Valorisation of digestate through hydrothermal carbonization (HTC): a preliminary characterization of derived gaseous, liquid, and solid products

V. Benedetti[1], M. Pecchi[1], S. Celletti[1], D. Basso[1,2], F. Patuzzi[1], T. Mimmo[1], S. Cesco[1], M. Baratieri[1]

[1] *Faculty of Science and Technology, Free University of Bozen – Bolzano, Italy*
[2] *HBI SrL, Italy*

Introduction

Input

System:
Cow

Output

Introduction

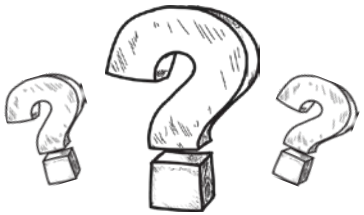
Biogas

- Electricity
- Heat

Anaerobic digestion plant

Digestate

- Fertilizer



Introduction

In Europe, Directives 2016/2284/EU and 91/676/EEC regulate the distribution of digestate on agricultural land, limiting the intake of N to 170 kg ha^{-1} $year^{-1}$

- Water pollution: nitrate and nutrients leach into the groundwater causing eutrophication and hypoxia
- Air pollution: ammonia volatilization
- Very high water-content and residual biological activity ⇨ management issues
- Economic and environmental impacts

Introduction

Landfilling

Composting

- Long times
- Bad odor
- GHGs emissions
- Land availability

Pre-treatment step to decrease the moisture content

Incineration

HTC

Hydrothermal carbonization (HTC)

- Treatment of biomass in hot (180-250 °C) compressed water at residence times varying from minutes to several hours
- Ideal for biomass with high moisture content (> 60 %)
- Products:
  - Hydrochar (HC)
  - Aqueous HTC liquid (AHL)

Hydrothermal carbonization

Hydrochar
(HC)

Aqueous HTC Liquid
(AHL)

- Bioenergy production
- Soil amelioration
- Carbon sequestration
- Wastewater treatment
- Carbon materials
- Energy storage
- Anaerobic digestion
- Fertilizers
- Recirculation
- Microalgae growth
- P recovery

