Biochar Systems for Sustainable Agriculture

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Outline

• The many possible uses of biochar
• The relevance of soil: EU policies
• Introduction to biochar production technologies
• Biochar characteristics
• Biochar to offset GHG emissions
• Biochar integrated to sustainable agriculture
• Biochar and Anaerobic Digestion
Biochar is a “multiple-win” approach, as it

• can be produced by many (incl. residual) feedstocks & various processes
• is a mature technology, available in a wide range of scales, generating solid material (fuel/amendment) + high temperature renewable heat
• sequesters large amount of long-term stable recalcitrant C
• supports sustainable (more organic, less fossil) agriculture & well matches with cover cropping, catch cropping/agroforestry, conservation agric., etc
• is a key solution for poor/marginal land recovery → adaptation to Climate Change → food & feed + energy/materials (e.g. water treatment)
• well combines with AD and digestate use/composting

A cost-competitive decentralized solution enabling sustainable agriculture & developing local/rural economy
Many uses of Biochar

✓ Animal Feed, Biogas/Biomethane, Metallurgy, Buildings, Water Treatment, Air Treatment, Textiles, Food, Preserving, Colour, Medicine, Cosmetics, Electronics, Batteries, Industrial Materials, Dessicant, etc.

Source: Ithaka institute: «55 uses of Biochar»

➔ We will focus on Biochar use in sustainable agriculture
V. [...] no EU-level strategy on desertification and land degradation. Rather, there is a range of strategies, action plans and spending programmes, such as the Common Agricultural Policy, the EU Forest Strategy, or the EU strategy on adaptation to climate change, which are relevant to combating desertification, but which do not focus on it.

[...] we make recommendations to the Commission aimed at better understanding land degradation and desertification in the EU; assessing the need to enhance the EU legal framework for soil; and stepping up efforts towards delivering the commitment made by the EU and the Member States to achieve land degradation neutrality in the EU by 2030.

While climate change is projected to improve conditions for growing crops in parts of northern Europe, the opposite is true for crop productivity in southern Europe. According to projections using a high-end emission scenario, yields of non-irrigated crops like wheat, corn and sugar beet are projected to decrease in southern Europe by up to 50% by 2050.
Soil and C in REDII and EU Green Deal

- **Healthy soil**: essential for food/feed, sustainable bioenergy and bioeconomy
- REDII includes C-in-soil measurements (Annex V)
- Soil is a key component in the new **EU Green Deal** (part of 6 in 9 EU Green Deal goals) and **UN SDGs**
THE 2° PARIS GOAL REQUIRES C-NEGATIVE ACTIONS

[...] No scenarios are at all likely to keep warming under 1.5ºC without greenhouse-gas removal. “It is built into the assumptions of the Paris agreement,” Gideon Henderson, Oxford University. [...] COP23, Bonn.
The Decarbonisation Pathway in the EU

Different zero GHG pathways lead to different levels of remaining emissions and absorption of GHG emissions.

Source: A Clean Planet for All, EC
BIOCHAR

SOLID PRODUCT
FROM THERMOCHEMICAL CONVERSION OF BIOMASS FEEDSTOCKS

HIGH CONTENT IN RECALCITRANT C
LARGE POTENTIAL FOR C SEQUESTRATION AND STORAGE IN SOILS

(J. Lehmann, 2006)
Biochar & Agri
Biochar as Soil Amendment and for Slow N-release

- *Terra Preta* (Central America) is a well-known example in Biochar
- But also EU has been engaged in biochar for long time
- **Justus Von Liebig** (1803-1873), “father” of organic chemistry
- Liebig questioned the prevailing theory that humus or black soil was essential for plant growth because it imparted a vital life force to plants. Believers in humus thought that the black soil contained an organic life force or “vitalism” that could not be derived from dead, inorganic chemicals. This theory was based on the well-known fact that “virgin” soil from recently cleared forests was black and fertile.
- He also stated: “[..] But how inferior is the agriculture of Europe to that of China! [..]”

Liebig recommended, “calcined mud and finely divided charcoal as additives to retain nitrogen (Agric.Chem., p 66)

[[..] charcoal “surpasses all other substances in the power which it possesses of condensing ammonia within its pores... it absorbs 90 times its volume of ammoniacal gas, which may be again separated by simply moistening it with water.” (Agricultural Chemistry, p 35.)

