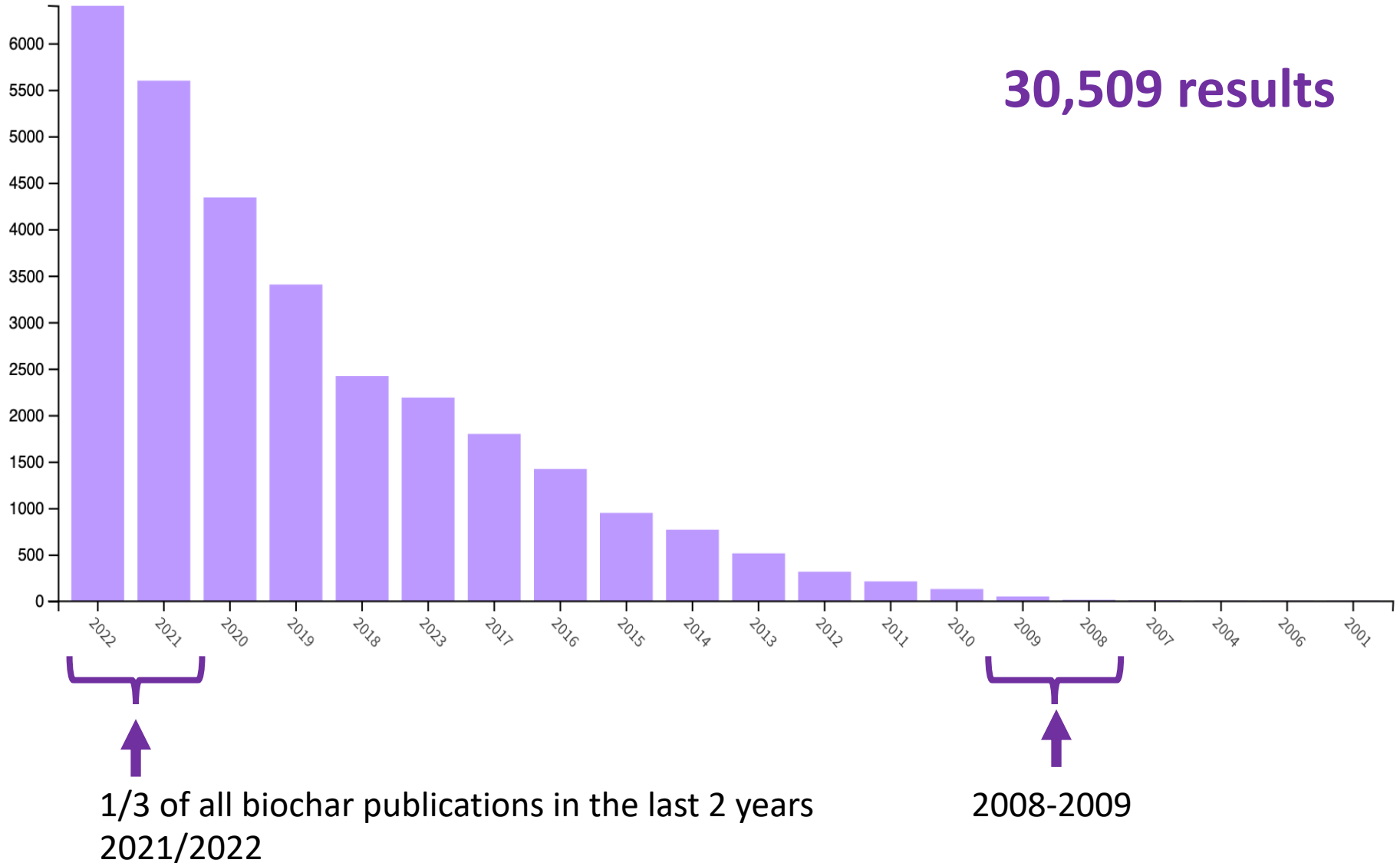


Biochar: When Does it Work? When Doesn't it?