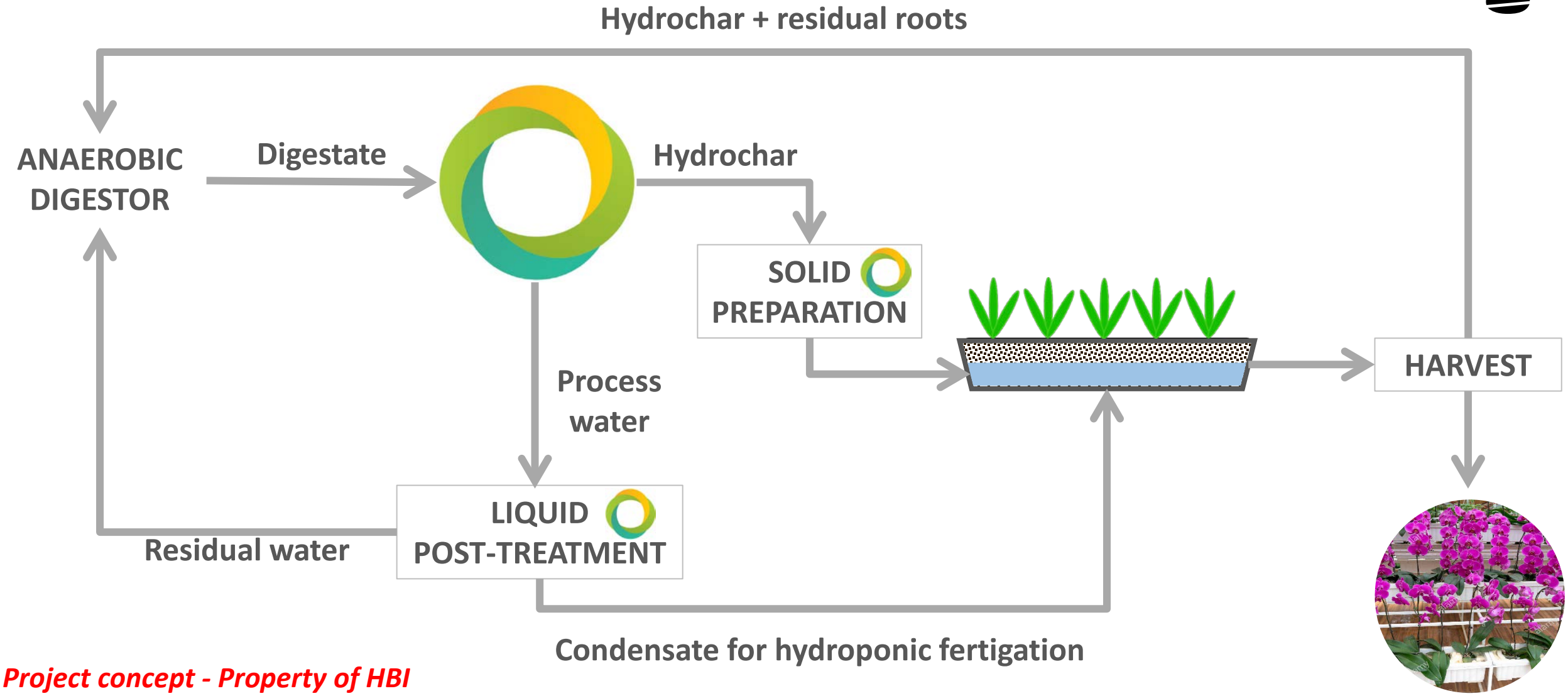
HB Ponics

Funding: Project **“HB Ponics”** (FESR1104; EFRE-FESR 2014-2020; CUP: B51B17000860008), financed by the European Regional Development Fund (ERDF) Investment for Growth and Jobs Programme 2014-2020.

