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Faculty of Tropical AgriSciences

Biochar for agriculture and energy

BACHELOR'S THESIS

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Author: Kseniia Paramonova

Chief supervisor: Ing. Tatiana Ivanova, Ph.D.

Declaration

I hereby declare that this Thesis entitled “Biochar for agriculture and energy” is my own work and all the sources have been quoted and acknowledged by means of complete references.

In Prague 20.4.2018 ……………………………………

Kseniia Paramonova

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Abstract

Infertility of soils occurs worldwide. Soils are diversified and there are several factors of their infertility such as low organic carbon content, high turnover rates of organic matter or contamination, etc. Along with global climate change and energy crisis nowadays, there is an effort for widespread use of effective sustainable technologies. One of the promising solutions is biochar application in agriculture and alternative energy. The modern biochar concept was drawn from the *Terra Preta de Indio* concept. Biomass converted to biochar has unique characteristics. Due to these characteristics, the benefits of biochar usage are multiple: soil improvement, climate change mitigation and production of bioenergy, and it has a great potential in both developing and developed countries. Research in the field of biochar production and application has increased significantly in the recent years.

This Bachelor Thesis entitled "Biochar for agriculture and energy" was written in the form of literature review based on search and analysis of information from scientific articles obtained from the well-known professional journals. The present Thesis summarizes information about biochar applications in sustainable agriculture as an important contributor to soil health and productivity as well as in bioenergy. The origin of biochar and the main biochar production technology such as slow pyrolysis were described. Various pyrolysis parameters and different types of a feedstock were analyzed and in addition their influence on some biochar's properties was mentioned. The environmental impacts of biochar usage in agriculture and renewable energy sector has commonly got positive nature. Environmental performances are reviewed and evaluated, including carbon sequestration, reduction of greenhouse gases emissions and agricultural waste management. On the other hand, some environmental risks exist and they have been discussed, too.

Keywords: pyrolysis, terra preta, biomass, sustainable farming, bioenergy

Abstrakt

Neúrodnost půdy je celosvětový problém. Půdy jsou různorodé a existuje několik faktorů jejich neúrodnosti, jako je nízký obsah organického uhlíku, vysoká míra obratu organické hmoty nebo kontaminace atd. Spolu s globálními změnami klimatu a energetickou krizí je v současné době snaha o rozsáhlé využívání účinných udržitelných technologií. Jedním ze slibných řešení je aplikace biouhlu v zemědělství a alternativní energii. Moderní koncept biouhlu byl vyvozen z konceptu *Terra Preta de Indio*. Biomasa převedená na biouhel má jedinečné vlastnosti. Vzhledem k těmto vlastnostem jsou přínosy využívání biouhlu mnohonásobné: zlepšení půdy, zmírňování změny klimatu a výroba bioenergie a zároveň má velký potenciál jak v rozvojových, tak v rozvinutých zemích. Výzkum v oblasti výroby a použití biouhlu se v posledních letech významně zvýšil.

Tato bakalářská práce s názvem "Biouhel pro zemědělství a energetiku" byla sepsána formou rešerše literatury založené na vyhledávání a analýze informací z vědeckých článků získaných od známých odborných časopisů. Práce shrnuje informace o aplikaci biuhlu v udržitelném zemědělství, kde významně přispívá ke zdraví a produktivitě půdy, stejně jako v oblasti bioenergie. Byl popsán původ biuhlu a hlavní technologie výroby biosystémů - pomalá pyrolýza. Byly zanalyzovány různé parametry pyrolýzy a různé typy surovin a kromě toho byl zmíněn jejich vliv na některé vlastnosti biouhlu. Environmentální dopady využití biouhlu v odvětví zemědělství a obnovitelných zdrojů mají obecně pozitivní charakter. Environmentální výkonnosti byly přezkoumány a vyhodnoceny, včetně sekvestrace uhlíku, snižování emisí skleníkových plynů a hospodaření se zemědělskými odpady. Na druhé straně existují některá rizika pro životní prostředí, jenž byly v práci také prodiskutovány.

Klíčová slova: pyrolýza, terra preta, biomasa, udržitelné zemědělství, bioenergie

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1. Introduction

Nowadays the major global challenges are degrading soil quality and productivity. These processes are exacerbated by climate change and improper management practices (Peter 2018). In addition, a primary contributor to atmospheric greenhouse gases is agriculture (Qambrani et al. 2017).

Biochar is a value-added product, which can be used for many purposes (Lee et al. 2013). When biomass is converted into biochar and it is applied to a soil, carbon can to be drawn from the atmosphere and can be stored for more than 1,000 years. It is a solution for diminishing the global impact of farming (Brassard et al. 2017). Biochar application in agriculture may have a significant effect on reducing global warming. At the same time, biochar can help to improve soil health and fertility as well as to enhance agricultural production (Qambrani et al. 2017).

