Biochar from water hyacinth - turning a plague into a resource

>> Can biochar from water hyacinth efficiently increase the water holding capacity of a ferralsol soil? <<

Bachelor Thesis

for the attainment of the academic grade

Bachelor of Science (B.Sc.)

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1. Introduction

The strive for sufficient food supplement has been a main task in human history ever since. Even today, where parts of humanity are surrounded by a high-tech computerized world, people struggle for this very basic need. Yet the achievement of food security is not only a question of simple physical satisfaction, but further the necessary foundation for any societal or economic progress. Thus, the United Nations Organization proclaimed the fight against hunger as one of their sustainable development goals for 2030.[1]

A growing world population demands to be fed and simultaneously occupies and degrades the soil on which crop production is naturally depended on. The value of fertile soil is substantial and the preservation and improvement of this resource plays a key role for sustainable food security. Since mankind took its first steps in agriculture, approaches to improve soil productivity are known. One attempt to achieve this purpose is found in charred matter, that is amended to soil.

Infertile soils treated with charred material experience an increase in productivity. The usage of so called biochar can be found in different cultures on every continent.[2] However the awareness of biochar faded in the near past. It was only recently, that the scientific rediscovery of „Terra Preta" - an anthropogenic, dark earth, modified with charred matter - brought biochar back to a broader perception. By applying this measure, ancient indigenous communities of the Amazon basin kept their soils fertile. The effect can still be noticed today, which is surprising as such tropical soils tend to degrade easily.[3]

A considerate amount of research has shown, that soil characteristics are altered when biochar is added to a soil.[4] Among those, is an increase in water holding capacity (WHC).[5] This could mean a crucial soil improvement for drought vulnerable areas.

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[1] N.N. „Transforming our world: the 2030 Agenda for Sustainable Development" The United Nations General Assembly (2015): 15.

[2] Wiedner, Katja, and Bruno Glaser. "Traditional use of biochar." Biochar for Environmental Management: Science, Technology and Implementation 15 (2015): 18-31.

[3] Jeffery, Simon, et al. "Biochar effects on crop yield." Biochar for environmental management: science, technology and implementation 2 (2015): 303.

[4] Biederman, Lori A., and W. Stanley Harpole. "Biochar and its effects on plant productivity and nutrient cycling: a meta-analysis." *GCB bioenergy* 5.2 (2013): 202-214.

[5] Masiello, C. A. et al. "Biochar effects on soil hydrology." *Biochar for environmental management* (2015): 547.

This biochar (BC) needs to be produced from an organic matter. Commonly wood is used in this instance. Yet the exploitation of wood is a main cause for deforestation and is highly connected with soil degradation.[6] A sustainable approach for soil improvement would need to rely on another source, in order to prevent exacerbating the problem that it is trying to solve. One such possible substitute, that shall be discussed in this thesis, is the water hyacinth.

The water hyacinth (WAHY) is a water plant native to the waterbodies of south america. Its beauty made it popular and led to a dispersion through man as an ornamental flower around the globe. From ponds it soon spread into streams and lakes. With the lack of natural predators and a growth rate that is among the highest in plant kingdom, it quickly becomes invasive. Meanwhile it can be found worldwide in the tropics and subtropics.[7] With its enormous growth rate it has had a severe impact on the aquatic ecosystems and subordinated socio-economic systems. Introducing the WAHY for the production of BC could create an incentive for removing it from infested waterbodies.

Such a water hyacinth based biochar (WAHY-BC) would have an individual characteristic in its structure and in its effects on soil. WAHY-BC could possess the capacity to alter the WHC of a soil. In a dry climate WAHY-BC might serve as a soil improver. An appropriate evaluation of such an effects needs to be bound to an area, which soil is in risk of (or has experienced) soil degradation and is prone to drought periods. Further its waterbodies needs to be infested with WAHY, thus the plant is available for processing.

The Butare area in Rwanda and its ferralsol soils satisfy these criteria, which are presented in the second chapter of this thesis. In chapter three a detailed description of BC is given and its effects on soil and vegetation are explained. Thereby the possible benefits a BC implementation can have on stressed soils are carved out.

In chapter four WAHY is presented as a possible source for BC. A focus is set on the excessive growth of the plant and the resulting negative consequences, but also on the potential that lies in the plants productivity. In chapter five the previously stated topics are merged into the following research question: Can biochar from water hyacinth (WAHY-BC) efficiently increase the water-holding capacity of a ferralsol soil?

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[6] Boyette, Michael Doyle, Brittany Parker Alston, and Justin Alan Macialek. "The rapid production of biochar." American Society of Agricultural and Biological Engineers (2012): 1.

[7] Sullivan, Paul R., and Rod Wood. "Water hyacinth (Eichhornia crassipes (Mart.) Solms) seed longevity and the implications for management." *Eighteenth Australasian Weeds Conference (*2012): 1.

The methodology chapter consists of three executed measures:
Firstly a soil sample similar to the soil of the Butare area is analyzed. The Köhn method and the Coulter method are therefore applied that indicate the granulometry of the soil. Thus the effects of a later WAHY-BC amendment can be comprehended correctly. Secondly the processing of WAHY to WAHY-BC by applying pyrolysis is explained and executed. Thirdly the gained WAHY-BC is blended with the soil sample in different concentrations and analyzed for its water-holding characteristics. The survey is carried out through a gravimetric measurement.

In chapter seven the results of the three stated measures are presented. This is continued by the discussion in chapter eight, where the question of comparability of the Butare soil and the soil sample used are highlighted and uncertainties in the analysis methods are named. Further questions of the thesis significance for crop growth and feasibility are raised. With a conclusion in chapter nine the value of this work is defined.

2. The Butare area

This thesis investigates an effect within distinct environmental conditions. Such are proneness to soil degradation and drought stress. Also an access to WAHY infested waterbodies needs to be present. A matching area could therefore possibly serve for further implementation of the surveyed measure. Such an area is rather delimited by the fulfillment of the required environmental conditions than by political boundaries. Around the town of Butare in Rwanda´s Southern Province, these conditions are found. The area stretches among three neighboring Rwandan districts but doesn't fully cover any of them.

The present chapter discusses the relevant characteristics of the Butare area, namely it’s location, climate and soil. Finally a broad economical description is enclosed to underline the significance the surveyed measure could bear.

2.1. Geographical location

The selected area is situated in Rwanda's Southern Province, overlapping parts of the districts Huye, Gisagara and Nyaruguru (Fig. 1). All districts combined attain a size of 2,270 km^2. The landscape is overall hilly with scattered mountains, whose height and numbers increase towards the west.

They form the foothills of the eastern wall of the Albertine Rift, which is a part of the western branch of the East African Rift Valley system, that separates the Nile from the Congo basin. Altitudes range from 1,300 - 2,000 m.[8] [9] [10]

Due to human activity the natural forest coverage has been pushed back. Land has widely been transformed for pasture and farming. Still, in the west towards the mountainous Nyungwe national park vast forest areas extend.

Fig. 1. In this map of Rwanda, the Districts of the Butare area are highlighted.
The Akanyaru river that boarders Burundi and Lake Cyohoha are also depicted.[11]

Several small rivers, of which some are intermittent, cross the landscape in a north-south direction and discharge in the Akanyaru River. The Akanyaru again flows eastwards and is a contributor to the lake Victoria. Its riverbed defines the southern boarder of the Gisagara and Nyaruguru districts to neighboring Burundi.

[8] N.N. ``Huye District Development Plan“ Republic of Rwanda - Southern Province - Huye District (2013): 5-7.

[9] N.N. “District Development Plan (2013/14-2017/18)“ Republic of Rwanda -Southern Province - Nyaruguru District (2013): iii-iv.

[10] N.N. “District Development Plan 2013-2018“ Republic of Rwanda -Southern Province- Gisagara District (2013): 4-6.

[11] N.N. “Rwanda - Map No. 3717 Rev. 10“ United Nations Cartographic Section (2008) (with own editing).

Heavy infestations of WAHY in the Akanyaru river and the related lake Cyhohoha have been reported approximately 10km downstream the Butare area. Thus an infestation of the Butare area is highly likely due to its proximity and equal habitat.[12] [13]

2.2. Climatic characteristics

Figure 2 displays a climate diagram of Butare town. Since the diagram only refers to the climate conditions within the town, it cannot comprise the various microclimates, that emerge within the hilly relief.

The temperatures stays almost constant throughout the year. Due to the high altitudes it levels at an moderate average 19°C, despite its proximity to the equator.

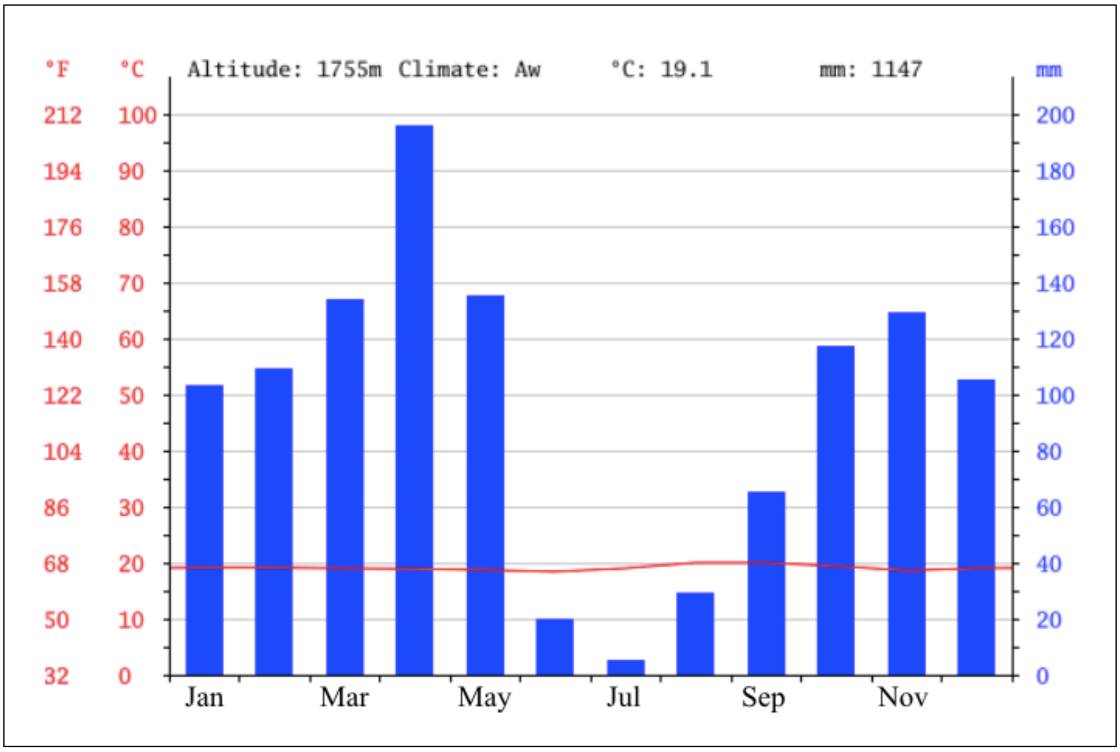

Fig. 2. Climate diagram of Butare, displaying annual distribution of temperature and precipitation [14]

[12] Nsabagasani, C., Nsengimana, S., & Hakizimana, E. “Biodiversity survey in Akanyaru wetlands, unprotected important bird areas in Rwanda“ (2008): 20.

[13] Kitunda, Jeremiah Mutio. “A History of the Water Hyacinth in Africa: The Flower of Life and Death from 1800 to the Present.“ (2017): 79.

[14] Internet: https://en.climate-data.org/location/44897/ (accessed on 06/06/2018).