https://www.hbigroup.it/hb-ponics/

Hydroponic cultivation

Introduction



Project concept - Property of HBI

Materials and Methods

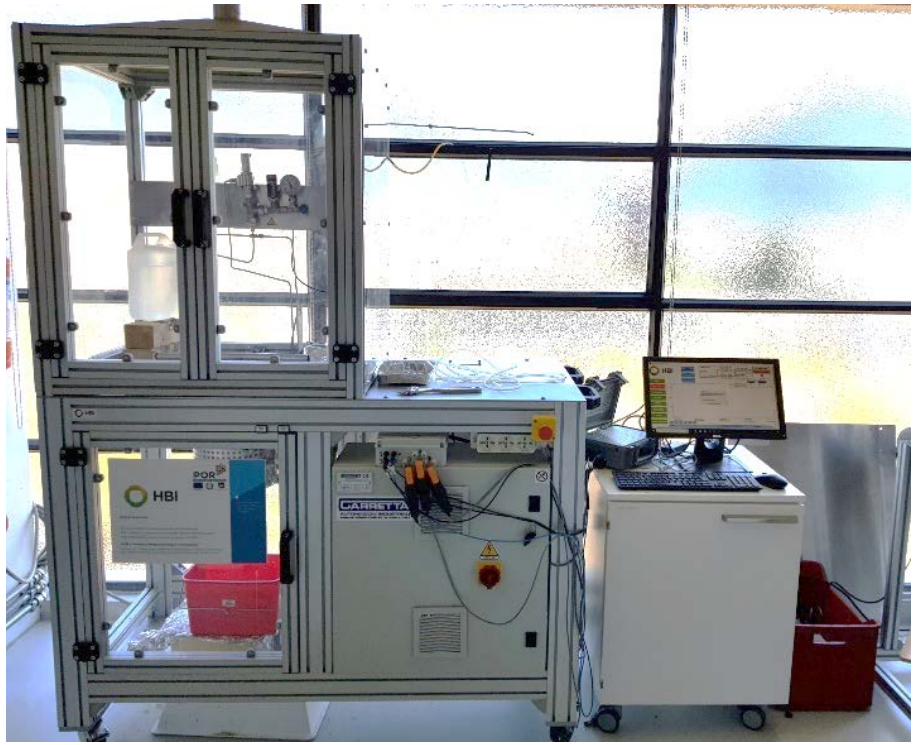
Digestate

Source: courtesy of Biogas-Wipptal

Digestate		
Ash content	[%wt]	26.83
C	[%wt]	39.11
H	[%wt]	4.87
O	[%wt]	26.56
N	[%wt]	1.94
S	[%wt]	0.68
HHV	[MJ/kg]	14.31
LHV	[MJ/kg]	13.24

- 2.5 kg per experiment
- Previously kept in refrigerator at 4 °C
- No pre-treatment

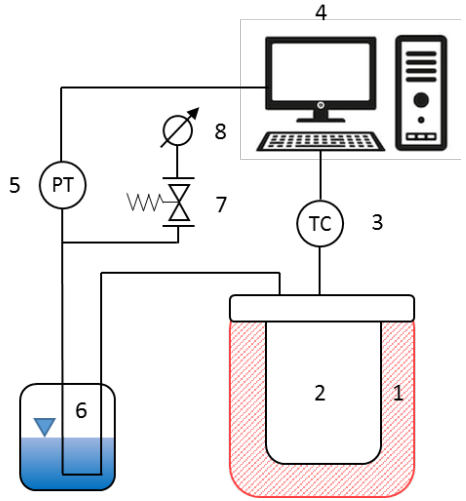
Materials and Methods



Batch reactor – 4 L

Hydrochar – oven-dried at 105 °C for 24 h

Aqueous HTC Liquid



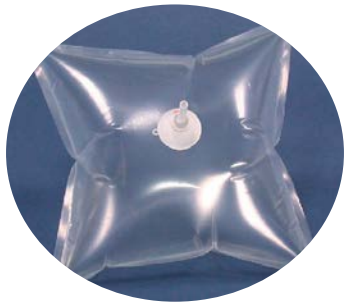
1. Electric furnace
2. HTC reactor
3. Temperature controller
4. HTC controller
5. Pressure transducer
6. Cold trap
7. Safety valve
8. Manometer

Scheme of the experimental lay-out

Operating condition	Experimental range		
Feedstock	digestate		
Temperature [°C]	180	220	250
Pressure	endogenous		
Residence time [h]	3		
Repetitions	3		

Gas analysis

HTC reactor



Gas sampling bag

µGC

HTC temperature	CO_2 %	H_2 %	CH_4 %	CO %
180 °C	65.49	0.04	0.26	0.12
220 °C	68.40	0.16	0.41	0.36
250 °C	79.18	0.35	0.70	0.30

