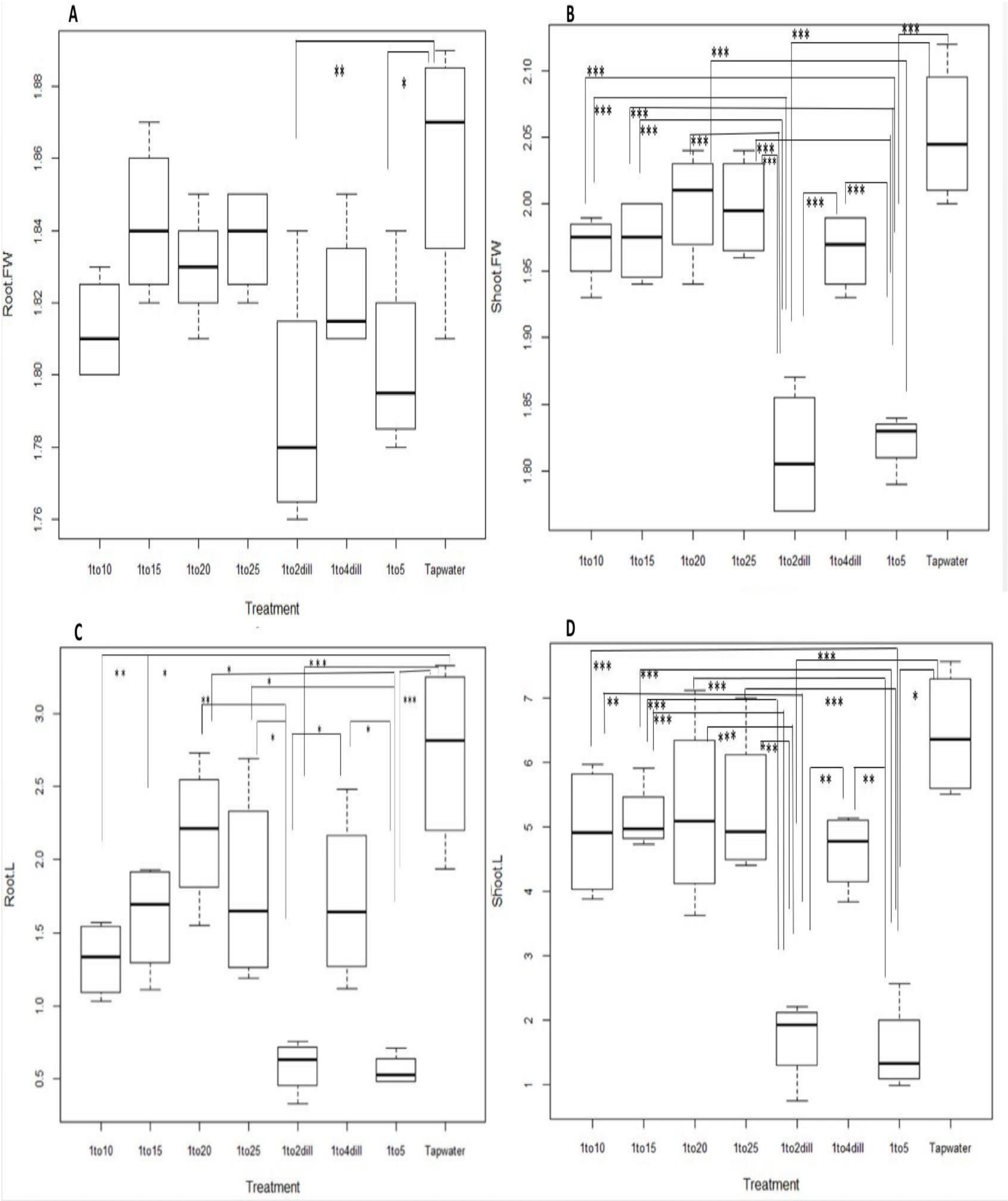

*Figure 6.2 (A) Root Fresh Weight Versus Treatment, (B) Shoot Fresh Weight Versus Treatment, (C) Root length Versus Treatment and (D) Shoot Length Versus Treatment. Significant differences are labelled by asterisk ('***' 0.001, '**' 0.01, '*' 0.05).*