The efficiency of biochar produced from biomass is highly depended on production parameters. Type and composition of feedstock, the pyrolysis temperature, heating rate, biomass particle size and reactor conditions are influencing the biochar properties (Qambrani et al. 2017). There are variabilities in physicochemical properties of biochar such as surface area, microporosity and pH. This feature provides avenue field for biochar to maximize its effectiveness to targeted applications (Oliveira et al. 2017).

The biochar addition to soil is virtually irreversible. Therefore, it is important to have a comprehensive understanding of how biochar interacts with a soil in a long term before the wide-scale application of biochar to soils is exploited (Lone et al. 2015, Brassard 2016).

According to Wang et al. (2017) faster development of bioenergy has been hindered by drawbacks of biomass properties (such as low bulk density, poor grindability, high moisture content and relatively low calorific value). Torrefaction (or mild pyrolysis) is an efficient way to upgrade biomass into high quality solid fuel. It is a promising technology for converting a range of biomass into renewable energy. Torrefied biomass is characterized as a homogenous solid fuel with higher carbon content and energy, and lower hygroscopicity than the raw biomass (Roy & Dias 2017, da Silva et al. 2018).

According to Scholz et al. (2014) a dedicated research on biochar started in the late 1990s (apart from some notable early research before 1950). In recent years the number of publications has accelerated. In the last decades the leading researcher in the field is Cornell University (New York, USA), namely soil scientist Johannes Lehmann (Lone et al. 2015).

The present Thesis provides description and summarization of potential benefits of biochar application in sustainable agriculture and bioenergy production.

2. The aim of the Thesis

The aim of this Thesis was to summarize scientific information about biochar usage in sustainable agriculture and bioenergy with a focus on description of biochar's parameters, its impact on soil health and productivity as well as analysis of the main biochar production technologies taking into account different feedstock. The specific aim of the work was also to highlight environmental impacts of biochar production and utilization such as carbon sequestration, organic waste management and life cycle assessment of biochar fuel.

3. Methods

The present Thesis was compiled as a literature review (consisting of three main chapters: Characteristics and production of biochar, Agriculture and Bioenergy) based on scientific articles.

The Thesis was elaborated according to the manual of the Faculty of Tropical AgriSciences for writing Bachelor`s Thesis and all literature is cited in by the mandatory rules of the Faculty.

Literature review preparation was based on searching articles from web databases like EBSCO Discovery service, Google Scholar, Web of Knowledge. The journals referenced in the present work were: Pedosphere, Bioresource Technology, Renewable and Sustainable Energy Reviews and others. The search for scientific information was done by the key words: pyrolysis, terra preta, biomass, sustainable farming, bioenergy, etc.

The information obtained was processed and analyzed.

4. Literature review

4.1. Characteristics and production of biochar

4.1.1. Anthropogenic dark earths

Interest in a biomass-derived black carbon (material, nowadays called biochar) and its application was prompted by studies of soils found in the Amazon Basin, referred to as *Terra Preta de Indio* (Lehmann & Rondon 2006).

On the global level tropical rainforests are very important for climate regulation and biodiversity. These ecosystems are characterized by nutrient-poor and highly weathered soils. In addition, there are high turnover rates of organic matter and they are prone to loss of ecosystem services when anthropogenically disturbed (the major threat is deforestation resulting in irreversible loss of rainforests). Thus, currently tropical rainforests are very vulnerable. Surprisingly, small patches of highly fertile soils were discovered within these ecosystems. These soils are known as **anthropogenic dark earths (ADEs)** (Glaser & Birk 2012). According to Barrow (2012) synonyms are: anthropogenic black earths, black carbon soils, anthrosols. Generally, scholars use terms such as Amazonian dark earths (Barrow 2012), *terra preta de I´ndio* (Indian black earth) (Lima et al. 2012), *terra preta* (Glaser et al. 2001) or *terras pretas* (Arroyo-Kalin 2010). *Terra preta* is the most known term.

According to Fraser et al. (2011) ADEs were found at archaeological sites throughout the Amazon basin. Their formation is a result of Amerindian settlements in the pre-Columbian period (2,000–500 BP). That is the product of inorganic amendments such as ash, bones (especially fish) and organic amendments such as biomass wastes, manure, excrements, urine and biochar to infertile Ferralsols (Glaser & Birk 2012). It is worth to remark that depending on soil classification, this type of soil can be classified as Oxisols. According to Lima et al. (2012) the *Terra Preta* Anthrosols of Amazonia are mainly Oxisols, Ultisols and Inceptisols with an anthropic horizon.

The enhanced fertility of *terra preta* soils is signified by higher levels of soil organic matter, nutrient holding capacity, and nutrients such as nitrogen (N), phosphorus (P), calcium (Ca) and potassium (K), higher pH values and higher moisture-holding capacity than in the surrounding soils (Glaser et al. 2001). Illustration of Terra Preta and Oxisol profiles is presented in the Figure 1.

Figure 1. Typical profiles of 'Terra Preta' (left) and Oxisol (right) sites

Source: Glaser et al. (2001)

The pyrogenic carbon present in ADE was named "black carbon", because there is no knowledge that the pre-Columbian natives had the intention of soil amelioration (generally, the term "biochar" is used as meaning "pyrolyzed biomass prepared specifically for soil improvement") (Lucheta et al. 2017).