AHLs characterization

TOC analyisis

Feedstock	TOC	
AHL 180 °C	[g/L]	7.07
AHL 220 °C	[g/L]	7.43
AHL 250 °C	[g/L]	7.89

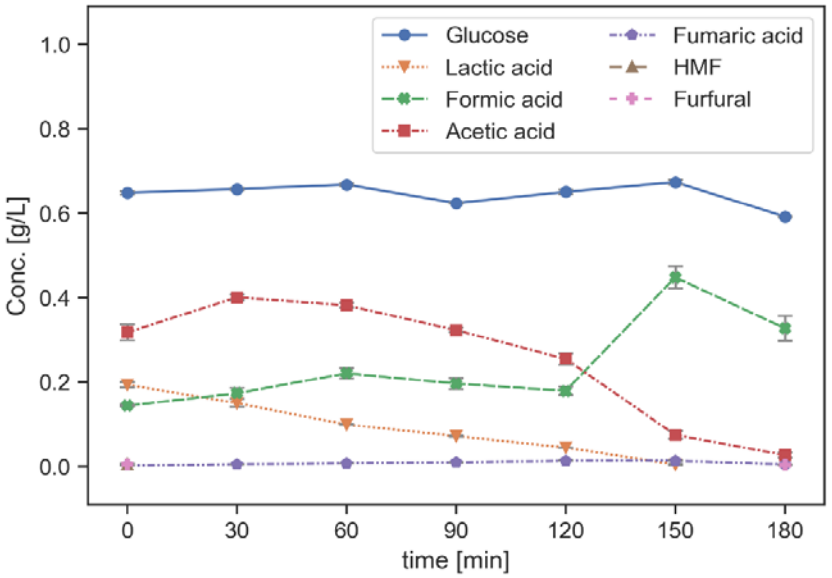
Semi-continuous analysis
Spillages every 30 min during operation

HPLC analysis

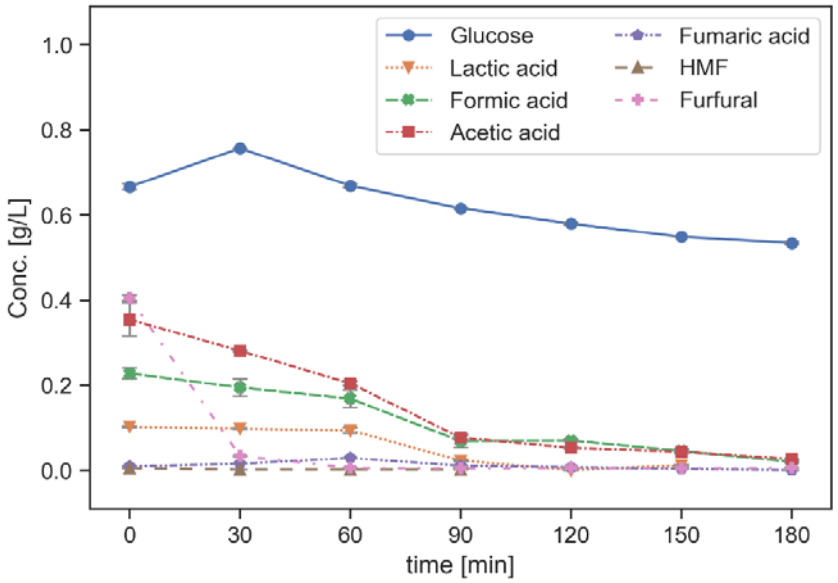
- Glucose
- Lactic, Formic, Acetic, Fumaric Acid
- Hydroxymethylfurfural (HMF), Furfural

