Biomass and biochar potential, a chance for semidesertic areas like Aguascalientes, Mexico

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***Abstract*—Biochar obtained from thermochemical conversion of biomass reduces greenhouse gas emissions, improves the physicochemical and microbial properties of soil and absorbs pernicious substances. In addition, applying biochar in agriculture helps to significantly reduce the water consumption for irrigation, an important issue for Aguascalientes, a semidesertic site in the center of Mexico. Therefore, declaring the benefits by applying biochar to soils and estimating the minimum biomass and biochar potential of Aguascalientes is the key issue of this paper.**

***Index Terms*—biomass potential, biochar, Aguascalientes**

INTRODUCTION

Biochar benefits agriculture, livestock farming, economy and the environment [1]. Introducing biochar to the soil is a potentially valuable agricultural practice that affects the physicochemical properties of the soil, reduces greenhouse gases (CO_2, CH_4 and N_2O), and improves the microbial health of soil [2,3,4]. The main effect of applying biochar to the soil in the long term is an increment in soil fertility, increasing soil nutrients such as K and Mg [5,6,7], improvement of cation exchange capacity, porosity, density, moisture and lowering soil pH [8,5].

Biochar is produced by thermochemical conversion of different types of biomass including agricultural waste (invasive plants, crop residues), animal manure, bones and woody biomass (tree cuttings), in an oxygen-limited thermochemical process [9] (e.g., slow pyrolysis, fast pyrolysis, hydrothermal carbonization, flash carbonization, torrefaction, and gasification).

The highest benefit of biochar is its high inner surface area [10] thanks to its high porosity [11] and its large number of micropores [12]. Application of biochar to the soil has the potential to improve soil properties [13] to create a better environment for plant root growth, root penetration, and nutrient and water uptake.

Biochar carbon content (C) is more than 50 % [14,15] and is typically 70%–80% (except for biochar derived from sewage sludge, paper sludge and manure). In addition to carbon, biochar is composed of oxygen, nitrogen and other elements. Biochar is relatively stable and can be preserved for hundreds of years, due to its alkyl and aromatic compounds [8,16,17,15]. Adding biochar to the soil improves the biochemical conversion processes, the soil is better able to hold moisture and enhances mineral nutrition for the development and reproduction of microbes [18,19].

Aguascalientes in the center of Mexico is a semidesertic municipality with about 800 000 inhabitants and an area of 1173 km^2 [20]. Aguascalientes suffers from water paucity [21] and lacks natural methods for soil improvement and water saving. For this reason applying biochar to the semidesertic soils of Aguascalientes can help to overcome the urging water deficit of that region. Here we evaluate the biomass and biochar potential for Aguascalientes, using data from the two main municipally recollection centers: the municipal compost and the municipal landfill.

INFLUENCES OF BIOCHAR ON SOIL QUALITY

Effects on soil chemical characteristics

Application of biochar can improve the chemical properties of soil [22]. Microbe and enzyme function enables complicated biochemical processes. These processes stimulate the material cycle and energy flow of inorganic and organic matter [23]. Hydrogen, nitrogen, oxygen and sulfur, which form gaseous products during pyrolysis, tend to decrease with increasing production temperature, while carbon content tends to increase [24,25].

In this paper we want to lift the soil physical properties from the soil chemical properties, since we want to focus the soils property of retaining water, a crucial issue in the semidesertic municipality of Aguascalientes.

Effects on soil physical characteristics

Biochar influences physical properties of soil, such as soil porosity, compaction, density, permeability and water content [26,27,23].

Biochar increases the soil water, air and nutrient levels [28]. The water content of soils is also affected by the soil structure, texture and the amount of organic matter. The water absorbance and water-holding capacity of soil increase with biochar content [29]. Biochar changes the water-holding capacity of soil by changing the soil porosity and agglomerate

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level [5,30,31]. The water content in soil increases with the amount of biochar added, because of its internal structure (Figure 1). At the highest ratio of bichar to soil studied (2:3), the water content increases to 56 % [23]. Physical properties of biochar, including surface area, pore structure, and adsorption properties, are related to the feedstock composition and pyrolysis temperature [28,32].