Soil types with anthropological biochar addition have occurred in different soils and climates and these findings arouse great interest. For example, the European Plaggen soil demonstrates *Terra Preta*-like characteristics (the highly fertile nutrient status of P and Ca in this soil has been attributed to carbonised particles (biochar) present due to anthropogenic activity).

In Australia, the pre-European Aboriginal inhabitants in nomadic camps above the flood zone of the Murray River were using earthen ovens to cook food (at the same time as the pre-Columbian Indians were using ovens in the Amazon). Cumulic Anthroposols exist in Australia and exhibit all the features typical to *Terra Preta* soils. These *Terra Preta Australis* soils have been created via anthropological addition of charred organics (biochar) to the soil hundreds of years ago but in a temperate climate with low rainfall. Australian agricultural soils are suitable precursors of *Terra Preta* formation (Downie et al. 2011). Another excellent example of an existence of anthropogenic dark earth beyond the humid tropics with favorable properties is the Nordic Dark Earth (Wiedner et al. 2015).

In last decades, the *Terra Preta* phenomenon has gained increasing interest. It is assumed that *Terra Preta* could act as a model for promoting sustainable agricultural practices in the humid tropics and for other soils which exhibit a low nutrient holding capacity (Glaser & Birk 2012).

Brazil is a pioneer in a research on ADEs and 'new ADE' (locally known as *Terra Preta Nova*, which is the (re)creation of ADE), a well-known actor in biochar research and also the world's largest producer of charcoal (Rittl et al. 2015).
As it can be seen from the above, new instances of traditional practice using biochar are still being discovered around the world (Scholz et al. 2014).

4.1.2. Specification of the term biochar

It is important to emphasize that biochar it is not one homogenous material. Biochar can be produced from almost as many types of feedstock as there are types of biomass. It can be created over a wide range of temperatures and time. And thus it could be applied to a diversity of soil types (Scholz et al. 2014). Further all these aspects will be described.

In general, according to International Biochar Initiative (IBI, 2018) biochar is defined as "*a solid material obtained from the carbonization thermochemical conversion of biomass in an oxygen-limited environments*".

This definition of biochar will be used for the purposes of this Thesis.

Biochar is distinguished from charcoal by the fact that biochar is produced with the prior intent to be applied to soil (for improving soil productivity or carbon storage or both).

The array of feedstocks for biochar is much broader than for wood charcoal used as fuel. In principle, biochar can be made from any type of biomass (Scholz et al. 2014).

4.1.3. Feedstock for biochar production

As a general matter, biochar production and following application are provided in a sustainable way. Adoption of biochar management does not require new resources. There is a unique opportunity to improve soil fertility and produce bioenergy using locally available and renewable materials as a feedstock. In resource-constrained agroecosystems biomass and organic residues can be convert into biochar (Lehmann & Joseph 2009). Pyrolysis systems operate at different scales and require different amounts and sources of biomass (Scholz et al. 2014). According to Akolgo et al. (2018) the suitability of each type of biomass as feedstock for biochar production and soil application is dependent on its chemical composition, thermal process and agro-system involved, economic and logistical factors.

The majority of the biomass is the woody biomass which includes stem, branch, leaves, bark, lumps, chips of different trees like pines, spruces, oaks, maples, redwoods and larches, etc. Agricultural biomass is the next source of biomass which comprises a wide range of different agricultural crops. Stalks, straw, shells of these crops are used as biomass. Other than these different parts of various plants, flowers, grass can also be used as biomass (Tripathi et al., 2016).

Lignocellulosic biomass is typically composed of three main components: cellulose, hemicellulose and lignin (Figure 2) (Dhyani & Bhaskar 2017).

Cellulose and hemicellulose contribute to the bio-oil production yield. Lignin yields larger proportion of solid char (Kan et al. 2016).

Other typical components of lignocellulosic biomass are grouped as extractives and minerals. Extractives are generally smaller organic molecules or polymers like proteins, acids, salts. Minerals are inorganic compounds like alkali metals mainly K, Ca, P, sodium (Na), silicon (Si) and magnesium (Mg) and also chlorine (Cl) in herbaceous biomass (Sharma et al. 2015).