AHLs characterization

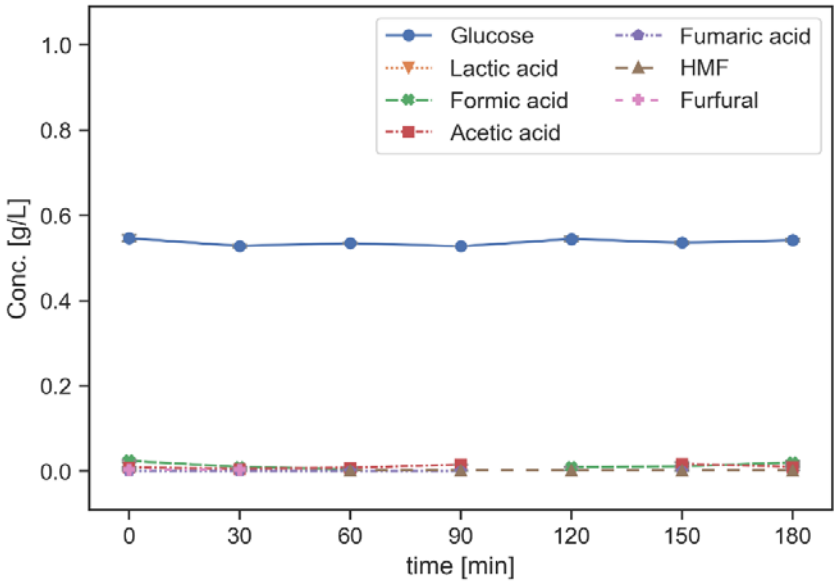
T_{HTC} = 180 °C



T_{HTC} = 220 °C



T_{HTC} = 250 °C



- Increase of the reaction rate of **hydrolyzation** and **dehydration** that become the governing reactions of the process.
- Sugars, HMF and furfurals are **less stable at high temperature** and **residence time**.
- Polymerization and formation of secondary char.

HC characterization

Elemental analysis

1

Calorimetric analysis

2

Physisorption analysis

3

Germination tests

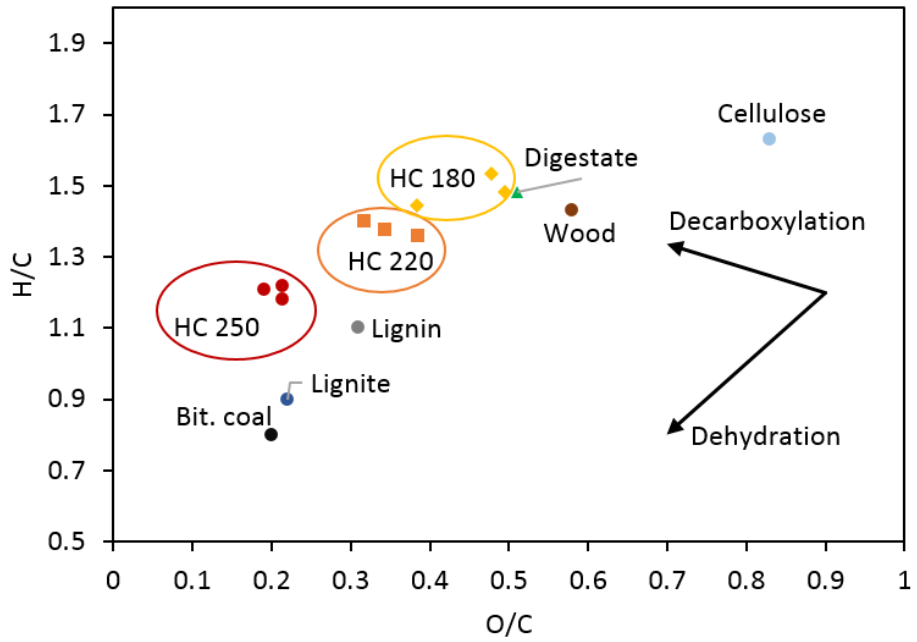
4

HCs characterization

	C	H	O	N	S	Ash	HHV
	$\%wt_{dry}$	$\%wt_{dry}$	$\%wt_{dry}$	$\%wt_{dry}$	$\%wt_{dry}$	$\%wt_{dry}$	MJ/kg
Digestate	39.11	4.87	26.56	1.94	0.68	26.83	14.31
HC 180	40.14	5.01	24.09	2.03	0.71	27.76	16.11
HC 220	42.53	4.92	19.71	2.16	0.62	29.79	16.70
HC 250	45.03	4.54	12.35	2.59	0.59	34.68	18.10

This is due to the **decarboxylation** and **dehydration** reactions that occur during the HTC process