Sebastian Behrens

Minnesota Biochar Summit
June 28th, 2023

Web of Science (June 2023): Search term “biochar” (All Fields)



Web of Science (June 2023): Search term “biochar”; Citation topics



Web of Science (June 2023): Search term “biochar”; Citation topics



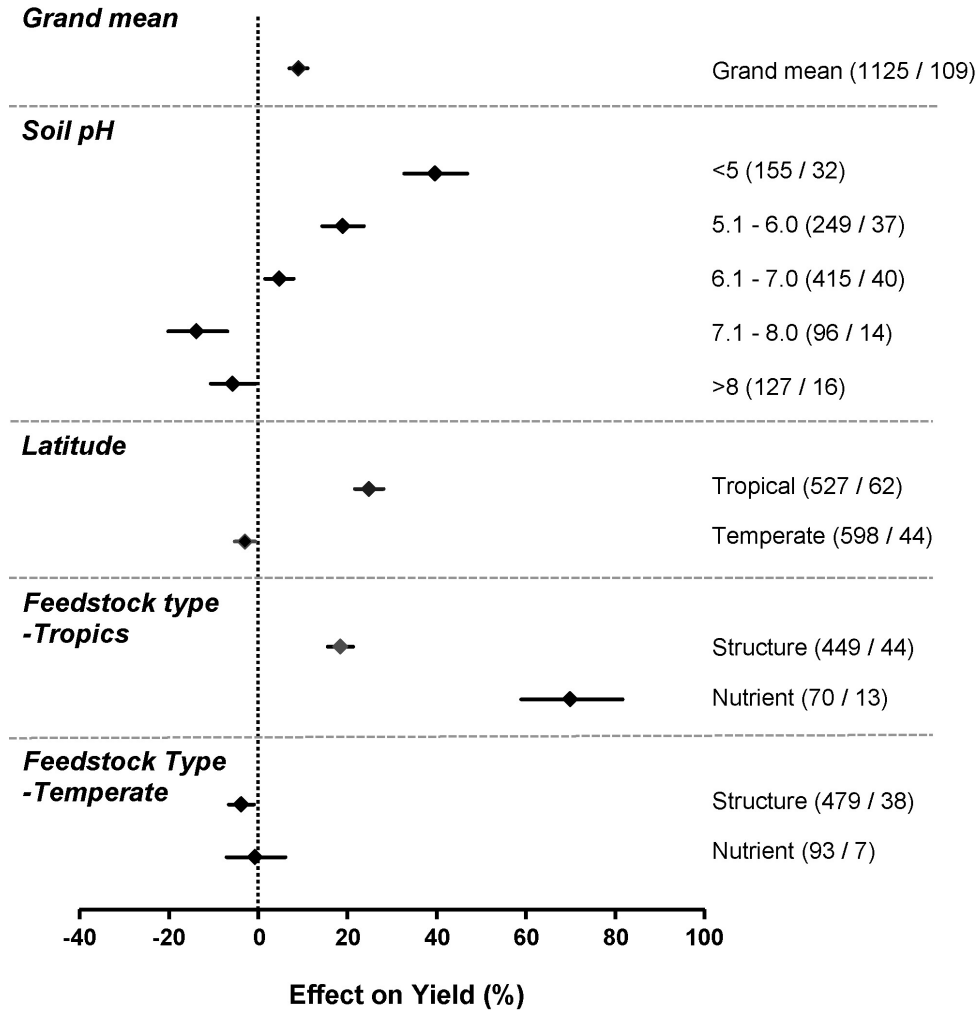
Meta-analysis

Noun: Statistics

1. Examination of data from a number of independent studies of the same subject, in order to determine overall trends.

2. *"An important component of meta-analysis is the investigation of the consistency of treatment effects across studies"*

“Biochar boosts tropical but not temperate crop yields” ?



-> Study claimed that plant productivity increase is not based on biochar feedstock, biochar ash content and resulting soil pH but latitude.