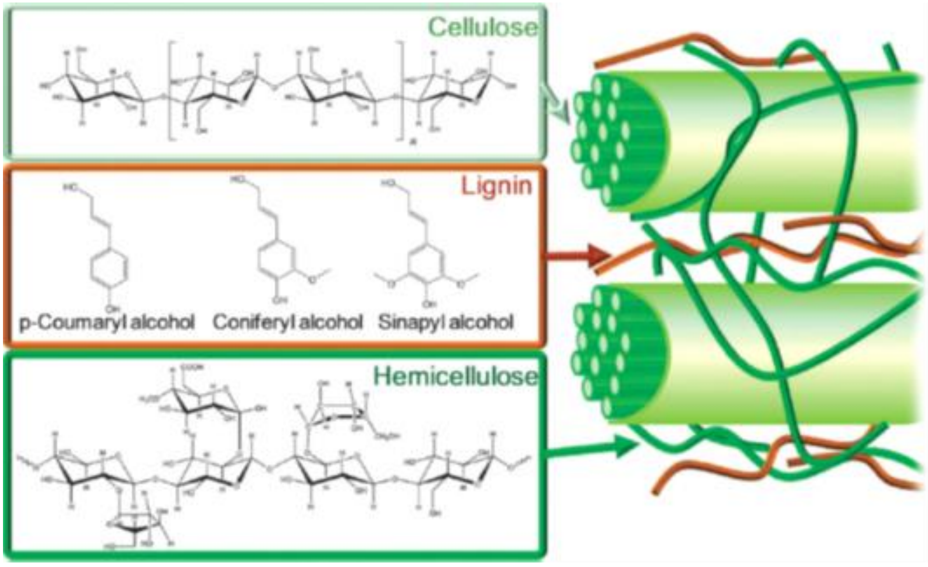

Figure 2. Structural representation of lignocellulosic biomass with cellulose, hemicellulose and building blocks of lignin

Source: Kambo & Dutta (2015)

The chemical composition of the lignocellulosic biomass is variable. Factors inherent to the material itself as follows: species, age and position on the stem of the plant, apart from the soil and climatic conditions and management to which they were subjected during their growth (da Silva et al. 2018).

Besides the plants and their derivatives, biomass can be also **non-lignocellulosic** (NLBM). Components mainly include proteins, lipids, saccharides, inorganics as well as a fraction of lignin and cellulose. Compared with lignocellulosic biomass, the NLBM has a greater threat for the environment because of its higher contents of heavy metals and heteroatoms like N, P and sulfur (S) (Li & Jiang 2017).

Seaweeds are novel feedstock for biochar production. They can be sourced from ocean farms, land-based cultivation or from seaweed blooms that occur in eutrophic waters ("green tide"). The conversion of green tide biomass into biochar can help to reduce the volume of a material to be removed from coastal areas and use nuisance biomass in sustainable way; for instance, green seaweeds from the genus *Ulva* which are highly promising for biochar production. It is a bloom forming seaweed that is an issue in eutrophic water bodies (mostly famous along the Shandong coast in China and in Brittany, France). This green tide represents a significant resource of feedstock. Biochar produced from seaweed has a lower carbon content (~30-35%) than biochar which is produced from lignocellulosic biomass (typically >70%), but high concentrations of exchangeable trace elements and macro-nutrients (N, P, Ca, Mg, K, zinc (Zn) and molybdenum (Mo). In this way seaweed biochar is effective particularly in low fertility soil (Roberts & de Nys 2016).

In recent years the research works have been performed in a field of reusing solid digestate as a potential feedstock for preparing biochar. Digestate is a residue of anaerobic digestion for biogas production. Experimental results suggested that due to the mesoporosity and the abundance in nutrient minerals as well as functional groups the solid digestate-based biochar might be used as a biofertilizer, biosorbent or soil amendments. Soil improvement while using digestate-based biochar may be obtained by the potential benefits, for example increased cation-exchange capacity (Hung et al. 2017).

Biochar derived from a halophytic plant has been investigated. For example, *Achnatherum splendens* L. offers a unique feedstock for biochar production. There is abundant biomass of this species all over Northwest China and could help to sustain national energy security and additionally combat global warming (Irfan et al. 2016).

4.1.4. Biochar production technology

Demirbas & Arin (2010) defined pyrolysis as a thermal degradation of biomass by heat in the absence of oxygen, which results in the production of solid, liquid and gaseous products.

Depending on the operating conditions pyrolysis is classified by different authors in different ways. Pyrolysis may be broadly divided into two major categories – **fast and slow** (Sharma et al. 2015). According to Tripathi et al. (2016) pyrolysis can be also categorized into six subclasses: slow pyrolysis, fast pyrolysis, flash pyrolysis, vacuum pyrolysis, intermediate pyrolysis and hydro pyrolysis. Each type of pyrolysis is having its own advantages and limitations.

The yield and properties of pyrolysis products depend on pyrolysis configurations and operating conditions (Table 1). Biochar is the main product of the slow pyrolysis process. This product occurs at moderate temperature, low heating rate and longer residence time (Roy & Dias 2017).

Table 1. The reaction conditions and product distribution of various modes of pyrolysis

Process	Temperature (°C)	Residence time	Yields %		
			Biochar	Bio-oil	Syngas
Slow pyrolysis	300-700	Hour-days	35	30	35
Intermediate pyrolysis	~500	10-20 s	20	50	30
Fast pyrolysis	500-1,000	<2 s	12	75	13
Gasification	~750-900	10-20 s	10	5	85
Torrefaction	~290	~10-60 min	80	0	20

Source: based on Qambrani et al. (2017)

This Thesis is related to solid pyrolysis byproduct; therefore the slow pyrolysis is described more detail below.