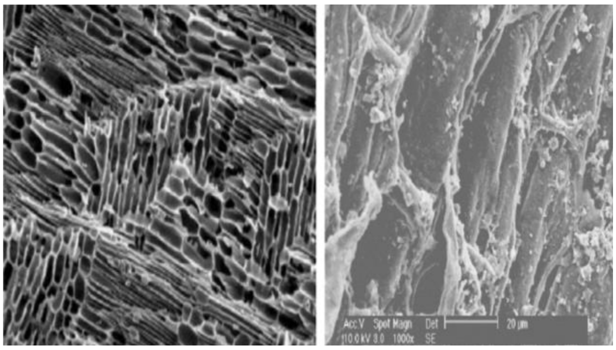

Fig. 1. Microscopic surface scan of biochar. Microscopic surface scan of straw. [23]

RESULTS: BIOMASS AND BIOCHAR POTENTIAL FOR AGUASCALIENTES

Our aim was to estimate the minimum biomass and biochar potential for the municipality of Aguascalientes, using data from the two main biomass recollection centers: the Municipal Compost of Aguascalientes and the Municipal Landfill.

In order to calculate the biochar potential for a region, one needs the following parameters:

(1) Amount of biomass available in the area of interest (2) Water content of wood: used for conversion of biomass to biochar (3) Char yield and thermochemical transformation technique usually given for dry matter (DM). (4) Char density, used for conversion of volume [m^3] into mass [t].

The properties of biochar depend on the raw materials [33,34,35] and the thermochemical conversion conditions and the used pyroliser respectively [36].

TABLE I. WOODEN BIOMASS TYPES AND ABUNDANCE RECEIVED AT THE MUNICIPAL COMPOST OF AGUASCALIENTES IN ONE YEAR

Biomass type (English / Spanish)	***Amount %***
Ficus / Ficus	25
Ash tree / Fresnos	15
Casuarina / Casuarina	15
Creole pepper tree / Pirul criollo	15
Rose pepper tree/ Pirul brasileño	10
Ceder / Cedros	10
Palm trees/ Palmas	10

Measurements on the density of biochar showed that biochar skeletal density (not including pore space) increases with pyrolysis temperature and ranges from 1.34 g cm^{-3} to 1.96 g cm^{-3} [37]. Biochar envelope density includes pore spaces within the material particles in the measurement and therefore is less than the skeletal density when the material is porous. Biochar envelope density depends on the raw material and ranges from 0.25 to 0.3 g cm^{-3} for grass biochar and from 0.47 to 0.60 g $cm^{-3}$for wood biochar. Therefore it is higher for wood biochar than for grass biochar; this difference is attributed to plant cell structures obtained during the thermochemical transformation [37].

For the pyrolysis process in Aguascalientes, we propose a Kon-Tiki flame curtain kiln [38,39], a recent development which produces high quality char with low emissions [40,41].

The Kon-Tiki kiln is fast compared to traditional kilns (hours instead of days), easy to operate and cost-effective, thanks to its smart design based on modern thermodynamics. Yield of the Kon-Tiki was measured at rates between 15 % and 25 % on a dry matter basis, which correspond to other high temperature pyrolysis chars [38] (https://www.biochar-journal.org/en/ct/39; http://www.ithaka-institut.org/ithaka/media/doc/kon-tiki-presentation.pdf).

In order to determine the biochar potential (Table 2) and the area of amended soil for the municipality of Aguascalientes (Table 3) we made the following assumptions:

(1) Envelope density: 0.5 g m^{-3} [37], used for conversion of volume [m^3] into mass [t]

(2) Water content of wooden biomass: 20 % [38], (http://www.ithaka-institut.org/ithaka/media/doc/kon-tiki-presentation.pdf), used for conversion to dry biomass (with no water content)

(3) Char yield with the Kon-Tiki kiln: 25 % (transformation from dry biomass to biochar) [38] (http://www.ithaka-institut.org/ithaka/media/doc/kon-tiki-presentation.pdf).

Municipal Compost

The municipal compost of Aguascalientes receives about 2400 m^3 of wooden biomass per year (personal communication from Ruben Perez, Municipally Compost, June 2017), including ficus, ash tree, casuarina, pepper tree, ceder and palm tree. See Table 1 for the percentage of the different biomass species.

After the thermochemical transformation of this biomass, we detemined a potential annual charyield of 240 t and 480 m^3 (Table 2).