A bimodal pattern of rain can be observed, that is driven by the annual progression of the intertropical convergence zone, thus forming four seasons: a small rain season from mid September till mid December, a small dry season from mid December till February, a great rain season from march till may and a great dry season from June till mid September. The area receives an overall precipitation of 1147 mm per year. Noteworthy is the contrast in precipitation, which lies between 5-30 mm a month during the great dry season and up to nearly 200 mm within the great rain season. Applying the climate classification by Köppen and Geiger, the climate is a winterdry tropical climate or Savannah climate (Aw).[15]

However, the succession of seasons tend to become irregular, leading to floods and dryness. Extreme weather events are also increasing. When rain is lacking it can result in droughts, whereas heavy rainfall causes floods and landslides.[16]

2.3. Soil characteristics

The soils in the Butare area have developed from paleoproterozoic rocks prior to the Kibaran orogeny, consisting of migmatites and gneisses of which some have retrometamorphosed and cataclasted.[17] The paleoproterozoic era spanned from 2,500 to 1,600 million years ago. Their enormous age explains an intense rock weathering that acted over time and ultimately disintegrated the solid structures, generating the base for the soils. In the Butare area the soils to be encountered are comprehended as Ferralsols. They constitute from a mixed dispersion of haplic Ferralsols and umbric Ferralsols.[18]

Ferralsols are defined as deeply weathered soils, that occur in the tropics and subtropics. They develop from silicate or carbonate rocks in long periods of undisturbed high temperature and high moisture content, that are typical to forests of the humid tropics. A red or yellow Bu-Horizon of 25 to 200 cm soil depth is typical and caused by an enriched Fe- and Al-oxide content. The silicates have been weathered and mainly washed out.[19]

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15 Köppen, Wladimir, and Rudolf Geiger. "*Handbuch der klimatologie.*" (1930): 41-43

16 Republic of Rwanda - Southern Province - Gisagara District. "District Development Plan 2013-2018" (2013): 6.

17 Schlüter, Thomas. "Geological Atlas of Africa" (2006): 188.

18 Jones, A., et al. "Soil Atlas of Africa." *European Commission, Publication Office of the European Union (2013):* 111.

19 Schachtschabel, Paul et al. "Lehrbuch der Bodenkunde (14. Auflage)" (1998): 450 (own translation).

To further specify: the haplic Ferralsol is strongly weathered, low in nutrients and showing no major characteristics. The umbric Ferralsol occurs with an additional thick, dark colored acid surface horizon and is rich in organic matter.[20]

Ferralsols often appear with a weakly defined macrostructure. In contrast its microstructure is stable, whereas silt and clay particles tend to aggregate and form pseudo-sand. The pseudo-sand shows similar characteristics to sand in relation to water conductivity and water retention.[21] [22]

That effects its agricultural usability. The ferralsol structure is friable and easy to work, though it is vulnerable to drought stress. Weatherable minerals have been washed out and are absent or scarce, leading to a poor chemical fertility. The majority of the cycling nutrients are concentrated within the biomass and thus the plant available nutrients mainly occur in soil organic matter. As a result, the soil is vulnerable to nutrient depletion if biomass is removed without compensation.[23]

As in most of Rwanda, the soils in the Butare area are reckoned as vulnerable to soil erosion. Throughout Rwanda about 40 % of arable land are considered to have a very high erosion risk. Alteration of nature through man, especially through agriculture and deforestation constitutes the main erosion threat.[24]

Erosion is thereby distinct from soil degradation as an ablation of physical soil contents. Whereas soil degradation is defined as a permanent decline of soil function or structure, through physical, chemical or biotic agents, that includes erosion.[25] In the hilly environment crops are cultivated on steep slopes of up to 55 %. With such high gradients soil particles are easily washed into the lower marshlands or ultimately the stream network.

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[20] Jones, A., et al.(2013): 66.

[21] Zech, Wolfgang, Peter Schad, and Gerd Hintermaier-Erhard. "*Böden der Welt: ein Bildatlas*." (2014): 102.

[22] Boedt, L., and W. Verheye. "Évaluation of profile available water capacity. 3. A model for estimating profile available water capacities for wheat on soils under irrigation, using simple physical and chemical soil properties." *Pédologie* 36.1 (1986): 35.

[23] N.N. "World Reference Base for Soil Resources 2014." WRB IWG (2014): 156.

[24] N.N. "REMA (2009): Rwanda State of Environment and Outlook Report" Republic of Rwanda - Southern Province - Huye District (2009): 10.

[25] Sander, Heinz "Lexikon der Geographie" *Spektrum akademischer Verlag* (2001): 186 (own translation).

Much of Rwandas domestic and also industrial energy demands are satisfied with fuel wood, which has manifested in an intense deforestation. Without the stabilizing features of the root system that forestial plant communities provide, erosion is vigorously accelerated.[26]

In the Nyanguru district respectively the Gisagara district 13 % and 4 % of arable land are affected from moderate soil degradation, such as overland flow erosion and erosion by intrusion. All remaining arable land within the area is affected by low soil degradation, mainly through slash erosion.[27]
The threat of soil erosion has meanwhile been addressed by the local authorities and measures for soil protection such as compiling terraces are implemented.[28]

2.4. Economic situation

For the 635,000 inhabitants of the three cited districts (Huye, Gisagara and Nyaruguru) agriculture constitutes the main share of economic activity. There is little industry, which is mostly related to the processing of agricultural products. Also, tourism only provides few income opportunities.[29] [30] [31]

In each district more than 80 % of the workers are occupied in agriculture, either as wage workers or on their own farms. Though, a broad number of agricultural work accounts to subsistence farming. An unsteady marketing of crops is resulting in little income, which is depicted in the high level of poverty.[32] [33] [34] According to the Rwandan EICV4 survey 53.3 % of the population of Gisagara, respectively 47.9 % of Nyaruguru and 32.5 % of Huye are considered as poor (applying the EICV4 definition where poor is someone, who is not able to purchase sufficient basic goods and food).[35]

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[26] N.N. Rwanda Environment Management Authority (2009): 10.

[27] N.N. “Seasonal Agricultural Survey (SAS)–2017 Season A“ National Institute of Statistics of Rwanda (2017): 42.

[28] ibid: 39.

[29] N.N. Republic of Rwanda - Southern Province - Gisagara District (2013): 8-10.

[30] N.N. Republic of Rwanda - Southern Province - Huye District (2013): 8-12.

[31] N.N. Republic of Rwanda - Southern Province - Nyaruguru District (2013): X-XII

[32] N.N. Republic of Rwanda - Southern Province - Huye District (2013): 8-12.

[33] N.N. Republic of Rwanda - Southern Province - Nyaruguru District (2013): V-X.

[34] N.N. Republic of Rwanda - Southern Province - Gisagara District (2013): 7-11.

[35] National Institute of Statistics of Rwanda “Rwanda Poverty Profile Report, 2013/14“ (2015): 17-23.

The majority of agriculture is performed manually. Mechanization, improved seeds and the usage of inorganic fertilizer and pesticides are rare. Irrigation techniques are only applied on a minority of farmlands (3.8 % in Nyaruguru, 9.8 % in Gisagara and 19 % in the Huye district).[36] The main food crops are wheat, maize, beans, rice and potatoes. Cash crops that are planted are tea and coffee. In addition the majority of households keep some sort of livestock. Productivity is low and due to insufficient road network and electric infrastructure, post-harvest losses are high. Markets are hard to reach and agro-processing plants sparse.[37] [38] [39]

3. Biochar and its effects

In this chapter Biochar (BC) will be defined and its production will be described. Furthermore, the interactions with soil properties, especially with WHC will be explained, from which its relevance for drought-prone soils is derived. The chapter will close with an excursion to crop yield increases achieved by BC application, which will emphasize the substantial potential BC bears.

3.1. Production process

The production process of Biochar is identical to charcoal and is only distinguished by its soil additive purpose.[40] Both are a high-carbon solids formed from pyrolysis. Pyrolysis is a heating process of carbon-bearing solid material under oxygen-starved conditions. Long-chained carbon compounds, such as cellulose, are thereby cracked into short-chained carbon compounds and chemical bound moisture volatilizes.[41]

The material can originate from an open range of biomass materials and is not bound to a certain vegetable or animal matter. The chemical structure of the feedstock is thereby directly influencing the physical characteristics of the BC produced. The thermal decomposition and microstructural rearrangement of organic matter, that the feedstock experiences are always based on its original chemical composition.[42]

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[36] N.N. National Institute of Statistics of Rwanda (2017): 30-35.

[37] N.N. Republic of Rwanda - Southern Province - Huye District (2013): 8-10.

[38] N.N. Republic of Rwanda - Southern Province - Nyaruguru District (2013): V-IX.

[39] N.N. Republic of Rwanda - Southern Province - Gisagara District (2013): 7-11.

[40] Brown, Robert. (2009): 127.

[41] Hartmann, Hans, et al. “Grundlagen der thermo-chemischen Umwandlung biogener Festbrennstoffe.“ *Energie aus Biomasse*, (2009): 378.

[42] Brown, Robert. "Biochar production technology." *Biochar for environmental management* (2012): 127.

The pyrolysis or carbonization system by which the BC is produced further alters its physical properties. Traditionally charcoal kilns for charcoal production are used, but advanced types of reaction vessels provide a better control of temperature and pressure. All steps of the pyrolysis system that alter the feedstocks characteristics, have an impact on the produced BC. Those consist of pre-handling steps like shredding, drying, and the addition of catalytic chemicals; post-handling steps like grinding, sieving, and oxidative activation; and the pyrolysis process itself, that can vary in heating rate, pressure, duration, highest treatment temperature, ancillary inputs and the character of the reaction vessel. For the conversion rate, the highest treatment temperature is expected to be the most influential.[43]

3.2. Effects on soil

„Humid substances derived from coal have been found to increase the water-holding capacity, as well as the stability of degraded soil.“[44]

When BC is amended to soil several alterations in soil properties have been observed. Among those are an: increased WHC, increased gas exchange, increased cation exchange capacity, increased surface sorption capacity and altered soil pH. Under certain circumstances BC has the ability to reduce nutrient leaching and volatilization and thus it increases the nutrient availability to plants and microbes. The effects vary with the type of BC used and the type of soil it is applied to. Thus statements can only be made individually for a certain BC interacting with a certain soil. [45] [46]

The processes that determine these alterations have not been fully understood yet. Though one expects the high porosity of BC, that offers abundant entries for gas and fluid exchange, to be the main cause. Porosity is equivalent to a very high specific surface area that results in a high adsorption capacity. The chemical structure of BC also shows variable charged organic material that reacts or bonds with exposed matters.[47]

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[43] Downie, Adriana et al. “Physical properties of biochar.“ *Biochar for environmental management: Science and technology*, (2009): 16.

[44] Major, Julie, et al. "Biochar effects on nutrient leaching." *Biochar for environmental management.* (2012): 273.

[45] Baronti, Silvia, et al. "The biochar option to improve plant yields: first results from some field and pot experiments in Italy." *Italian Journal of Agronomy* 5.1 (2010): 3-12.

[46] Lehmann, Johannes, et al. "Biochar effects on soil biota–a review." *Soil biology and biochemistry* 43.9 (2011): 1812-1836.

[47] Masiello, C. A., et al. "Biochar effects on soil hydrology." *Biochar for environmental management* (2015): 544-545.