Slow pyrolysis

In general, the biomass is heated in an oxygen limited or oxygen free environment, with typical heating rates between 1 and 30 °C min^{-1}. This process is usually carried out at atmospheric pressure. The process heat is typically supplied from an external energy source – generally from combustion of the produced gases or by partial combustion of the biomass feedstock (Ronnse et al. 2012). Specific type of slow pyrolysis, which is widely used in the bioenergy field is called torrefaction and it will be presented in the Chapter 4.3.

4.1.4.1. Reactors and kilns

A variety of pyrolysis units or reactors have been developed for biochar production. Pyrolysis reactors operate on similar principles such as regarding O_2 absence, but parameters like heating rates, pressures, and residence times might be different (Qambrani et al. 2017). The choice of a pyrolysis technology depends on final products targeted - biochar, bio-oil or syngas (Brassar et al. 2017).

According to Tripathi et al. (2016) pyrolysis reactors can basically be classified into two categories. The reactors with no movement of the biomass throughout the pyrolysis are termed as **fixed bed reactor**.

The **moving bed reactors** are those in which the biomass is not stationary during the pyrolysis (Tripathi et al. 2016).

Fixed bed reactors for charcoal production are generally simpler to conceive. For example, the use of kilns made of earth or metal is a traditional method for biochar production. Biomass is piled and heated in the airtight kiln for many hours (Brassar et al. 2017).

Smebye et al. (2017) described several biochar production methods/technologies which exist in low-income rural conditions:

- **Earth mound** or **earth covered pit kilns** - traditionally they are used most frequently. They are slow (several days), free of investment cost, merely requiring some poles and sand to cover the pyrolyzing biomass.
- **Retort kilns** involve a higher material investment and partially combust pyrolysis gases.
- **Pyrolytic cook-stoves** can generate biochar while providing heat for cooking. Advantages include that they burn cleanly thus reducing indoor air emissions.
- **Flame curtain kilns** come in two basic concepts: as a conical, all-steel deep-cone bowl and as a simple soil pit, consisting of a conically shaped hole in the ground which can be dug in a few hours and is essentially free of investment cost.

- A recent development has introduced the **Kon-Tiki flame curtain kiln**, which is faster comparing to traditional kilns (hours instead of days), cost-effective and easy to operate.

4.1.5. Properties of biochar

Physical properties

The **surface** of biochar is typically a rectangular pore structure, unlike the original feedstock (Figure 3). The abundant pore structures of biochar affect the infiltration route and water velocity in the soil. The high moisture content can enhance the fixation of soil nutrients (Tan et al. 2017).

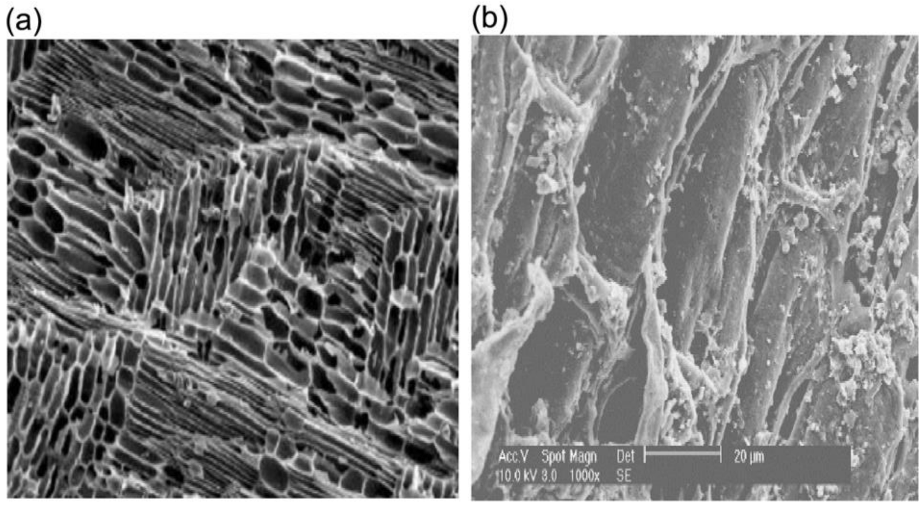

Figure 3. Microscopic surface scan of biochar (a), microscopic surface scan of straw (b)

Source: Tan et al. (2017)

Biochar pore size is highly variable. Pore size encompasses nano- (<0.9 nm), micro- (<2 nm) and macro-pores (>50 nm). Biomass rich in lignin (e.g. bamboo and coconut shell) develops macroporous-structured biochar. Biomass rich in cellulose (e.g. husks) yields a predominantly microporous-structured biochar (Li et al. 2017).

According to Igalavithana et al. (2017) in general, the biochar **surface area** ranges from 0.1 to >900 $m^2\ g^{-1}$.