Source: The Biochar Journal
THE PYROLYSIS PROCESS

THERMOCHEMICAL DECOMPOSITION (CONVERSION) OF ORGANIC MATERIALS THROUGH HEATING IN COMPLETELY ANAEROBIC CONDITIONS

PRODUCTS OF THERMOCHEMICAL CONVERSION

- SOLID
  - Charcoal
- LIQUID
  - Bio-oil
- GAS
  - Pyrogas

SLOW PYROLYSIS

TYPICAL PROCESS TEMPERATURE: 400 ÷ 600 °C
LONG RESIDENCE TIME OF SOLIDS AND VAPORS
LOW HEATING RATE: 0.1 ÷ 2 °C s⁻¹
PRODUCTS → CHAR + BIO-OIL + GAS

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Biochar Production Technologies

Biochar is a product of Thermochemical Biomass Conversion

- **Pyrolysis (Flow, Fast), Gasification, Hydrothermal Carbonisation**
- Biochar is the **main product of SLOW Pyrolysis**, that also produces High-Temperature Renewable Heat
- **SLOW Pyrolysis**: very robust and mature technology. Many reactor types available at any size.
- A **Multi-Feedstock** technology

![Diagram showing the composition of pyrolysis products: Gas, Char, Water, Organics.](image)
Understanding the Char Structure is key for appropriate production and use

- 130-140 °C: Release of water and steam extraction of VOCs
- 140-400 °C: Hemicellulose degrades, Cellulose-lignin bonds break down
- 400-600°C: Main Pyrolysis reactions, massive pyrogas release
- 600-800 °C: Aromatic frames development
- 800-2500 °C: Turbostratic rearrangement, towards graphene sheet
Specific surface, water retention capacity...

Source: Luke, Finland. X-ray tomographic reconstruction of a willow biochar sample pyrolysed at temperature 320 °C. Image resolution is 1.14 μm. Camera moves through pores relevant for water retention (approx. 10 and 50 μm in diameter). [YouTube video](https://www.youtube.com/watch?v=xZeU8mNlxZQ)

Brewer CE, et al., New approaches to measuring biochar density and porosity, Biomass and Bioenergy (2014), http://dx.doi.org/10.1016/j.biombioe.2014.03.059
**WOOD STRUCTURE: HARDWOOD/SOFTWOOD**

Hardwood *Angiosperms-Monocotyledons*  

Softwood *Coniferous*

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**Biochar** structure depends on *feedstock* characteristics + *technology* + *process conditions*  

*Source: Marco Togni, DEISTAF, University of Florence*

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*Source: Marco Togni, DEISTAF, University of Florence*

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AGRONOMIC CHARACTERISTICS OF BIOCHAR

- **HIGH POROSITY** (MICRO-, MESO- E MACRO- PORES):

  - *Slow Pyrolysis of Black Pine – 1000X*
  - *Slow Pyrolysis of Poplar – 5000X*
  - *Slow Pyrolysis of Poplar – 10000X*

- **HIGH MOISTURE RETENTION CAPACITY**
- **HIGH POTENTIAL TO LIMIT LEACHING OF NUTRIENTS**
- **SUITABLE HABITAT FOR MICRORGANISM GROWTH**
- **HIGH REACTIVE SURFACE, WITH REACTIVE FUNCTIONAL GROUPS (CEC AND AEC)**
Charcoal production: traditional systems
EU TRADITIONAL CHARCOAL MAKING
TRADITIONAL CHARCOAL MAKING AND POLLUTION
Biochar production: modern industrial processes

- Energy Recovery
- Emission Control
- Efficient use of feedstocks
TCP/CRO/3101 (A) Development of a sustainable charcoal industry

Second Announcement and Programme for the Expert Consultation

**Sustainable Charcoal Production, Trade and Use in Europe**

5 - 6 June 2007
Zagreb, Croatia

Jointly co-organised with Energy Institute Hrvoje Pozar

Supported by

Ministry of Agriculture, Forestry and Water Management of the Republic of Croatia

www.drveniugljen.hr

2007

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2017
Biochar production facilities at Re-Cord

**Rotary Kiln**
Slow pyrolysis of biomass & waste to fuels and products
- Solid (as fuel or amendment) + high T heat
- Integration in large-scale Advanced Biofuel supply chain
- IN=100 kg/h

**CarbOn RE-CORD**
Slow pyrolysis of biomass for charcoal and biochar making.
- Fixed bed, Open-top Oxidative Reactor (Autothermal)
- Designed and developed for small farmers
- Continuous operation.
- IN=50 kg/h. OUT=12kg/h ($\eta_c = 24$ wt.%)
Biochar Properties depends on various elements

- **Feedstock Type & Characteristics**: Moisture, Size, Ashes, etc.
- **Process Parameters**: Max Process Temperature (T\text{Max}), Vapour Residence Time (VRT), Solid Residence Time (SRT), Heating Rate (HR), etc.

Biochar is a rather general term: many similar but different products are classified as Biochar.