BC has also shown to increase the biomass and community composition of soil microbes and stimulate their activity. An animated soil biota positively impacts the nutrient mineralization of dead vegetable matter and also certain nutrient transformations within the soil.[48]

Another noteworthy feature is BCs persistence over time. Microorganisms in the soil are not capable of instantly breaking most of the carbon and nitrogen bonds (and probably other nutrients) of the pyrolysed matter because of its chemical stability.[49] “97 % of the added BC can persist in soils on a centennial scale“[50] until decomposing processes alter its structure. Its endurance states a clear benefit for an implementation in agriculture because repeated application are minimal.

3.2.1. Alteration of WHC

Aside the already mentioned effects on soils, the focus shall be set on BCs alteration of soil WHC. WHC, or field capacity, is defined as the maximum water uptake, „that is hold by capillary and adhesion force, against gravity in a free-draining soil in undisturbed bedding above ground water level. It depends on the granulometry, the bulk density and the content of organic matter.“[51] For practical concerns it is understood as the water content that a soil shows 2-3 day after a long rainy period.[52] An amendment of BC is modifying the three WHC determining parameters: granulometry, bulk density and organic matter content altogether.

Firstly, pyrolysis creates predominantly very small BC particles. Those alter the granulometry when added to sand or silt dominated soils. This is intensified when small sized feedstock particles are being used. Small sized particles lead to a great surface area where water can bond, which increases WHC. BC itself is highly porous bearing a high specific surface area and thus amplifies the potential for water retention.[53]

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48 DeLuca, Thomas H., et al. "Biochar effects on soil nutrient transformations." *Biochar for environmental management: science, technology and implementation* 2 (2015): 424.

49 Lehmann, Johannes, et al. (2011): 1814.

50 Wang, Jinyang, Zhengqin Xiong, and Yakov Kuzyakov. "Biochar stability in soil: meta-analysis of decomposition and priming effects." *Gcb Bioenergy* 8.3 (2016): 521.

51 Brunotte, Ernst, et al.; “Lexikon der Geographie“ Spektrum Akademischer Verlag (2001): 370 (own translation).

52 Strübel, Günter “Lexikon der Geowissenschaften“ Spektrum Akademischer Verlag (2000): 139 (own translation).

53 Masiello, C. A., et al. (2015): 544-547.

Secondly, size and shape of the BC particles influence the bulk density. The way they fill up the empty space between soil particles is dependent on their spatial properties. BC particles in the soil can change the volume, size and connectivity of soil spaces and is expressed in an altered soil pore geometry. If consequently the fraction of slow draining micro-pores is increased, the WHC increases likewise.[54]

Thirdly, is a high organic matter content generally related to a high WHC. BC consists almost entirely of organic compounds, thus an increased WHC due to soil amendment can be expected. [55]

A main determinant of an alteration in WHC is of course the soil that BC is applied to. Present scientific literature highlights an explicit trend, where an increase of WHC is documented for sandy soils, whereas WHC decreases in clay soils. That is likely due to the small particle size and high bulk density typical for clay soils, that is rather diluted by BC.[56] This finding is supported by the executed experiements, which are listed in Table 3. There, experiments that show no effect on or an reduction of WHC only appear in clay soils.

An opposite finding only occurs in one experiment carried out with a BC of hay origin and in sandy soil. There an the BC amendment did not cause an alteration in WHC. The hay-BC was found to have high porosity, which made an increase in WHC likely, but its highly hydrophobic surface was found to hinder water intrusion into the pores.[57]

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[54] Masiello, C. A., et al. (2015): 544-547.

[55] Mollinedo, Javier, Thomas E. Schumacher, and Rajesh Chintala. "Influence of feedstocks and pyrolysis on biochar's capacity to modify soil water retention characteristics." *Journal of Analytical and Applied Pyrolysis* 114 (2015): 100-102.

[56] Blanco-Canqui, Humberto. "Biochar and soil physical properties." *Soil Science Society of America Journal* 81.4 (2017): 700-704.

[57] Jeffery, Simon, et al. "Biochar application does not improve the soil hydrological function of a sandy soil." *Geoderma* 251 (2015): 50-52.

Location	Soil type	Biochar feedstock	Biochar pyrolysis temperature (°C)	Biochar rate	WHC
China	Sand	Wood	550	0, 7, 15, 25 g kg^{-1}	Increased
Italy	Sand	Wood	~550	20 g kg^{-1}	Increased
Sri Lanka	Sand and sandy loam	Rice husk	~600	0, 1, 5, and 10 g kg^{-1}	Increased
Denmark	Sand and sandy loam	Straw and wood	750–1200	10 g kg^{-1}	Increased
Iran	Sandy loam	Rice husk and wood chip	350–550	20 g kg^{-1}	Increased
Zambia	Sandy loam	Maize cob	350	0, 8, and 25 g kg^{-1}	Increased
Spain	Sandy loam	Wood and sewage sludge	500–620	0, 1.5, and 15 Mg ha^{-1}	Increased
Poland	Loamy sand	Miscanthus × giganteus and wheat straw	300	0, 5, 10, 20, and 40 g kg^{-1}	Increased
China	Loam	Peanut shells	350–500	0 and 28 Mg ha^{-1}	Increased
India	Loam	Maize stalks	350	0, 5, 10, 20 g kg^{-1}	Increased
China	Loam	Crop straw	450	0 and 16 Mg ha^{-1}	Increased
China	Loam	Maize straw	400	0, 10, 20, and 30 Mg ha^{-1}	increased
Italy	Silty clay loam	Wheat bran	800–1200	14 Mg/ha	Increased
China	Clay loam	Maize straw and wood	n/a	0 and 7.8 Mg ha^{-1}	Increased
China	Clay loam	Straw, wood, and wastewater sludge	500	0, 20, 40, and 60 g kg^{-1}	Increased
Japan	Clay	Sugarcane bagasse	400–800	30 g kg^{-1}	No change
Brazil	Clay	Woodchip	~450	0, 8, 16, and 32 Mg ha^{-1}	Decreased or no change

Tab. 3. Experiments surveying BC effects on WHC, mostly resulted in increased WHC.That occurred independent from varying source material or pyrolysis temperature. Only clay soils showed no or an opposite effect.[58]

As a final remark it should be noted, that WHC is not synonymous with plant-available water - but highly related. Soil water is available to plant roots until the suction force of the roots is equal to the adhesive force of the soils micro-pores. The difference of the water content at this -so called- permanent wilting point (PWP) and the water content at WHC defines the plant-available water. BC is likely to alter the PWP as well. An increased fraction of water is held permanently against the root suction by the adhesive micro-pore structure of BC. Yet the increase in WHC is supposed to exceed the increase in PWP.[59] [60]

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58 Blanco-Canqui, Humberto (2017): 701.

59 Masiello, C. A., et al. (2015): 552.

60 Blanco-Canqui, Humberto (2017): 700-704.

3.3. Effect on vegetation

The way BC affects vegetation mainly rely on the fundamental alteration of physical and chemical soil characteristics, that have been depicted before. A further effect can be constituted in a fertilization through a direct nutrient influx. BC consists of stable chemical bonds, but within the inevitably co-produced ash content plant-available nitrogen compounds are present. Together these modifications influence the vegetation productivity.

Crop yield is the most relevant plant productivity measure for agricultural used plants. Other aspects such as gain in biomass, plant growth or root density are omitted here. Studies concerned with crop yield showed statistically significant differences between BC soil amendments and their reference soil (Fig. 4). Differences in the BC feedstock were not found to have significant impact on the outcome.

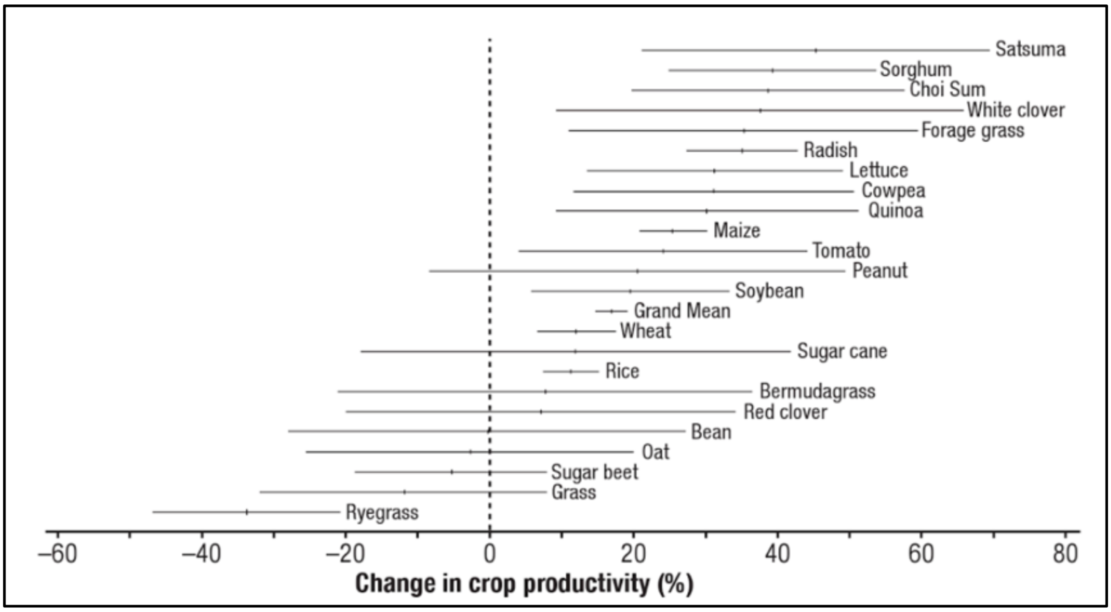

Fig. 4. Crop productivity surveyed for various crops after BC amendment. The black dot re presents the median, the black line the quintiles for productivity changes. Although there is a mostly broad range of the effect, the majority of crops receive an increase in productivity.[61]

In the chart a significant increase in productivity for a large number of agricultural crops when grown with a BC amendment is shown. That includes some of the most important commercial crops such as wheat, rice, soybean and maize, that increased their productivity above 15 % and more.

[61] Lehmann, Johannes, et al. (2015): 307.

Some other crops like sugar cane, oats and red clover showed no verifiable alteration or even a decreased productivity like ryegrass. The review that is represented in the chart did compare 60 studies that were carried out in various conditions, regarding soil type, amount of added BC and climate conditions. The conclusions derived from it, thus are of restricted precision, but still indicate a general direction of intensified crop production after BC amendment.[62]

4. Water hyacinth

In this section the WAHY will be introduced, starting with a botanical description. Further the exceptional growth rate of this plant will be highlighted, as it bears both, an enormous threat and an exciting potential. The various negative consequences of the fast propagation of the plant will be addressed, which will at the same time illustrate the positive side-effects an utilization of the WAHY could have.

4.1. Botanic description

Water hyacinth (*Eichhornia crassipes (Martinus) Solms-Laubach*) is assigned to the Pontederiaceae family, that contains 34 flowering freshwater plants of the tropics and subtropics. It is native to South America with a habitat that extends within tropical and subtropical boundaries, from Mexico and some carribean islands in the north to Argentina and Chile in the south. With man acting as a diligent dispersal agent the plant got spread to wherever climatic conditions are suitable and now can be found on every continent between 38°N and 38°S.[63]

The WAHY develops from a rhizome, that remains submerged and can grow up to 30 cm in length. From the rhizome numerous roots and petioles generate (Fig. 5). The roots remain submerged and vary in their length from 10 cm in nutrient-rich water to 300 cm in nutrient-poor water. They appear in thin tufts, giving them a featherish impression. The roots are free floating in the open water but can anchor in the soil in shallow water or in mud.[64]

[62] Lehmann, Johannes, et al. (2015): 307-308.

[63] Gopal, Brij "*Water hyacinth*" (1987): 43.

[64] ibid: 12-14.