Chemical properties

Effects on soil nutrient dynamics and the high stability of the carbon, which is its main component, are of the most remarkable and currently best-understood properties of biochar. Biochar retains between 10 % and 70 % (on average about 50 %) of the carbon present in the original biomass (Scholz et al. 2014).

pH

Generally, biochar is **alkaline** with some exceptions depending on a feedstock. Biochar pH increases with increasing pyrolysis temperature. Increasing temperature led to higher ash component, which positively correlated with biochar pH, suggesting that ash component is a factor contributing to biochar high pH (Li et al 2017).

Soil fertility depends on the **cation exchange capacity (CEC)** of biochar. The CEC of biochar also affects the CEC of the soil it is applied to. The CEC reaches a maximum when the surface area of the biochar is the largest (Tan et al. 2017).

Impact of a pyrolysis temperature on different properties of biochar and its yield is shown in a Figure 4.

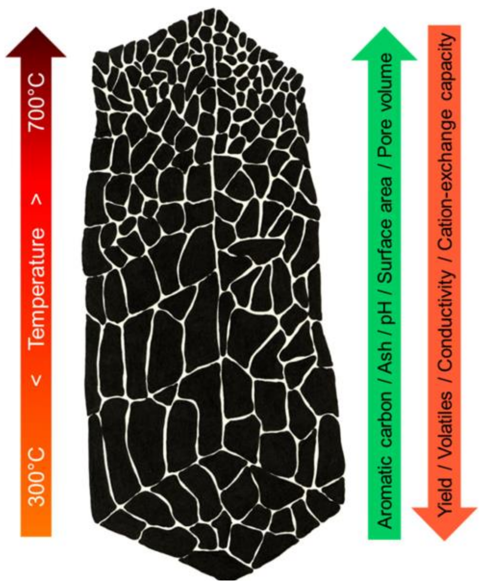

Figure 4. Graphical presentation of effects of the temperature on biochar properties

Source: Nanda et al. (2015)

4.2. Biochar in agriculture

4.2.1. Impacts on soil health and agricultural productivity

This chapter considers opportunities of biochar applying in agricultural sector.

Soil improvement is a necessity in many regions of the world. In both industrialized and developing countries, soil losses and degradation are occurring at unprecedented rates. It is profound consequences for soil ecosystem properties. Loss in soil productivity occurs despite intensive use of agrochemicals, concurrent with adverse environmental impact on soil resources. Biochar usage is able to play a major role in expanding options for sustainable soil management by improving upon existing best management practices, not only to improve soil productivity (Lehmann & Joseph 2009).

Biochar can be distinguished from charcoal and similar materials by the fact that it is produced with the intent it be applied to soil as a means of improving soil productivity and for carbon storage. It is notable that commercial suppliers have developed various trade names, for example Agrichar (Barrow 2012).

Some of the key factors that influence the impact of biochar application on soil health and agricultural productivity include: soil pH, nutrient availability, soil moisture, soil organic matter and the amount of biochar applied (Scholz et al. 2014).

International Biochar Initiative has prepared standardized product definition and product testing guidelines for the biochar that is used in a soil (IBI 2018).

According to Scholz et al. 2014 there is a number of reasons why biochar systems might be particularly relevant in developing countries. Biochar has great potential to impact agriculture in these regions because of the abundance of marginal or degraded soils in many parts of tropics.

Slash-and-Char

For example, an interesting field experiment was conducted by Niu et al. (2015) using the slash-and-char technique (Figure 5). An agricultural red loam soil highly contaminated by the heavy metals like cadmium (Cd), lead (Pb) and Zn was treated on-site. The biomass feedstock (rice straw) was converted into biochar in only one day. In comparison to the untreated soil, the treated soil was associated with decreased bioavailability of the heavy metals and increased vegetable yields.

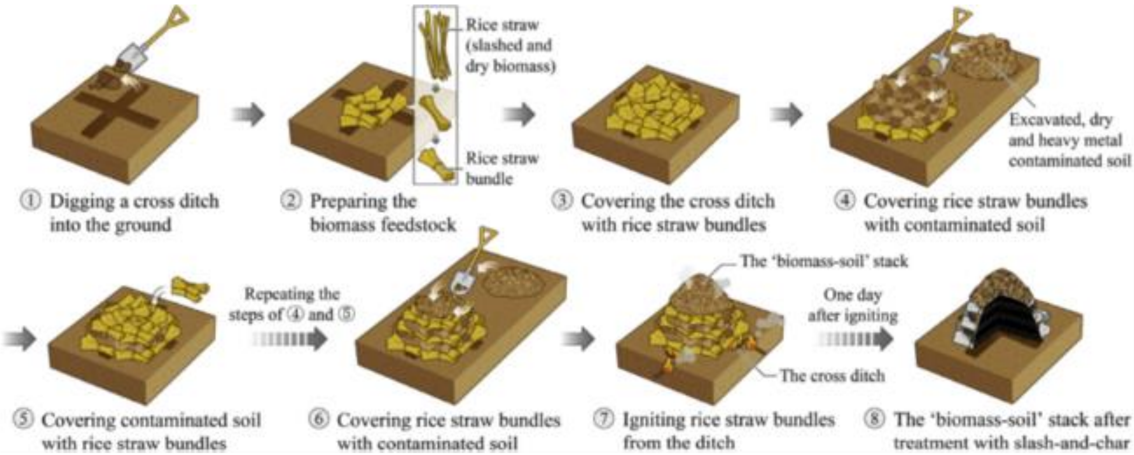

Figure 5. Schematic diagram showing the major steps of the slash-and-char technique