The solid product differ as regards:

- Porosity
- Organic Carbon and Ash Content (C_{\text{Org}}, Ash)
- Stability (H/C \text{Mol}, O/C \text{Mol})
- pH
- Functional Groups on Biochar Surface (CEC-AEC)

These elements determines the effects of the biochar when used. The Biochar performance are also very different depending on the type of Soil.
BIOCHAR & SOIL FERTILITY

• Improvement of soil **physical** properties
  • *Mechanical structure*
  • *Soil porosity and aeration*
  • *Moisture retention capacity*

• Improvement of soil **chemical** properties
  • *pH increase in acidic soils*
  • *CEC and AEC*
  • *Improved N-cycle*
  • *Addition of C-recalcitrant to soil*
  • *Environment suitable for microorganism*
  • *Nutrient addition (slow release) and reduced leaching*

• Improvement of **biological** properties
  • *Effects strictly liked to the two previous ones*
Biochar is highly stable in soil as demonstrated by C-14 studies.

Y. Kuzyakov et al. / Soil Biology & Biochemistry 70 (2014) 229–236

Biochar stability in soil: Decomposition during eight years and transformation as assessed by compound-specific $^{14}$C analysis

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Figure 27.1 GHG abatement per unit of feedstock dry matter, for a range of feedstocks, from LCA studies. ‘Manure’ also includes biosolids and poultry litter. The data sources are indicated in Table 27.1.
IPCC AND BIOCHAR: NEWLY DEVELOPED AND PUBLISHED ACCOUNTING FOR C-REMOVAL FROM BIOCHAR

2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories

GHG savings from biochar well documented by IPCC & other sources → Accounting is Possible

\[ \Delta BC_{\text{Mineral}} = \sum_{p=1}^{n} \left( BC_{TOT,p} \cdot F_{C_p} \cdot F_{perm_p} \right) \]

\( \Delta BC_{\text{Mineral}} \) = the total change in carbon stocks of mineral soils associated with biochar amendment, tonnes sequestered C yr\(^{-1}\)

\( BC_{TOT,p} \) = the mass of biochar incorporated into mineral soil during the inventory year for each biochar production type \( p \), tonnes biochar dry matter yr\(^{-1}\)

\( F_{C_p} \) = the organic carbon content of biochar for each production type \( p \), tonnes C tonne\(^{-1}\) biochar dry matter, Table 4A.1

\( F_{perm_p} \) = fraction of biochar carbon for each production type \( p \) remaining (unmineralised) after 100 years, tonnes sequestered C tonne\(^{-1}\) biochar C, Table 4A.2

\( n \) = the number of different production types of biochar
**BIOCHAR TO OFFSET GHG EMISSIONS**

Biochar to offset GHG emission is a **win-win-win-win** solution:

- Biochar deployable at large scale (land: 2\textsuperscript{nd} C-sink after oceans): **huge CO2 removal potential**: 1 t biochar $\rightarrow$ 3,66 t CO\textsubscript{2}
- It is probably the **cheapest CO2 offsetting option**
- It promotes **more sustainable agriculture** for food, feed, bioenergy, bioeconomy (**UN SDGs $\rightarrow$ consensus**)
- It supports **climate change adaptation** of land (**EU Green Deal**)

Moreover

- **Technology** is **mature** and available at many scales
- **C accounting** well developed at International level (**IPCC**)
AN EXAMPLE: SUSTAINABLE AVIATION

- **Biochar produced** from lignocellulosic residues
- **CO2 offset** through Biochar (measurable solution, thus evidence-based CO2 removal) → **C-removal form Biochar accounted** according to IPCC rules
- **Costs** for the action: **1/3rd-1/4th then SAF** (per tCO₂ saved)
- **Food, Feed, Energy and Products** from Biomass promoted
- **Consensus** is generated in Agriculture/Forestry
- The model can be well **combined with other sust.agricultural models** (as Agroforestry, Biogas Done Right, 4 pour mille initiative, FAO initiatives, etc)
COM-BI for healthy soil, resilience to climate change and C sequestration

BIOCHAR sequesters C (Climate Change Mitigation)

EU MED (PT, ES, FR, IT, HR, GR, CY):
8.5 Mha marginal lands (source: S2Biom project)
COMBI produced, characterized and tested in two sites in Spain, in the framework of the H2020 BIO4A project on HEFA biojet (www.bio4a.eu)
Biochar & Anaerobic Digestion

1. **Feedstock** → **AD Reactor**
   - Biogas
   - Digestate
   - Biochar
   - Pyrolysis

2. **Biogas Treatment**
   - Biochar
   - H2S

3. **Biochar** → **SOIL USE**

4. **Forest Residues** → **Agro-Residues** → **Biochar** → **Pyrolysis** → **AD Reactor**

5. **CO-GENCHP** → **Heat** → **Power** → **Separation** → **Biogas Treatment** → **SOIL USE**

6. **Digestsate** → **SOIL USE**
**Biochar & Anaerobic Digestion**

- **Pyrolysis**
- **Forest Residues**
- **Agro-Residues**
- **Biochar**
- **Co-Compost**
- **Digestate**
- **Soil Use**
- **Power**
- **Biomethane**
- **Separation**
- **Agricultural Uses for Biochar**

Biochar can be used as a soil amendment to build healthy soil in a variety of applications.
Biochar concentration in the final product:
14.9 - 19.8 - 22.8% w/w d.b.