Van Krevelen diagram

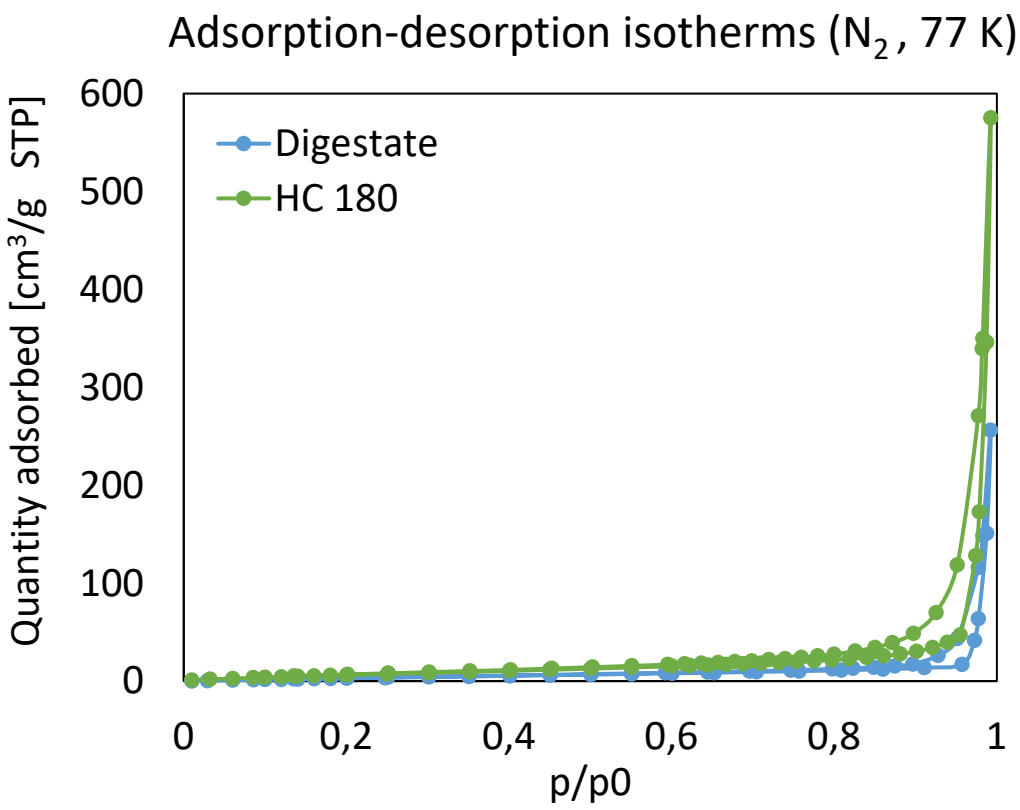


HCs characterization

	S_{BET}	Pore volume	Pore size
	m^2/g	cm^3/g	nm
Digestate	20	0.40	60
HC 180	35	0.79	56
HC 220	41	0.85	49
HC 250	52	0.86	47

Type V adsorption-desorption isotherm
- Weak gas-solid interaction
- Characteristic of macro-porous materials

Type H3 hysteresis loop
- Indicative of slit pores



HCs in soilless cultivation

Why?
Phytoxicity tests on Cress (*Lepidium sativum* L.)

What?
- Hydrochars HC180, HC220, HC250.
- Water extracts at two different concentrations (5% and 10%, w/v) and two different pH (9 and 7).

How?
- Germination tests.
- Evaluation of plant morpho-physiological parameters (number of germinated seeds and total root length).
- Extracts characterization.