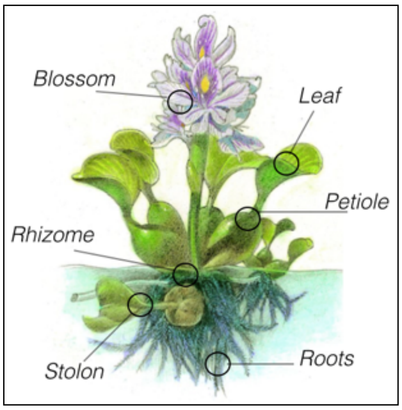

Fig. 5. Schematic graphic of a WAHY and its parts[65]

The petioles spring from the rhizome in a basal rosette. Usually they develop a bulbous dilatation near the bud that serves as a float and taper towards the leaf, but their shapes can differ. Each petiole carries one leaf that with an ovoid to kidney shape and of a coarse structure.[66] Some prolonged petioles develop an inflorescence comprised of numerous blossoms. They display in pale-blue to violet with a yellow central patch.[67]

It colonizes still or slow floating waters, that due to its high productivity results in thick extensive mats. Depending on its growing conditions two distinct morphologies appear. In dense surface coverage the petioles become prolonged and reach up to 1 m in height bearing circular leaves. If the plant appears sporadic it shows a short and bulbous growth, with kidney-shaped leaves.[68]

An optimal growth is achieved at a pH of 6-8 and within temperatures around 25°C (though it can grow within a wide range of temperature, from 10-40°C).[69] There are to be five main factors limiting its growth rate: salinity, temperature, nutrient availability, mechanical disturbance and natural enemies. In the absence of its native enemies outside its indigenous habitat it can quickly become invasive.[70]

65 Internet: http://planet.botany.uwc.ac.za/nisl/bdc321/ekapa%20cape%20towns%20lowlands/module4/Water-hyacinth.htm (accessed on 07/08/2018) with own description.

66 Gopal, Brij (1987): 61-65.

67 Coetzee, J. A., et al. "Eichhornia crassipes (Mart.) Solms-Laub.(Pontederiaceae)." Biological Control of Tropical Weeds using Arthropods. (2009): 184.

68 ibid.

69 Malik, Anushree. "Environmental challenge vis a vis opportunity: the case of water hyacinth." *Environment international* 33.1 (2007): 123.

70 Gopal, Brij (1987): 46-50.

4.2. A closer look at its reproduction and growth rate

„[Water hyacinths] productivity is one of the highest for photosynthetic organisms.“[71]

An outstanding feature, next to its enchanting appearance is the velocity of WAHY biomass productivity and its rate of reproduction. As for every plant both factors are highly determined by their environmental conditions, especially nutrient availability and climatic environment.

This variability becomes apparent in the WAHYs daily biomass production, that shows a high variability. The daily dry weight production ranges from 1.6 to 26 g/m^2 in natural waterbodies, though the latter value is only occurring in eutrophic waters. As a comparison: the highest daily biomass production of all bamboo species is stated with 13 g/m^2.[72]

With an even higher nutrient availability, such as given in wastewater effluents, WAHY production rates have been reported to reach up to 72 g/m^2.[73] The gain in biomass is expressed in an increased ramen production, shoot:root ratio, density accumulation and plant height.[74] This illustrates the impacts eutrophic waters have on WAHY habitats and vice versa.

The reproduction of WAHY corresponds to its biomass productivity and is also very rapid. WAHY are able to reproduce vegetatively and sexually, where the vegetative propagation is the more important ability. Stolons develop through mitosis, which later separate as daughter plants from the WAHY. This method allows the WAHY to double their number in a very fast amount of time. Under favorable conditions doubling times of 3.7 days have been reported.[75]

Sexual reproduction plays a subordinated role, but secures an outlasting survival of the plant within an ecosystem. WAHY is monoecious and thus can reproduce with any other fertile WAHY.[76]

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71 Sullivan, P., et al. (2012): 37.

72 Scurlock, J. M. O., D. C. Dayton, and B. Hames. "Bamboo: an overlooked biomass resource?." *Biomass and bioenergy* 19.4 (2000): 239 (converted from the given 47 t/ha/year).

73 Gopal, Brij (1987): 149-152.

74 Heard, Tim A., and Shaun L. Winterton. "Interactions between nutrient status and weevil herbivory in the biological control of water hyacinth." *Journal of Applied Ecology* 37.1 (2000): 117.

75 Gopal, Brij (1987): 100.

76 Gopal, Brij (1987): 70.

Further the plant is capable of producing fertile offsprings through self-pollination.[77] If conditions are favorable it can flower repeatedly throughout the year. A single Blossom can produce up to 450 seeds, though the average is less.[78] These seeds germinate within a few days or remain dormant up to 15-20 years to weather drought stress. If conditions improve the seeds germinate and renew the growth cycle. Thus attempts to eradicate the plant within an ecosystem need persistent vigilance.[79]

Their fast reproduction and gain in biomass leads to a rapid expansion upon the waterbody. This is reflected in the occupied surface area, that can increase up to 12 % per day.[80] The limiting factor for further growth soon becomes the scarcity of space.[81] It is obvious, that such a dominant appearance has a broad impact on an ecosystem and the leveraging socio-economic structures.

4.3. Effects on invaded socio-ecologic systems

Corresponding to the varying growth rate of the WAHY are the WAHYs effects to different socio-economic systems. It can generally be suspected, that with a higher growth rate and lesser response of the ecosystems, higher impacts of this alien plant occur. Negative effects that are broadly reported are: obstruction of water infrastructure, decrease in dissolved oxygen, leading to a decreased fish population and catch, distribution of pathogenic vectors and an increased evapotranspiration. Those effects shall be explained in detail.

Fig. 6. Obstructed river in Vietnam.[82]

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[77] Barrett, S. C. H. "Sexual Reproduction in Eichhornia Crassipes (Water Hyacinth). I. Fertility of Clones from Diverse Regions." *Journal of Applied Ecology* 17, no. 1 (1980): 101.

[78] Gopal, Brij (1987): 102.

[79] Malik, Anushree (2007): 123.

[80] Gopal, Brij (1987): 100.

[81] Gopal, Brij (1987): 144.

[82] Internet: https://vietnamnews.vn/english-through-the-news/267196/water-hyacinth-chokes-rivers.html#CdjOSpFASWgzYecF.97 (accessed on 07/06/2018)

Accumulated mats of WH can obstruct fairways and ports. Smaller boats can be halted from transporting passengers and freight, bigger ships at least hindered (Fig. 6). The output of other water infrastructure facilities such as hydroelectric power plants and irrigation systems can be reduced or halted entirely when accumulated WAHY clog the intake pipes of the facilities.[83] A reduced water flow caused by thick WAHY mats in natural streams is further known to be a cause for water stasis and extended flooding.[84]

When the number of WAHY mats increases above a surface coverage of 10 %, submerged photosynthetic organisms are negatively effected by the shadow cast. Also the dense plant mats impede a direct oxygen exchange between air and water. This is expressed in a decline in dissolved oxygen concentration and reduced phytoplankton production, both negatively effecting the aquatic fauna.[85] A decline in dissolved oxygen further lowers the waterbodies ability to adsorb organic pollution, which negatively effects the waters quality (for example for potable use).[86]

Fishermen face a decline in catch when a large WAHY infestation occurs. Besides the negative impacts on the fish population through reduced oxygen concentrations, the WAHY is known to cover fishing grounds, „delaying access to markets because of loss of output, increasing fishing costs because of the time and effort spent in clearing waterways, forcing translocation, and causing loss of nets.“[87]

The appearance of the WH are also discussed as an amplifier for parasitic pathogens. The increased plant surface on the waterbody represents an ideal habitat for the Anopheles mosquitos potentially carrying malaria and snails transmitting bilharzia.[88] [89] Both debilitating and sometimes lethal disease. Dense plant mats are also known to serve as excellent habitats for rats.

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83 Mailu, A. M. "Preliminary assessment of the social, economic and environmental impacts of water hyacinth in Lake Victoria Basin and status of control." *ACIAR proceedings*. (2000): 133-136.

84 Gopal, Brij (1987): 168.

85 McVea, Charles, and Claude E. Boyd. "Effects of Waterhyacinth Cover on Water Chemistry, Phytoplankton, and Fish in Ponds 1." *Journal of Environmental Quality* 4.3 (1975): 376-377.

86 Gopal, Brij (1987): 169.

87 Kateregga, Eseza, and Thomas Sterner. "Lake Victoria fish stocks and the effects of water hyacinth." *The Journal of Environment & Development* 18.1 (2009): 62.

88 Gopal, Brij (1987): 173.

89 Masifwa, Wanda Fred, Timothy Twongo, and Patrick Denny. "The impact of water hyacinth, Eichhornia crassipes (Mart) Solms on the abundance and diversity of aquatic macroinvertebrates along the shores of northern Lake Victoria, Uganda." *Hydrobiologia* 452.1-3 (2001): 87.

Waterbodies that are infested with WAHY show higher evaporation. This is caused by the high transpiration rate generated by the plants metabolism, that can be up to six times higher than water surface evaporation.[90] That constitutes a crucial loss of available water in areas of water scarcity.

Due to its overrunning growth rate positive effects are few, but noteworthy to mention. In sparse WAHY populations juvenile fish can benefit from the cover and camouflage the floating roots provide.[91] Several studies attested WAHY a high potential for nutrient and pollutant depletion of eutrophic or waste water, if the grown biomass is translocated from the waterbody.[92] Multiple concepts in using the plant as green manure, as an additional fodder plant or for weaving in rural communities have also been implemented.[93] But as a relatively new plant that has had no traditional use, training is needed to emphasize such attempts to a broader perception.

Transforming WAHY biomass into fuel (charcoal, ethanol, biogas) has also been investigated, but as other resources show a better energetic ratio, they didn't progress.[94] Only if other resources are unattainable or unaffordable, does WAHY biofuel become an option.

The amount and intensity of the negative effects is leading to the need for a WAHY management. There are three possible control methods: mechanical (harvesting or cutting), chemical, or biological (introduction of insects of WH native range). Thus a control of the population is possible, but a lasting eradication is still hard to achieve. The mechanical measure, though labour intense, can be carried out with limited techniques and knowledge. The thereby harvested biomass can be understood as a resource for further purposes.

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90 Pieterse, A. H. "The water hyacinth (Eichhornia crassipes)-a review." *Abstracts on Tropical Agriculture (Netherlands)*. (1978): 9-12.

91 McVea, Charles, and Claude E. Boyd. (1975): 376.

92 Dhote, Sangeeta, and Savita Dixit. "Water quality improvement through macrophytes—a review." *Environmental Monitoring and Assessment* 152.1-4 (2009): 150-151.

93 Jafari, N. "Ecological and socio-economic utilization of water hyacinth (Eichhornia crassipes Mart Solms)." *Journal of Applied Sciences and Environmental Management* 14.2 (2010): 45-46.

94 Gunnarsson, Carina C., and Cecilia Mattsson Petersen. "Water hyacinths as a resource in agriculture and energy production: A literature review." *Waste Management* 27.1 (2007): 119-122.

5. Merging the strands - development of the research question

„Biochar experiments in Ferralsol soils are promising, as it seems suitable to overcome unfavorable soil conditions.“[95]

Previously two problems of the Butare area have been presented: its drought-proneness and the WH infestation of its waterbodies.

It was shown, that the rain-fed agriculture carried out in the Butare climate bears a drought-risk. Even more as extreme weather phenomenas are increasing. The drought vulnerability is further exacerbated due to the progressed stage of soil erosion. Though soil protecting measures are being implemented, already eroded soils need decades or centuries to recover. As the majority of inhabitants work in agriculture droughts are critical for the local economy and food security. So far, improvement of soils by manuring could only have short-term effects, as the organic matter decomposes. Implementing irrigation infrastructure in contrast is hindered by the hilly topography and the lack of financial resources.