- CB2 and CB3 completed the bio-oxidative phase about 4 days earlier than CD and CB1, keeping the same peak temp
- CB2 showed the lowest stabilization time, the highest degree of humification, and the lowest ammonium/nitrate ratio index
- CB3 was the only case with *E.Choli* proliferation

**Table 2** Initial windrows compositions

<table>
<thead>
<tr>
<th></th>
<th>U.M.</th>
<th>CD</th>
<th>CB1</th>
<th>CB2</th>
<th>CB3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Windrow (kg d.b.)</td>
<td>160.6</td>
<td>156.5</td>
<td>153.0</td>
<td>149.6</td>
<td></td>
</tr>
<tr>
<td>Starting moisture (% w/w w.b.)</td>
<td>61.6</td>
<td>60.0</td>
<td>59.2</td>
<td>58.3</td>
<td></td>
</tr>
<tr>
<td>Biochar content (kg w.b.)</td>
<td>0.0</td>
<td>12.0</td>
<td>18.0</td>
<td>24.0</td>
<td></td>
</tr>
<tr>
<td>Biochar rate (% w/w d.b.)</td>
<td>0.0</td>
<td>7.3</td>
<td>11.2</td>
<td>15.2</td>
<td></td>
</tr>
<tr>
<td>C/N index</td>
<td>36.3</td>
<td>40.4</td>
<td>42.7</td>
<td>45.2</td>
<td></td>
</tr>
</tbody>
</table>
BIO4A: >10 M€ H2020 project on SAF from marginal land and UCO

Background fertilization: 11/01/19
Seeding date: 14/01/19

Field trials: Ciudad Real (ES)
BIO4A: >10 M€ H2020 project on SAF from marginal land and UCO

How to make this linear biofuel thinking sustainable (GHG) enough?

Which opportunities Bioenergy & Bioeconomy offer to make agriculture more sustainable (beyond GHGs, towards SDGs)?

From linear to circular, from energy-driven to sustain.agricultural models

Bioenergy / Bioeconomy can make Sustainable Agriculture possible
**Biochar & Biomass Value Chains**

- **Slow Pyrolysis integrated in Biofuel chains:**
  - Providing heat for biomass treatment or power
  - Providing char to thermochemical conversion or as soil amendment
  - Decentralized: easily sizeable to the bioenergy/bioproduct chain

- **Bioenergy/Biofuels & Sustainable Agriculture**
  - Long-term shift from fossil-based to sustainable bio-based agriculture

- **Bioenergy Supported Sustainable Agriculture**
  - Value chains revised to embrace the *multi-annual dynamic nature of agriculture*. Multi-year land management, rotation, agroforestry, etc
  - Food, feed, energy, products.
  - There is one agricultural system only!
Thus... is co-composting worth?

- If the amount (tons) of biochar in co-composting or blend is the same → no major difference in sequestered fixed C, no strong motivations for co-composting from the C-value economic point of view. Therefore:
  → Does co-composting pay off, or is instead blending sufficient and a better economic choice?

- Answering this question is site- and policy-dependent, and requires extensive further work.

- AD plants (expecially OFMSW AD) largely implement pasteurization step → thus composting not strictly needed from the sanitary point of view.
Thus... Is co-composting worth?

• If thus digestate can be directly spread on soil, avoiding composting save CAPEX and OPEX. **Blend will most likely be the preferred choice**

• If composting process acceleration is instead required, adding Biochar could be an option. This could be the case of some OFMSW composting units.

• If biochar deployment (dust) is an issue, **co-composting will help** (but other options are possible)

• Detailed analysis of local (soil) benefits from collected nutrients favour co-composting, but customer must pay for this (market to be developed).
The deployment of biochar, biochar & compost and COMBI will necessarily be a **policy-driven issue** (EU: LULUCF in CAP)

**Multiple policies** could interact impact. Studies needed to provide policy makers with recommendations. e.g.:

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**Research paper**

Policy measures for sustainable sunflower cropping in EU-MED marginal lands amended by biochar: Case study in Tuscany, Italy

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CONCLUSIONS

• Biochar can play a significant role in many different applications and fields and deliver C-negative actions.

• Bioproducts are increasingly important for a sustainable society (Bioeconomy and Biorefinery).

• Thermochemical and biochemical integration, multidisciplinary synergistic research, «contamination» and integration: key in future R&D.

• Biochar-based value chains support sustainable agriculture and feedstock production for bioenergy and all markets towards the achievement of UN SDGs.

Bioenergy/Bioeconomy supported Sustainable Agriculture

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