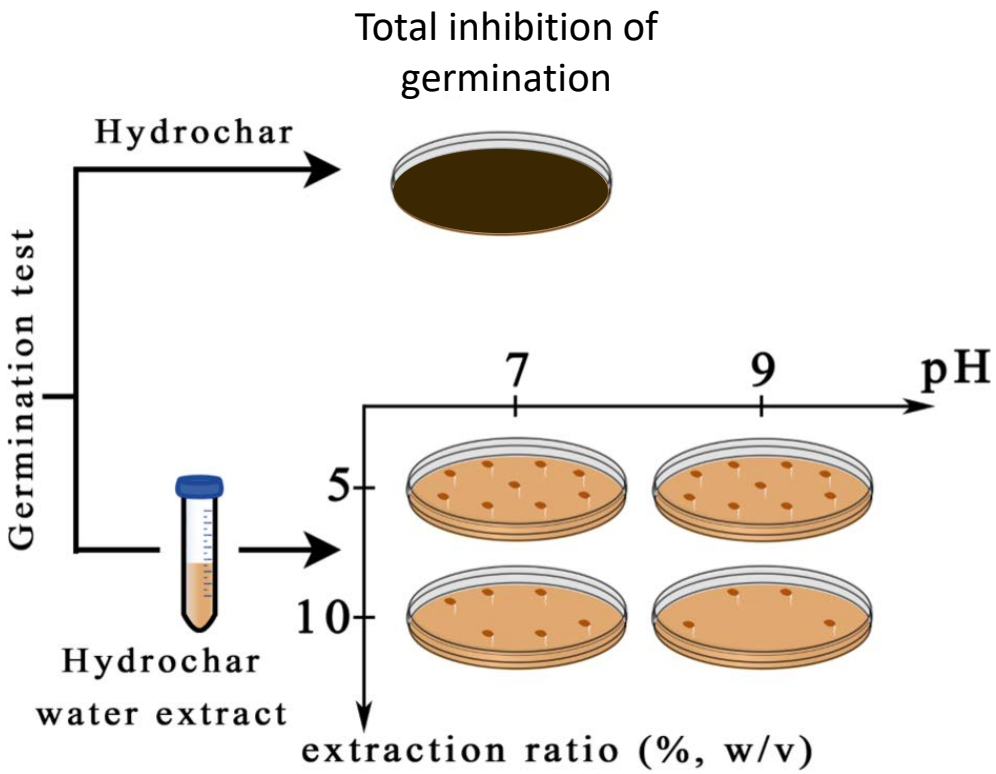
Cress (*Lepidium sativum* L.)

S. Celletti et al., ***Phytotoxicity of hydrochars obtained by hydrothermal carbonization of manure-based digestate***, Journal of Environmental Management (2021).

HCs in soilless cultivation

Main results

- Germination tests found hydrochar water extracts to show significantly lower phytotoxicity than the hydrochars themselves.
- The germination rate was reduced even further at higher process temperatures.
- The phytotoxic effect of the extracts decreased with decreasing extraction ratio and increasing pH.
- The chromatographic characterization of extracts identified the presence of potential phytotoxins, such as furan compounds.



S. Celletti et al., ***Phytotoxicity of hydrochars obtained by hydrothermal carbonization of manure-based digestate***, Journal of Environmental Management (2021).

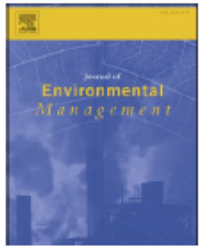
HCs in soilless cultivation

Journal of Environmental Management 280 (2021) 111635

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: http://www.elsevier.com/locate/jenvman



Research article

Phytotoxicity of hydrochars obtained by hydrothermal carbonization of manure-based digestate

Silvia Celletti [a,*], Alex Bergamo [a], Vittoria Benedetti [a], Matteo Pecchi [a], Francesco Patuzzi [a], Daniele Basso [b], Marco Baratieri [a], Stefano Cesco [a], Tanja Mimmo [a]

[a] Faculty of Science and Technology, Free University of Bolzano-Bozen, I-39100, Bolzano, Italy
[b] HBI S.r.l., Bolzano, Italy

Conclusions

- HTC to treat and valorize digestate
- Temperature and residence time affect AHLs composition
- Temperature strongly affects HC characteristics
- HCs in soilless culture systems (SCS)
- The phytotoxic effect of the extracts decreased with decreasing extraction ratio and decreasing pH
- To reduce phytotoxicity, it could be advantageous to mix hydrochars with other types of growing media and verify their suitability by conducting growth experiments with plant species usually cultivated in SCS

Thank you for your attention

Valorisation of digestate through hydrothermal carbonization (HTC): a preliminary characterization of derived gaseous, liquid, and solid products

E-mail: vittoria.benedetti@unibz.it

Website: https://bnb.groups.unibz.it/