A possible concept to tackle the drought vulnerability consists of a soil amendment of BC. The addition of BC to soil has proven to increase WHC in several studies. Thus it is considered as an approach to strengthen drought resilience of sandy soils.[96] Furthermore the positive effects of BC on nutrient availability and its long lasting structural stability suggest a broad range of benefits for crop crowing.

BC needs to be produced from a raw material. As an initial thought wood seems to be suitable as it is commonly used for the production of charcoal. But as charcoal and firewood already constitute 86% of Rwandas fuel stock they are considered as a major reason for deforestation[97] and thus for soil erosion and soil degradation. Further incentives for deforestation need to be avoided, consequently this excludes the use of wood as a feedstock for BC. Another source of organic material is required.

On the other hand the area is facing an infestation of its waterbodies by WAHY. This can have numerous negative effects on the socio-economic and ecologic system.

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[95] Zech, Wolfgang, Peter Schad, and Gerd Hintermaier-Erhard. (2014): 102 (own translation).

[96] Mulcahy, D. N., D. L. Mulcahy, and D. Dietz. "Biochar soil amendment increases tomato seedling resistance to drought in sandy soils." *Journal of arid environments* 88 (2013): 223.

[97] Sander, K., Hendriksen, G. “Establishing a green charcoal value chain in Rwanda - a feasibility study.“ The World Bank (2012): 14.

Some attempts were made to control the pest with biological measures, but so far the major efforts to clean waterbodies in Rwanda from WAHY are carried out by manual or mechanical extraction. The vast mass of WAHY that is carried to the shore is either used as green manure or simply left to rot.[98]

Having a look on both mentioned problems it becomes conceivable to use the accumulated biomass of WAHY as a feedstock for BC production. The yielded WAHY-BC could encounter the soils drought vulnerability and the demand for WAHY-BC would act as an incentive to remove WAHY from the waterbodies. The collection of WAHY, the production and scattering of BC require only manual labour, which is important as substantial farmers can hardly afford the acquisition costs of technical installations.

The characteristics of a BC and its effects on soils have shown to be determined by the feedstock and the production process of the BC, but also depend on the soil it is intended to be amended to. Consequently an individual trial for the selected feedstock, production process and soil is needed. The dominating soil in the Butare area is ferralsol. Therefore this thesis shall query whether BC from WAHY can efficiently increase the water holding capacity of a ferralsol soil.

6. Methodology

To answer the research question a experimental trial was set-up. Its structure is explained in this chapter and is summarized in Fig. 7. Why there was reorientation regarding the source of the soil sample to be examined, is reasoned in the first part. Next the collection of the soil sample and the methods of its granulometry analysis are described. This is followed by an explanation of the WAHY pyrolysis that has been used to produce BC. The yielded WAHY-BC has afterwards been blended with the sampled soil in different concentrations. By saturating the WAHY-BC enriched soil with water and weighing it after two days, the WHC of the samples was estimated.

[98] N.N. “Study to assess the impacts of invasive alien species (Flowering plants, fish and insects) in natural forests, agro-ecosystems, lakes and wetland ecosystems in Rwanda and develop their management plans“ Rwanda Environment Management Authority (2016): 34-36.

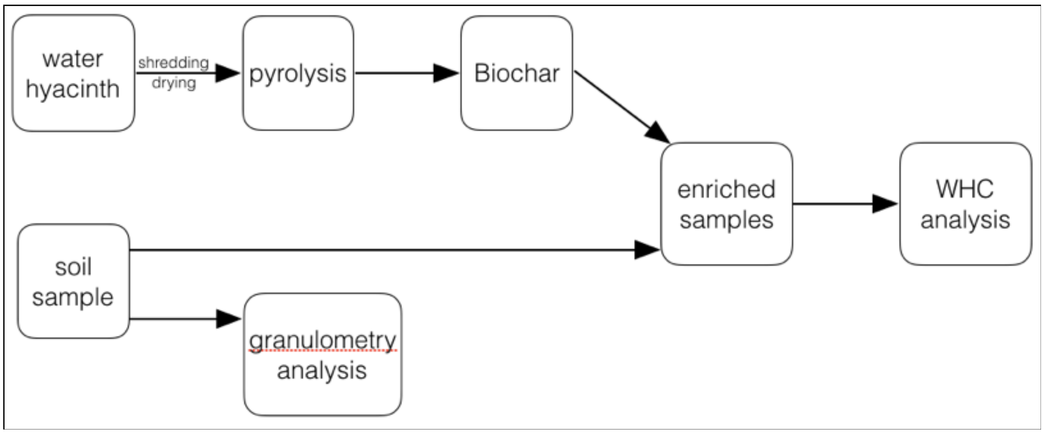

Fig. 7. Trial set-up for WAHY-BC effects on WHC[99]

6.1. Adaptation of the trial

Initially it was planned to conduct the trial in the Butare area. The geographical parameters, that have been presented in chapter 2, gave reason to believe that the Butare area would create appropriate environmental conditions for a favorable survey. However, due to logistical reason, it was impossible to execute a trial in this area with the pre-set timeframe. An alternative trial was needed, that would resemble the investigated character of soil WHC. The thesis itself is investigates impacts on a certain soil type, without geographical specification.

When searching for equivalent conditions, the soils around Entebbe in Uganda were found to be adequate. The soils are within the same category of soil, classified as haplic Ferralsols[100] that have developed from paleoproterozoic rocks.[101] Thus soil conditions there are suspected to be congruous enough to match the thesis requirement, of beeing a ferralsol.

A remarkable difference is the climatic condition in Entebbe. Contrary to Butare, Entebbe receives a perirenal climate. This results in a lesser drought-proneness, which means that any achieved outcome regarding altered WHC are less relevant for an implementation in the Entebbe area.

As a feasible option the trail was implemented in Entebbe where local WAHY was collected and soil samples were taken. The Headquarters of the Nile Basin Discourse (NBD) would kindly allow the usage of their facilities and their staff would support the trial with helpful advices.

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99 own graphic

100 Jones, A., et al. (2013): 111.

101 Schlüter, Thomas (2006): 238.

6.2. Soil analysis of an Entebbe Ferralsol sample

6.2.1. Collection of the soil sample

The soil sample was taken from 0°05'05.2"N 32°27'08.8"E near Nakiwogo landing site, that is within the municipal limits of Entebbe. The sample place was situated on a meadow with sporadic trees and bushes, which was used as pastureland. The position was on a gently angled slope with westward exposition. The „Bodenkundliche Kartieranleitung“ (KA5) served as a guideline for the collection of the sample.[102] It was ensured that the sample place was distanced to influential elements such as roads or constructions. The chosen position was situated within an evenly micro relief and showed no sign of any previous disposal or excavation site. Damage to the environment and an accident risk resulting of the digging were considered to be minimal.

A spade and shovel were used for the excavation. On an area of 1.5 x 1.5 m a hole was dug to a depth of 50 cm. The first 15 cm showed a dense root penetration that decreased with depth. From top ground surface to the bottom the soil showed a bright brown and had no change in color, that is supposed to be the Ah-Horizon typical to ferralsol soils. A humus content of about 30 % is causing its brownish color.[103]

The provision of the KA5 to excavate to a depth greater than 120 cm and to execute several excavations in the surrounding was not satisfied.[104] The detected Ah-Horizon lasted to a depth of 50 cm and a greater depth would not have been of interest for manual cultivation. Also the thesis focuses on the effects on an exemplary sample of a certain soil type, an examination of several soil samples would have exceeded the given capacities.

In the absence of a muffle oven, the collected soil was spread in a thin layer on a tarp and exposed to the equatorial sun to dry. After three days the soil was dusty-dry. Four samples of the soil were later surveyed in the laboratory of the Geographisches Institut of the Humbold-Universität zu Berlin. There, two measures to determine the soil granulometry were applyed: the Köhn-method and the Beckmann-Coulter-method.

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[102] Sponagel, H. et al. “Bodenkundliche Kartieranleitung“ Bundesanstalt für Geowissenschaften und Rohstoffe (2005).

[103] Zech, Wolfgang, Peter Schad, and Gerd Hintermaier-Erhard. (2014): 102.

[104] Sponagel, H. et al. (2005): 38.

6.2.2. Köln-Method

Applying the Köhn-method a soil sample was dried in an oven at 40°C for two days and weighted. The sample was mortared with caution to loosen clay particles, that may have accumulated with bigger particles.[105]

A sieve tower, consisting of a 0.63 mm, a 0.2 mm and a 0.063 mm sieve, was erected with the coarse mounted upon the fine sieve. That tower was placed at the bottom of a tub and the whole construction was installed on a vibration device (Fig. 8).

The sample was spread on the first sieve. Particles <0.63 mm were divided from the probe under constant vibration. Distilled water was sprayed on the sample to solve small aggregated particles and cleanse the sieve. This procedure was repeated with the lower and finer sieves. In this way coarse sand particles (2-0.63 mm) were separated from medium sand particles (0.63-0.2 mm) and these were separated from fine sand particles (0.2-0.063 mm). The material of each sieve was dried in an oven at 105°C overnight and weighed. A solution containing clay and silt particles was left in the tub.[106]

Fig. 8. Sieve tower on a vibration device.[107]

The remaining supernatant was filled into a glass cylinder and toped up with distilled water to a total amount of one liter. Afterwards it was blended firmly and the time for the following draws was taken. The glass cylinder was placed in a large tub filled with water at 20°C. The water levels in the tub and the glass cylinder were even. While the solution slowly sedimented, a defined amount of 21 ml of the solution was pipetted from the glass cylinder for four times.[108]

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105 Blume, Hans-Peter, Karl Stahr, and Peter Leinweber. “Bodenkundliches Praktikum: Eine Einführung in pedologisches Arbeiten für Ökologen, Land-und Forstwirte, Geo-und Umweltwissenschaftler.“ (2011): 82-85.

106 Blume, Hans-Peter, Karl Stahr, and Peter Leinweber.(2011): 82-85.

107 Internet: https://www.uibk.ac.at/geotechnik/labor/index.html.en (as accessed on 08/08/2018)

108 Blume, Hans-Peter, Karl Stahr, and Peter Leinweber.(2011): 82-85.

Sediments within the solution pipetted at a certain depth at a certain time correlate with a certain grain size. By using a chart that is based on empirical calculations of this trial-set, the grain size can be assigned to the solution sample. The subsample of coarse silt (0.02–0.063 mm) was taken from 15 cm after 0:42 min in the tub. The medium silt (0.0063–0.02 mm) subsample was taken from 10 cm after 4:39 min. The fine silt (0.002–0.0063 mm) subsample was taken from 10 cm after 46:55 min and the clay (<0.002 mm) subsample was taken from 5 cm after 3 h 52 min. The subsamples were dried at 105°C over night and than weighted.[109] The results needed to be mathematically corrected through dividing them by the pipette volume.

6.2.3. Beckmann-Coulter-method

Another sample´s granulometry was estimated through light diffraction using a laser diffractometer from Beckmann-Coulter. Therefore, an air-dried soil sample was cleansed of visual humus particles and dissipated with a sieve < 2mm. The remaining soil was weighted with a fine scale and defined the coarse soil. The sieved sample was filled into a cuvette, marked and placed in the Beckmann-Coulter device.