Source: Niu et al. (2015)

4.2.1.1. Interaction with compost

Biochar should not be seen as an alternative to existing soil management. It is a valuable addition that facilitates the development of sustainable land use (Lehmann & Joseph 2009). For instance cover crops, mulches, compost, or manure additions have been used successfully, especially in humid tropics. But these organic amendments have to be applied each year to sustain soil productivity (Lehmann & Rondon 2006).

Compost has been widely investigated as an organic amendment for improving soil quality and increasing agricultural output (for example, reduction of soil bulk density (BD), improvements to soil pore volume and water conductivity, improved water retention and reduced soil erosion). But for significant improvements it is required to make regular reapplication to soil over extended periods. Composted material is not stable over medium to long-term timescales. Biochar has been investigated as an complimentary amendment to compost in agricultural soils. Effect will be depended on complicated interactions between biochar and compost properties, soil, crop, climate and time (Bass et al. 2016).

According to Godlewska et al. (2017) compost can be affected by biochar in such characteristics as temperature, moisture, pH, organic matter, content of nitrogen and other nutrients, organic pollutants and emission of gases during composting.

4.2.1.2. Soil applications of biochar

Peter (2018) pointed out that it is best when biochar is mixed with a soil through tillage for effective incorporation. Biochar can be added to slurry or in muck spreading before direct application. But there is the risk of loss due to erosion (wind and water). This risk can be averted if biochar will be applied before laying of surface cover mulch.

According to Scholz et al. (2014) biochar could be introduced to the soil in the following ways:

- during plowing;

- through banding (localized application);

- by top dressing (applying to soil surface and allowing natural processes to incorporate it);

- in planting holes;

- as seed coating;

- in planting tubes;

- or when soils are built for establishing green roofs or recreational turf.

4.2.2. Environmental impact

4.2.2.1. Carbon sequestration

Different carbon capture and storage (CCS) strategies were developed and discussed in the literature, ranging from wide-spread afforestation and reforestation in terrestrial ecosystems to pumping of CO_2 into deep ocean and geological layers. The approach to carbon sequestration in terrestrial ecosystems through the application of biomass-derived black carbon (biochar) to soil, which offers both a large and long-term carbon sink were proposed (Lehmann et al. 2006).

Green plants absorb CO_2 by photosynthesis and store it in plant tissue. When plants die, decompose or burn, some carbon is ultimately returned to the atmosphere in the form of CO_2. This is the natural carbon cycle. If biomass is converted to biochar, the biochar carbon is in a stable form (recalcitrant to degradation). It can be fixed for a very long time. This process of transforming carbon into a fixed form to avoid carbon emissions is called **carbon sequestration** (Tan et al. 2017).

Significant carbon storage and stabilization are the most direct and important qualities for climate change mitigation efforts based on biochar (Scholz et al. 2014).

4.2.2.2. Benefit of waste management

The disposal of agricultural wastes is one of the rising important environmental concerns. Large amounts of organic wastes are generated with the intensive agricultural activities (Tang et al. 2013). Focus is placed on a use of "true wastes" in order to minimize disruption to local carbon and nutrient recycling (Scholz SM et al. 2014).

Biochar production has potential for managing the waste stream originated from animals or plants. Waste management can decrease the associated pollution being loaded on the environment (Ahmad 2014).

For example, in many countries pig producers are required to manage excess manure (due to regulations that restrict use of P fertilization). The mass of the solid fraction of pig manure can be reduced via pyrolysis by 65-88% and the final product will be a biochar with high P content. Biochar is more stable and dryer than the raw material, and its decomposition rate is slower. For these reasons it can be used as soil amendment which can be easily managed and transported. The other following agricultural, municipal and industrial residues can be pyrolysed in order to produce biochar: biosolids, papermill waste, straw, rice husk, maize straw, barley stover, nut shell, coffee grounds, etc. (Brassard et al. 2016).

4.3. Bioenergy from biochar

On the global scale, biomass is the third largest produced primary energy (following coal and oil fuels). In developing countries, biomass supplies a bulk of energy services: cooking, food preservation, space heating etc. It has been established that in the entire developing world about three billion people use solid biomass as their main source of energy for cooking (Akolgo et al. 2018). The main benefit may be that biochar production technology offers clean heat, which is needed to develop cooking technology with lower indoor pollution by smoke than it is typically generated during the burning of biomass (Lehmann 2009).