Municipal landfill

The municipal landfill of Aguascalientes receives about 372 t per year of matter which does not constitute paper, plastics, sheets, cardboard or glass. We assume that this matter represents biomass since the highest amount of metal is probably removed by local garbage selectors before arriving at the landfill.

After the thermochemical transformation of this biomass from the municipal landfill, we determined a potential annual charyield of 74.4 t and 148.8 m^3 (Table 2).

The total calculated annual biochar mass for the municipality of Aguascalientes, produced out of the biomass received by the municipal compost and municipal landfill is 314.4 t, which is equivalent to a biochar volume of 628.8 m^3 per year (Table 2).

TABLE II. BIOMASS AND BIOCHAR POTENTIAL FOR THE MUNICIPALITY OF AGUASCALIENTES

	Municipal compost	*Municipal landfill*	*Total*
biomass [m^{-3} / year]	2400	744	**3144**
biomass DM [m^{-3} / year]	1920	595.2	**2515.2**
biomass [t / year]	1200	372	**1572**
biochar [m^{-3} / year]	480	148.8	**628.8**
biochar [t / year]	240	74.4	**314.4**

We have seen that biochar changes the soil porosity and agglomerate level and therewith the water-holding capacity of soil [5,30,31]. The semidesertic municipality of Aguascalientes has a great need of saving water. Since water content in soil increases with the amount of biochar added [5,30,31,23], biochar can play an important role in the water management of Aguascalientes.

The water content is 20 %, in a soil without biochar (CK), 26 % with a biochar soil ratio of (1:15), 34 % with a biochar soil ratio of (1:7), 38 % with a biochar soil ratio of (1:3) and increases to 56% when the ratio of biochar to soil is (2:3) [23].

TABLE III. BIOCHAR SOIL AMENDED AREA, MUNICIPALITY OF AGUASCALIENTES, 628.8 T OF BIOCHAR PER YEAR RELATION BIOCHAR SOIL AND WATER CONTENT % [23]

Biochar soil ratio	***Amended soil water content %***	***Amended soil area [m^2] in one year***	***Amended soil area [km^2] in 50 year***
1:15	26	94320	4.716000
1:7	34	44016	2.200800
1:3	38	18864	0.943200
2:3	56	9432	0.471600

In this paper we estimated a maximum annual biochar potential of 314.4 t and 628.8 m^3 (see Table 2), for the municipality of Aguascalientes. Supposing that this biochar will be introduced to the upper 10 cm of soil, all the benefits from biochar could be observed. In Table 3, we calculated the amended soil area per year with different biochar/soil ratios. With a ratio of (2:3) and therefore a soil water content of 56 % in the soil [23], the beneficial area will be 9432 m^2. Since biochar is very stable and resistant to microbial decomposition [42,29] in ten years this area can be multiplied by 10 and will be 94320 m^2 and in 50 years 0.47 km^2. With a biochar to soil ratio of only (1:7) and a water content of 34 % [23], the amended soil area in 50 years will be more than 2.2 km^2, which is equivalent to nearly 0.2 % of the whole area of the municipality of Aguascalientes.

SUMMARY AND DISCUSSION

Biochar is an important product, termochemically transformed out of biomass, which has lots of applications. Regarding soil quality, biochar improves soil porosity, permeability, compaction, soil density, water content, and bulk density.

In this paper we show the biomass and biochar potential for the municipality of Aguascalientes, a semidesertic site in the center of Mexico. We focus on diminishing the water deficit in Aguascalientes, estimate the biomass and biochar potential and encourage the biochar application to soil in order to save water for irrigation.

With a ratio of biochar to soil of (2:3), the beneficial area would be 9432 m^2 after one year; after 50 years the amended soil area would be 0.47 km^2. With a biochar soil ratio of (1:15), the amended soil area would be 4.7 km^2 after 50 years, which is equivalent to more than 0.4 % of the whole area of the municipality of Aguascalientes. However, we expect that after 50 years the amended soil area will be major than that, since applying biochar to the soil enhances plant growth and therewith the biomass and biochar potential.

FUTURE RESEARCH

Future investigations should include: (1) the production of biochar on laboratory scale from different identified biomass, abundant in Aguascalientes, (2) analysis of different physio-chemical characteristics based on international certificates of the produced biochar and (3) test the biochar on its eco-toxicological influence and (4) possibilities to boost the biomass and therewith the biochar availability and production.

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