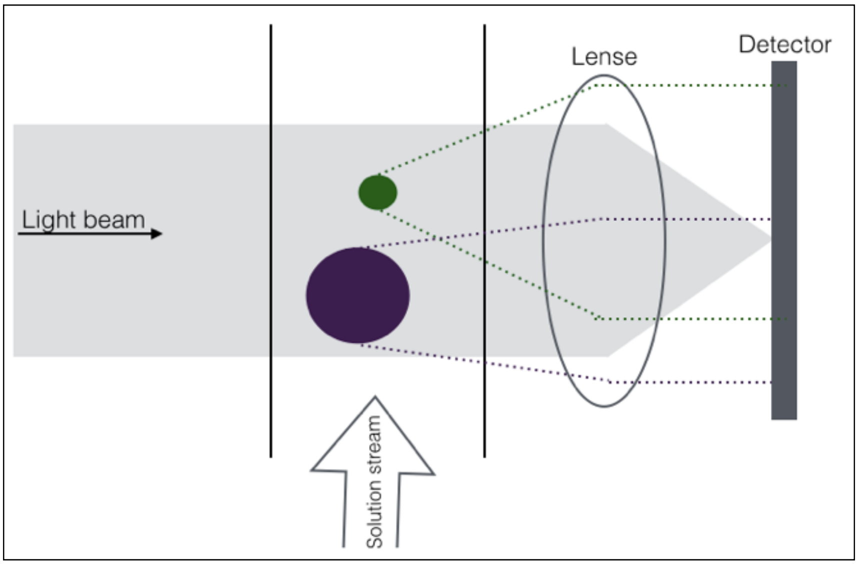

Fig. 9. Laser of the Beckmann-Coulter device is spotting at particles in the passing solution. Large particles scatter at small angles and vice versa. Their refraction is received by a detector.[110]

[109] Blume, Hans-Peter, Karl Stahr, and Peter Leinweber.(2011): 82-85.
[110] own graphic

Within the device, the sample was dissolved and the solution was spotted with a laser. The scattering angles of the particles in the solution were monitored by detectors (Fig. 9). As the scattering angle decreases with the particle size, the size of the particle spotted can be estimated. Thus a model of particle size distribution can be produced.[111] For both methods, soils were classified according to the KA5.

6.3. Pyrolysis of water hyacinth

WAHY was collected near Kitubulu Beach (0°04’58.7"N 32°29'05.8"E) on the shore of Lake Victoria. The collection process was carried out by hand. The plants picked were growing just on the water edge within the lake. Therefore, they had developed soil penetrating roots. The white roots were cut of the stem right away, as their water content was suspected to be higher[112] and carry more impurities. The harvested WAHY was weighted with a bathroom scale (± 1 kg) and 41 kg were transported to the NBD compound (Fig. 10).

To accelerate the drying process, the plants were cut into 2-4 cm long pieces using a machete and afterwards, crushed with a local kitchen scale mortar. The WAHY sludge produced that way, was spread in a thin layer on a tarp and left in the sun to dry (Fig. 11). After three days of intense sunshine, the WAHY material was brittle and dry. Its volume had noticeably decreased and its weight was now estimated at 3.2 kg.

Fig. 10. The freshly collected WAHY piled at NBD yard.[114]

Fig. 11. Mortared WAHY spread to dry.[113]

[111] Beuselinck, Laurent, et al. "Grain-size analysis by laser diffractometry: comparison with the sieve-pipette method." *Catena* 32.3-4 (1998): 195.

[112] Okoye, F. C., F. Daddy, and B. D. Ilesanmi. "The nutritive value of water hyacinth and its utilization in fish feed." *Proceedings of the International Conference on Water Hyacinth*. (2000): 67.

[113] own photo

[114] own photo

An iron stove was used for processing the WAHY material. The stove was a typical local two-chamber stove. It consisted of an ash chamber as the lowest and above that a burning chamber separated with a perforated lid. Additionally, an iron cover was used that could be mounted on top of the burning chamber, thus creating a heating chamber (Fig. 13). The stove was fueled with charcoal. It was burned in the burning chamber causing a hot upward flow, that left the heating chamber with a relatively even temperature and oxygen-depleted air.

A steel cylinder with a volume of 2,262 cm^3 was used to contain the WAHY material. Its lid was pierced with nine 2 mm holes allowing to release the pressure caused through the heating. Each of the holes however, were filled with a little wire string that had a small disk at both ends. The discs were intended to function as valves that would close the holes and thereby avoiding an influx of oxygen to the reaction, but that would move under the pressure of gases steaming out of the cylinder thus creating a steam outlet. The WAHY material was manually pressed into the cylinder, which was closed with its lid and placed in the heating chamber (Fig. 12).

The applied pyrolysis conditions had been established in a previous study from Masto et al. These conditions were established based on a stable organic matter yield index, that describes the ideal conditions to obtain a maximum WAHY-BC amount. According to this index, ideal conditions are achieved at a process temperature of 300-350 °C and a process time of 30-40 min. Less temperature or duration lead to an insufficient pyrolysis, while an increase of one of these parameters resulted in a higher combustion of the matter.[115]

The pyrolysis conditions suggested in the study were applied in a muffle furnace, that allowed a controlled, homogenous temperature level. In this thesis a simple covered stove was used, that made unwanted temperature peaks likely and an uneven heat spread probable. This led to an adaption of the suggestions with a targeted temperature at 300 °C and process time of 40 min.

The temperature in the heating chamber was surveyed through an infrared thermometer (Unit-T UT302D, ± 1.8°C). The regulation of the temperature of the charcoal stove was limited, thus the temperature of the cylinder content was in some attempts below the aimed range. In that case the cylinder would receive extra time in the heating chamber as compensation.

[115] Masto, R. Ebhin, et al. "Biochar from water hyacinth (Eichornia crassipes) and its impact on soil biological activity." *Catena* 111 (2013): 65-66.

Fig. 12. Cylinder upon the burning chamber, while the temperature in the burning chamber is checked.[116]

Fig. 13. The mounted lid creates the heating chamber.[117]

After 40 min (in some events longer, if temperature was to low) the cylinder was taken out of the heating chamber, opened and the produced material was rapidly filled into another (fully sealed) cylindrical container and submerged in a bucket of cold water to cool down quickly. This measure was supposed to prevent the hot bc from burning, after being taken out of the heating chamber and thus exposed to oxygen.

Fig. 14. Yielded WAHY-BC after cooling down.[118]

To harmonize the quality of the different draws, the yielded material was filled into a plastic barrel and firmly blended. The material is referred to as WAHY-BC in the following (Fig. 14), though it contains an undefined ash fraction as well.

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[116] own photo

[117] own photo

[118] own photo

6.4. WHC analysis of biochar treated soil samples

An orientation for the BC concentrations that should be surveyed was given in the previously referred paper. There BC concentrations of 15 g/Kg and 20 g/Kg as a soil amendment were examined.[119] These concentrations were adopted for two groups in this thesis. A concentration threshold beyond that negative effects crop growth would occur has so far not been defined and is likely to differ with soil and plant type.[120] Thus a third concentration of 30 g/Kg was chosen that could highlight a possible effect on WHC, probably without harming the plants. A fourth group was added with no BC amendment as a control group. Each concentration group was examined in six samples.

The collected soil and the WAHY-BC were blended separately for each sample. By weighing on a digital scale (accuracy ±1 g) it was ensured, that each soil-BC sample had a total weight of 2.5 kg. 24 plastic jerry cans were cut off their tops and their bottoms evenly pierced. The samples were filled into the prepared jerry cans. No further compression was applied.

The jerry cans were marked and evenly placed upon a leveled foil. The foil than was flooded with water. The water was not moving and reached a steady hight approximately 1 cm above the bottom of the jerry cans. The samples were given 4 h time to saturate with water (Fig. 15). Afterwards they were brought into a closed building that provided shadow and protection from wind. The jerry cans were lined up upon two small rails, that allowed excessive water to drain from the pierced jerry can bottom.

[119] Masto, R. Ebhin, et al. (2013): 65.

[120] Biederman, Lori A., and W. Stanley Harpole. "Biochar and its effects on plant productivity and nutrient cycling: a meta-analysis." *GCB bioenergy* 5.2 (2013): 207.

Fig. 15. Soil samples being saturated with water[121]

Fig. 16. After two days the samples are weighed (right section: remaining samples standing on rails)[122]

According to the previous explanation of WHC, soil water that is held for 2-3 days against gravity defines the WHC of a soil.[123] Consequently the samples remained undisturbed for 2 days and were weighed again on a digital scale (Fig. 16). The difference of the initial weight of the air-dried sample and the weight of the sample at WHC was estimated. Distinctions in the weight at WHC between the four groups would state an effect.

7. Results

In this chapter the results of the methods explained in the previous chapter are presented. The outcome of the soil analysis is given and the soil can be assigned to a soil type. The two analyzing methods show variations in the determined grain size fractions, which are highlighted. Secondly the quantities of the produced WAHY-BC are discussed. For further implementation correlations between the obtained BC amount and the process conditions are important, thus they are mentioned here. The chapter closes with the results of the gravimetric examination of the soil samples. The alterations in WHC in relation to their BC amendment are presented.

121 own photo

122 own photo

123 Schachtschabel, Paul et al. (1998): 202 (own translation).

7.1. Characteristics of the Ferralsol soil sample

The soil samples underwent sieving and sedimentation in application of the Köhn-method and were surveyed with a laser diffractometer (Beckmann-Coulter) to determine its different grain fractions. The results of the specific grain size fractions are presented in a granulometry in Tab.17 below:

Nakiwogo sample		Coulter 1	Coulter 2	Köhn 1	Köhn 2
Sand	coarse [%]	8,3	7,9	5,01	6,3
	medium [%]	18,8	19,7	6,4	19,1
	fine [%]	15,5	16,6	39,8	41,7
Silt	coarse [%]	12	11	7,3	–
	medium [%]	27,9	26,4	2,7	–
	fine [%]	14,8	15,4	10,9	–
Clay	[%]	2,8	3	27,8	–
Clay	[%]	3	3	27,8	–
Silt	[%]	54,7	52,8	20,9	–
Sand	[%]	42,6	44,2	51,2	67,1
Soil type		Us	Us	Lts	–

Tab. 17. Granulometry of examined soil samples

The Beckmann-Coulter data show a silt content above 50 % and a sand content above 40 % while the clay content is dwindling small. From such a characteristic granulometry its soil type can be classified as a sandy silt (Us). The samples deviation is below 1.6 % for each fraction.

A diverging picture is presented by the Köhn data. With a dominant sand fraction above 50 %, but a coequal silt (27 %) and clay (20 %) fraction it shows a more balanced characteristic, that refers to the \`clayish-sandy silt´(Lts) soil type.

The Köhn 2 sample was found to have irregularities in the sedimentation data. Consequently these data were not used. However the sieving data of this sample (representing the sand fractions) was not compromised and thus used for interpretation. Comparing the sand fractions of Köhn 1 and Köhn 2, the difference within the coarse and fine sand fraction is both below 2 % which is acceptable. The deviation of the medium sand fraction however showed a considerable difference of 12.7 %. Such a high difference of a fraction could question the liability of the Köhn samples.

Next the Beckmann-Coulter data were compared with the Köhn data. For a better understanding a grain size curve is generated from the table, adding up the fractions percentages (Fig. 18).