Biomass is a renewable source of energy. This biofuel technology can handle a range of biomass feedstocks such as agri-residues, forest residues, energy crops and municipal solid wastes. It is an attractive option for expanding the possibilities of using less desirable biomass (Roy & Dias 2017). Unlike conventional fuels such as oil and gas, which are concentrated in restricted geographical areas, biomass as a feedstock for biofuel production is globally available. But raw biomass has difficulties competing with fossil fuels in many applications due to its physical characteristics. Promising technology for improving the characteristics of biomass for energy utilization is **torrefaction** (Proskurina et al. 2017). Torrefaction is a pre-treatment for further biomass-to-energy conversion (Liu & Balasubramanian 2013).

According to Dhyani & Bhaskar (2017) **torrefaction** is slow pyrolysis operation, which is conducted in the temperature range of 225-300°C. It is a mild pyrolysis process that aims in increasing the energy density and fuel properties of biomass. During the torrefaction process, the moisture contained in the biomass as well as superfluous volatiles are removed, while the biopolymers (cellulose, hemicelluloses and lignin) partly decompose by giving off organic volatiles. The end product is the residual solid, dry, blackened material which is termed as **"torrefied biomass"** or **"bio-coal".** The product is free from volatiles and has much higher energy density than initial biomass. The decrease in weight and volume of the biomass also enables its easy transportation over long distances to plants for use or further processing. Torrefied biomass is also hydrophobic, meaning that it can be stored for long time durations without absorbing water. Torrefied biomass also requires less energy to crush, grind or pulverize; and the same tools as for crushing coal can be used.

Torrefied woody biomass has similar to coal energy content (caloric value) and energy density. This material is more environmentally-friendly than fossil fuel from the perspective of net GHG emission because torrefied biomass has lower ash content (Proskurina et al. 2017).

Biochar for energetic purposes can be co-combusted in existing coal-fired power plants. Also directly burnt in most systems to generate heat (replacing coal without any modification) or in combined heat and power (CHP) plants for clean heat and power generation (Roy & Dias 2017).

4.3.1. Life cycle assessment of biochar production

Biochar production system sustainability can be quantified scientifically by Life cycle assessment (Field et al. 2013).

Smebye et al. (2017) reviewed:

- Earth mound kilns were shown to have negative potential environmental impacts because of their gas and aerosol emissions.
- Flame curtain kilns had slightly lower potential impact than retort kilns and much lower impact than earth-mound kilns because of the avoidance of start-up wood, low material use and gas emissions. Making biochar from flame curtain kilns was observed to be environmentally neutral in a life-cycle perspective, as the production emissions were compensated by carbon sequestration.
- Pyrolytic cook-stoves and gasifiers showed the most positive potential environmental impact in the LCA due to avoided firewood consumption and emissions from electricity generation, respectively.

4.3.2. Environmental risks

CO_2, methane (CH_4) and nitrous oxides (NO_x) are important drivers of the anthropogenic greenhouse effect, which are released both through burning of fossil and biomass fuel as well as decomposition of above- and belowground organic matter (Lehmann et al. 2006).

From a climate change perspective the risks related to biochar lie primarily in the negative feedbacks that may occur directly or indirectly during biochar production and application.

Such risks include:

1. Emissions of CH_4 and NO_x during inefficient pyrolysis and degradation of soil organic matter after biochar application on unsuitable soils.
2. Char dust and other small particulate matter arising from biochar production can become airborne with uncertain global warming impacts.
3. Adverse impacts on human health.
4. Land use can be changed in demand for certain types of biomass.

Many of these risks can be avoided. For example, risk of land use changes in demand for certain types of biomass for biochar production can be minimized if only true wastes will be used. The application of appropriate standards and safeguards throughout the biochar production chain can help to prevent negative impacts. Currently documentation is being developed by a constantly growing community on a practice supported by science (Scholz et al. 2014).

5. Conclusion

At present a heightened interest to investigation and adoption of the sustainable technologies can be noticed, especially in agricultural and bioenergy sectors. Consequences of the intensive production in agriculture and the implementation of fossil fuels are clearly observed all over the world. Biochar attracts attention thanks to its potential multipurpose abilities to contribute to the solution of these problems. Due to its characteristics, biochar was found to be beneficial in the soil amelioration, climate change mitigation and production of bioenergy.

Generally, significant progress in understanding of the biochar techniques' main principles is achieved year to year, and the technology improvement follows that. Due to a large variety of biomass potentially available for the conversion into the biochar as well as possible processing conditions or parameters such as temperature, heating rate and the process duration as a result almost infinite number of biochar types could be produced. That is why this topic gives wide space to investigation. There is no practical way how to remove biochar from the soil. For that reason, special attention should be paid on safely usage of biochar taking into account its worthiness to the particular conditions such as soil type, plants and climate.

Advantages of the biochar in bioenergy include better storage, transportation and manipulation as well as high calorific value almost equal to coal, but renewable and more environmental.

It is also important that biochar can be used in both industrial countries and in the developing rural areas. In advanced nations biochar can contribute to mitigating climate change, and in the outlying developing regions it can improve the standards of living because of its cost-effectiveness.

To conclude, biochar represents effective, sustainable and eco-friendly tool in agricultural management and bioenergy sector. However, long-term field experiments and research works are still required.

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