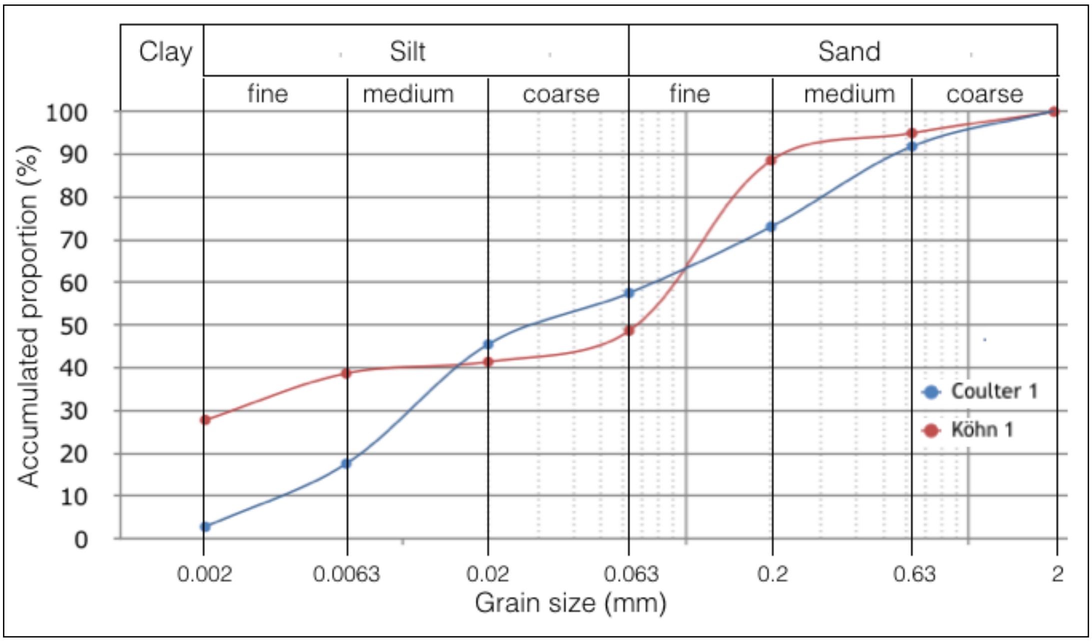

Fig. 18. Grain size curve of the Köhn 1 and Coulter 1 data showing their accumulated proportion of each fraction.

The Beckmann-Coulter samples showed little deviation, thus the Coulter 1 sample was chosen, to represent the methods data. There was just one Köhn sample to be used, representing the Köhn data as the other sample was incomplete. The standard deviation of the Coulter 1 data and the Köhn 1 data was estimated at a notable 8.5.

Most obvious is the difference of the clay and the medium silt fractions.
Regarding the clay fractions the Coulter samples shows a very low content of 3 %, while the content of the Köhn sample is nearly ten times bigger. In the medium silt fraction this circumstance seems reversed, as that fraction in the Köhn 1 data makes up only 2.7 % but is above 26 % in both Coulter data.

Another deviation is found in the fine sand and medium sand fraction. While the Coulter samples show relatively even values for both fractions, both Köhn sample show a sharp increase from medium to fine Sand. Such substantial variabilities in the data are unlikely to appear within one soil sample and moreover indicate a variation caused by the different measurement methods.

7.2. Biochar yield

For the pyrolysis of the WAHY the ideal conditions postulated in the quoted paper were emulated.[124] 15 draws were needed to process all of the dried WAHY material. Each draw varied in process duration, exposed temperature, starting matter and achieved yield. In Table 19 the parameters for each draw are displayed.

Draw	Matter in cylinder before pyrolysis (g)	Obtained amount (g)	Matter/yield ratio	Process duration (min)	Min temperatur (°C)	Max temperature (°C)	Midpoint temperature (°C)
1	153	57	0,37	40	200	360	280
2	154	73	0,47	30	300	350	325
3	183	46	0,25	45	265	390	327,5
4	176	109	0,62	30	260	410	335
5	226	110	0,49	46	220	340	280
6	220	122	0,55	40	305	420	362,5
7	223	115	0,52	40	290	403	346,5
8	219	116	0,53	46	270	450	360
9	227	137	0,60	51	200	350	275
10	227	133	0,59	50	167	280	223,5
11	221	115	0,52	44	320	410	365
12	219	116	0,53	39	310	415	362,5
13	243	122	0,50	46	210	301	255,5
14	261	141	0,54	48	250	480	365
15	262	136	0,52	50	310	420	365
Total	3214	1648	0,51				

Tab. 19. The determining conditions of the pyrolysis process -duration and temperature- and the yielded amount of WAHY-BC were listed for each draw. It shows a high variability for both parameters, a conclusion about their effects on the yield is not obvious. Apart from some outliers the yielded amount is relatively stable at half times the WAHY matter.

It was attempted to maintain the aimed temperature range of 300-350 °C, though controlling the temperature of the stove was delayed and not precise. It is notable that the temperature in most draws would vary about more than 100°C, draw 14 even showed a variation of 230°C. All of the draws reached the targeted temperature range as the max. temp column shows. Though maximum temperature exceeded the targeted 350°C in ten of the draws. 480°C was the highest temperature that a draw was exposed to. It needs to be noted, that the actual temperature range usually oscillated around the aimed temperature range. Unfortunately this fact could not be displayed more adequately.

The duration of the process was easier to control. 40 min was the aimed process time as it was suggested in the mentioned paper. If the aimed temperature was not achieved in a draw, the process time was prolonged for 10-15 min.

[124] Masto, R. Ebhin, et al. (2013): 65-66.

That also was the case if the produced material had by visual check obviously not fully pyrolysed. A prolonged process time was needed for five draws.

The vast of the obtained material had fibrous structure similar to the source material. It was stable when touched by hand, but cracked when it was flexed. It was of anthracite color and had a slight oily gleam. There was also a little dusty material in light grey mostly on the bottom of the cylinder. It is supposed that this was the visual ash content. When the anthracite matter had cooled down and was lit, it caught fire. This was an expectable reaction for produced BC, as ash wouldn't burn. The physical and chemical characteristics could not be analyzed with the available devices.

Within 15 draws 3,214 g of air-dried WAHY was processed into 1,648 g pyrolysed material. This results in a conversion ratio of 0.51. Standard deviation is at a low 0.09 but there are few low and high extremes (draw 4 at 0.62 and draw 3 at 0.25). There are no correlations found between process duration, max temperature and conversion ratios (Fig. 20). Neither the correlation coefficient nor the coefficient of determination show a relationship between these parameters.

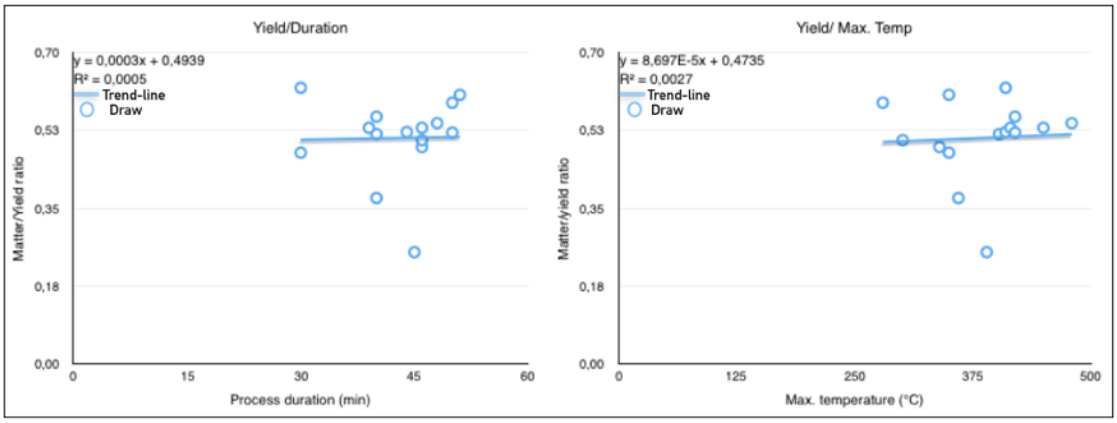

Fig. 20. The Matter/Yield ratio was examined on its dependency to the process duration (left diagram) and maximum temperature (right diagram). The scattered values show no obvious correlation neither do the derived correlation coefficients.

7.3. Effects on biochar treated soil samples

The six samples of each WAHY-BC concentration group had first been saturated with water and than were left for two days to discharge excess water. This state is thought to define the WHC of the soil. Gravimetric differences between the groups should allow conclusions about an altered WHC.

The weight for each sample before water saturation and its weight after two days was estimated. The difference of both defines the amount of water that is withhold by the soil at WHC. To clarify these results the retained water was converted for soil amounts of 100 g and presented in Table 21.

Sample	WAHY-BC content (g/kg)	Weight, air-dried (g)	Weight at WHC (g)	Weight difference (g)	Water retained per 100g soil at WHC (g)	Group average of retained water (g)	Ratio of retained water control/trial
I.a	0	2501	3275	774	30,9		
I.b	0	2500	3305	805	32,2		
I.c	0	2501	3371	870	34,8		
I.d	0	2499	3354	855	34,2		
I.e	0	2501	3376	875	35,0		
I.f	0	2500	3354	854	34,2	33,5	1,00
II.a	15	2500	3436	936	37,4		
II.b	15	2500	3397	897	35,9		
II.c	15	2499	3395	896	35,9		
II.d	15	2501	3484	983	39,3		
II.e	15	2499	3421	922	36,9		
II.f	15	2499	3450	951	38,1	37,2	1,11
III.a	20	2498	3424	926	37,1		
III.b	20	2502	3463	961	38,4		
III.c	20	2498	3450	952	38,1		
III.d	20	2497	3452	955	38,2		
III.e	20	2497	3429	932	37,3		
III.f	20	2504	3532	1028	41,1	38,4	1,14
IV.a	30	2501	3559	1058	42,3		
IV.b	30	2502	3497	995	39,8		
IV.c	30	2497	3518	1021	40,9		
IV.d	30	2499	3625	1126	45,1		
IV.e	30	2499	3578	1079	43,2		
IV.f	30	2502	3575	1073	42,9	42,3	1,26

Tab. 21. The weight difference before and at WHC for each soil sample were listed and con verted to 100 g. The average weight increase for each BC enriched group were than related to the average of the control group.

The results in the control group show an average WHC* of 33.5 g, with a range of 4 g. Therefore the values are very similar which is strengthened by the low deviation 1.5 g. In the group of 15 g/Kg BC amendment values show an even lower standard deviation of 1.2 g within a range of 3.4 g. The average value is 37.2 g which is recognizable higher than the control group. As there are no overlapping values, both groups show a sharp distinction. An overlapping however does occur among the 15 g/Kg BC and 20 g/Kg BC group. Five values of the 20 g/Kg BC samples are within the range of the 15 g/Kg BC samples. Reconsidering that both groups differ just in 5 g/Kg of BC amendment makes that comprehendible.

* WHC expressed as the weight of water hold at WHC

Still an increase of the average WHC to 38,4 g of the 20 g/Kg BC group is shown with an also low range and a low standard deviation. With the 30 g/Kg BC amendment the highest average WHC was achieved at 42.3 g. Values of this group differ the most which is shown in its range of 5.3 g and a standard deviation of 1.7 g. In figure 22 it becomes obvious, that although there is an overlapping of two values with the 20 g/Kg group, the 30 g/Kg group is notably detached from the other groups.

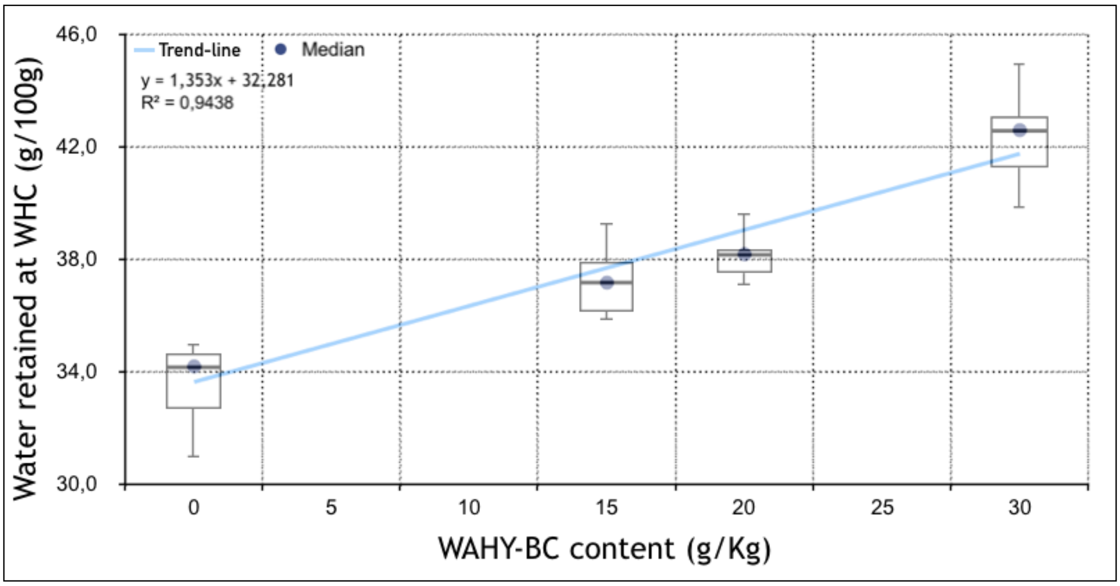

Fig. 22. The distribution of retained water at WHC can clearly be associated to the different WAHY-BC content groups, although an overlapping of values occurs. A linear correlation between BC content and WHC is visible through the trend-line.

For the water content at WHC of all samples and their related WAHY-BC content the correlation was calculated. The resulting r = 0.9 refers to a very close linear correlation between both measures. In the chart this is underlined by the positive trend line and the derived determination coefficient of 0.94.

A ratio of WAHY-BC content and WHC increase was derived. Therefore the average WHC of the control group was set as the base value and the average WHC of the other groups were related to it. Thus an increased WHC of 11 % occurs with a WAHY-BC amendment of 15 g/Kg. For an 20 g/Kg BC amendment WHC increased by 14 % BC and with a 30 g/Kg BC amendment WHC increases by 26 %.

8. Discussion

This chapter will discuss the uncertainties that arose out of the assumptions made in this thesis. Such as the decision to survey an Entebbe soil sample instead of a Butare soil sample. Also questions that emerged with the outcome of the examination process, like the differences in grain size estimation. For the quality of the yielded BC, which cannot be sufficiently explained suggestions for further investigation are given. Furthermore its relevance for a perspective implementation, regarding to its value for plant growth and economic feasability will be discussed.

8.1. Comparability of Entebbe and Butare soils

The results of this thesis could be of worth for a broader implementation in the drought-prone Butare area, rather than in a humid climate like Entebbe. Consequently a survey of Butare soils, would have been the most favorable but wasn't feasible due to logistical reasons. A survey of an Entebbe soil on the contrary was feasible.

The assumption that the characteristics of both soils are similar must be seen critical. The conditions influencing the genesis of these soils are likely to differ, in consideration of a 575 km distance between them. The most considerable difference among the conditions is the climate. While in Butare the annual precipitation is 1147 mm accumulated in two rainy seasons, Entebbe receives 1561 mm in a constant humid climate. Water is an important factor both for physical and chemical erosion.

Still, the source rock that both soils have generated from, are similar to each other. The soil classification system, that distinguishes soils according to their characteristics, classifies Butare soils and the Entebbe soil into the same group. Both are ferralsol soils. Since this thesis is primarily surveying an effect on ***a*** ferralsol soil, the geographical definition is less important.

8.2. Differences in granulometry survey

In the granulometry survey considerable differences in clay and medium silt contents were noted between the Köhn and the Beckmann-Coulter method. An explanation for this phenomenon can be found in the particle shape.

In the laser diffractometer unevenly shaped particles can produce a scattering angle that does not correspond with their equivalent diameter. Clay particles tend to stream through the Beckman-Coulter device with their flat side towards the laser as this creates the least water resistance. Thus they can imitate a falsely higher silt content, while they simultaneously escape an attribution to the clay fraction.
The sedimentation survey of the Köhn sample on the other hand was potentially deceived by fan-shaped silt particles. These sediment slower and thereby imitate a higher clay content.

Another remarkable deviation is the high fine sand fraction in the Köhn 1 data and low medium sand fraction compared to the Beckmann-Coulter samples. This can be explained by the mortaring of the Köhn sample prior the sieving. The mortaring implies the risk of producing smaller particles that would not be there naturally.

Some fractions show extreme differences, nevertheless the standard deviation of 5.2 % is relatively moderate. However the deviation leads to a different soil categorizations. This might not be unusual in light of the different survey methods that have been used and thus the reasons for the main deviations can be explained. Still, the results stay dissatisfying imprecise. By applying an additional survey method, for example the planimetric analysis, and comparing it with the previous methods, a more certain statement about grain fractions would be possible.

Nevertheless, both resulting soil types derived from the grain size curve (sandy silt, clayish-sandy silt) would benefit from an BC amendment. Unchanged or reduced WHC after BC enrichment are highly related to clay soils. The highest evaluated clay content in this survey was 27.8 % in the Köhn 1 sample and an increase in WHC was evident. Thus it can be concluded, that for a ferralsol with a smaller clay content, an increase in WHC will occur at the suggested WAHY-BC concentrations.

8.3. Biochar characteristics

Considering the yielded WAHY-BC it is noteworthy, that although the pyrolysis conditions were difficult to control, the resulting matter/yield ratios are surprisingly similar among the different draws. Yet, the physical and chemical characteristics of the WAHY-BC stay uncertain as a more elaborated survey of the BC was not feasible within the frame of this thesis. Different manifestations in porosity, average particle size, hydrophilicity and ash content do affect the effect of BC on soil, such as WHC.

With a further survey, using an electron-scanning microscope for clarifying porosity and particle size and a contact angle measuring instrument to estimate hydrophilicity, a deeper understanding of the WAHY-BC properties could be achieved.

8.4. Inconsistent bulk density

As the jerry cans were filled manually, variations in the bulk density could not be prevented. Bulk density is a defining parameter for soil WHC and thus effects on the latter would have been possible. Nevertheless all of the samples show a strong resemblance within their group and their standard deviation is low. Therefore differences in bulk density are supposed to not have interfered relevantly.

8.5. Assessment of the WHC

The gravimetric assessment was executed with a rather simple method, thus measurement errors are expected to be unlikely. The starting conditions for all samples were similar and distorting effects during the experiment (like higher evaporation by sun/wind exposure) could be excluded as far possible.

Previous its saturation the soil sample was dried through an three days exposure to the equatorial sun. Thus some moisture might have remained within the soil particles and interfered the survey. But the deviation of the increased WHC for each group and the range of group values are low. And the continuously rising average WHC shows a clear correlation to the amended WAHY-BC content. Summarizing this suggests a high validity of the results.

8.6. Value for vegetation

Even with an increased WHC it is not certain how much plants could benefit from this larger water content. The plant-available content of the soil water is a results of the WHC minus the permanent wilting point. This wilting point is assumed, where the suction force of the soil particles surpasses the suction of the plants. Alterations of the permanent wilting point, that may have been caused by the WAHY-BC amendment were not surveyed in this thesis. By estimating the wilting point with a tensiometer the plant available water could be clarified.

It is known that BC has a broad range of effects on soil chemistry, physics and biota. How and to which extend this particular WAHY-BC interferes with other soil parameters has not been investigated, though this is of importance for crop growth. Further elaborated surveys could be executed to examine the alteration of individual soil properties. Or alternatively further trials with seeds or seedlings with the suggested WAHY-BC concentrations could serve as a direct and cost-efficient way to explore the impacts on plants.

8.7. Economical perspective

The process effectiveness of converting 41 kg of fresh WAHY into 1.65 kg of BC is extremely low. It needs to be examined whether the benefits a farmers could gain from an increased WHC exceeds the expenses of producing WAHY-BC. The great advantages for WAHY-BC in such a feasibility study would be, that the feedstock comes at no charge and that the process techniques (collecting WH, pyrolysis and spreading on the field) require minimal knowledge and little specialized equipment. As the utilization of WH is tackling an environmental concern, which affects whole communities, possible public subsidies might also be taken into account.

Propagating the use of WAHY-BC could also lead to an increased awareness of WAHYs value as a resource for other purposes. The utilizations as a fodder plant or for weaving have been mentioned, but are still hardly common in infested areas. WAHY-BC might even serve as a possible substitute for wooden charcoal. The heat effectiveness is comparably low, but that might be exceeded by a high disposability of WAHY and the lack of wooden feedstock.

It should also be noted that BC amendments to soils are heavily discussed as a possible measure to store atmospheric carbon for centuries and thereby counter global climate change.

9. Conclusion

This thesis was investigating a measure to increase the WHC of a drought-prone soil, that is proximate to WAHY infested waterbodies. An area that is subject to these conditions was found around the town of Butare. However, the ferralsol soil that is local there, was not possible to be surveyed. Thus a ferralsol soil of the Entebbe area was investigated. With a rather simple pyrolysis method WAHY was converted to WAHY-BC.

The gained WAHY-BC was amended to the ferralsol soil in varying concentrations (15, 20, 30 g/Kg). Using a gravimetric measurement its effects on WHC were examined to answer the research question, whether WAHY-BC can efficiently increase the WHC of a ferralsol soil. For the surveyed concentrations an average increase in 11 %, respectively 14% and 26 % was estimated. A truly noteworthy degree of WHC increase considering the little amount added.

Yet, uncertainties remain, regarding the quality of the produced BC and -more delicate- for the exact grain fractions of the used ferralsol sample. Both are important interacting factors that determine an alteration in WHC. The validity of the outcome would be improved by a specification of those two. But regarding the given uncertainties in grain size a positive effect on WHC can be assumed for ferralsols with a clay content below 27%.

Further evaluations are needed on how WAHY-BC will support crop growth, but examples given in literature are promising. As higher WAHY-BC concentrations correlate with higher WHC, the evaluation should simultaneously estimate the highest WAHY-BC concentration, that is not negatively affecting plant growth. Thus its application could gain strong relevance for drought-prone soils like those in the Butare area. It could implicate a prolonged availability of soil water and thus an increase in food security - a sustainable development goal declared by the UN. The majority of inhabitants in the Butare area depend on agriculture. If they would benefit from the measure, a more stable economic foundation could be created.
Even though the efficiency of the WAHY-BC production has shown to be low, it was demonstrated that WAHY can be used as a possible feedstock. On the one hand this could relieve other stressed natural resources like wood and on the other hand it could create an incentive to yield the plant and thereby clearing it from the waterbodies. Resulting in positive effects on stressed subsequent ecological and economic systems.

The auspicious potential that WAHY-BC proved for increasing the WHC of a ferralsol soil is truly remarkable and could represent an important benefit for drought-prone areas. Additionally several positive side effects on other soil properties and through WAHY reduction in the proximate waterbodies can be expected. However, a successful implementation of the suggested measure will at last depend on whether its combined benefits outweigh its low production efficiency.

Declaration of originality

I hereby declare, that I have composed this paper by myself and without any asis-tance other than the sources given in my list of works cited. All direct quotes as well as indirect quotes which in phrasing or original idea have been taken from a different text (written or otherwise) have been marked as such clearly and in each single instance under a precise specification of the source. That also applies to fig-ures, photos and internet sources.

Thomas Betzold Berlin, 18.08.2018

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