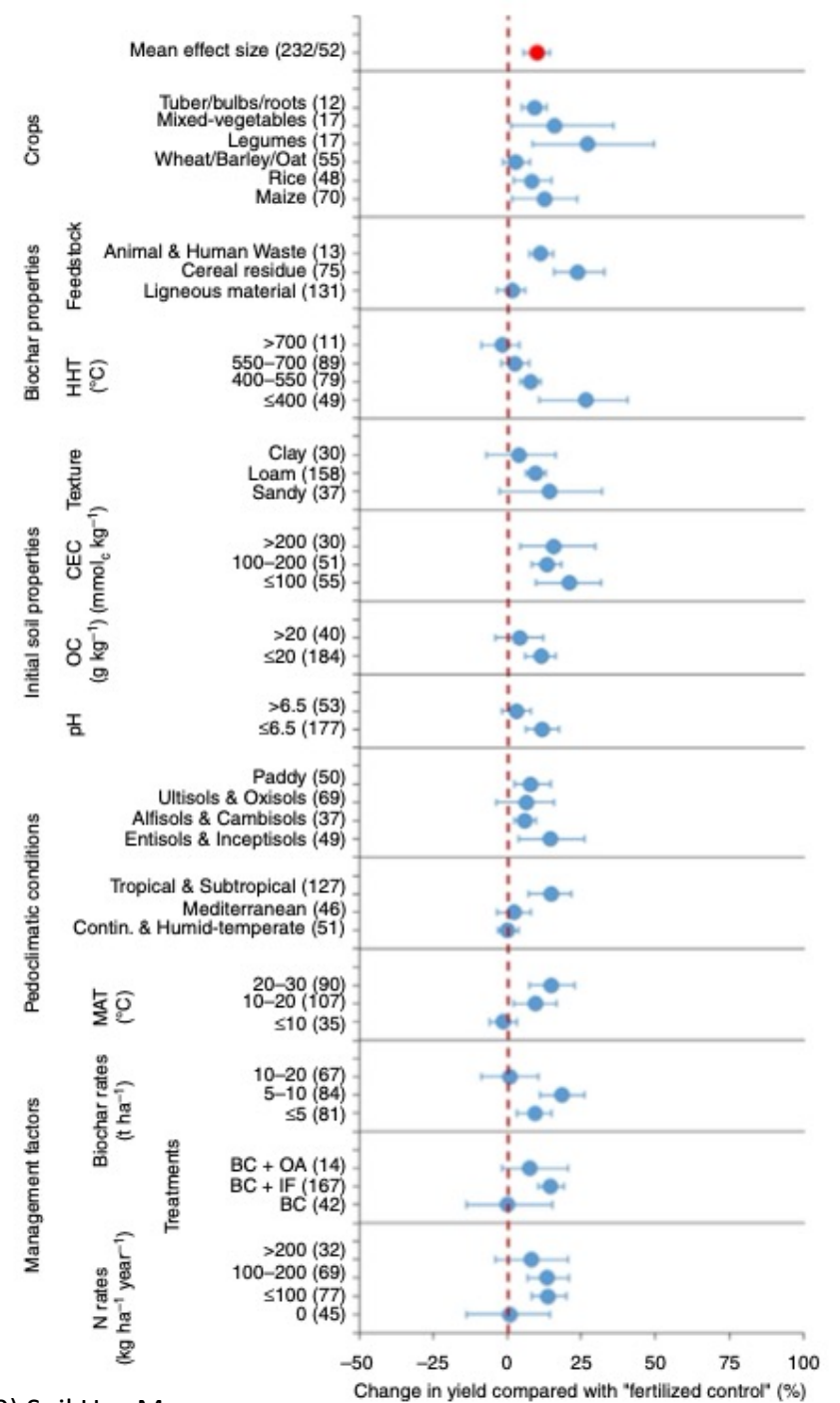
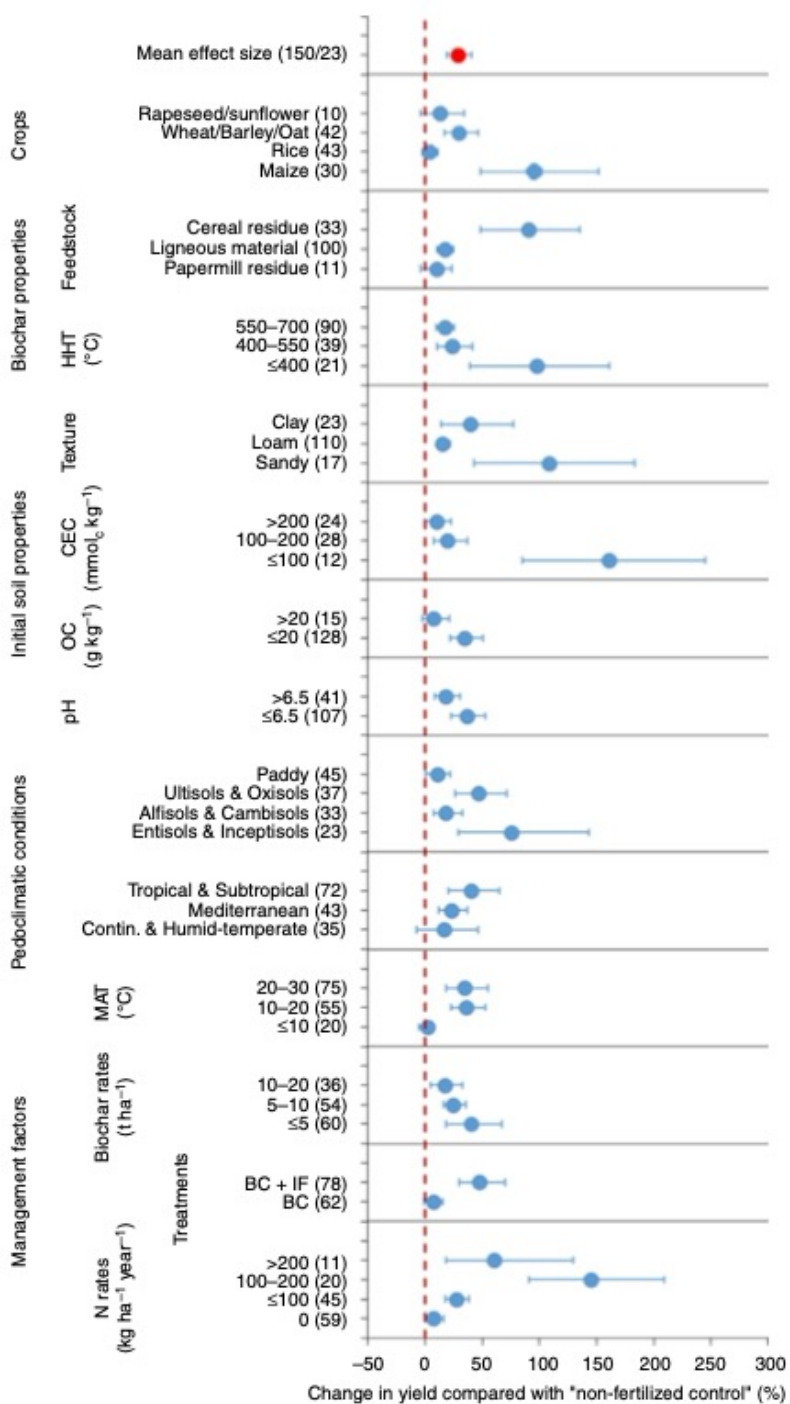
-> Conclusions: In temperate climate zones no biochar effect on plant yield, but in tropical regions 25% yield increase.

INVITED REVIEW

Biochar effects on crop yields with and without fertilizer: A meta-analysis of field studies using separate controls

Lili Ye^{1,2} | Marta Camps-Arbestain¹ | Qinhua Shen¹ | Johannes Lehmann^{3,4,5} |
Balwant Singh⁶ | Muhammad Sabir⁷

“As the response of crop yield to biochar addition was less a result of climatic zones or soil type than fertilizer use (chiefly N additions), **the choice of nutrient addition along with biochar should be priorities** for future research and development regardless of the region”

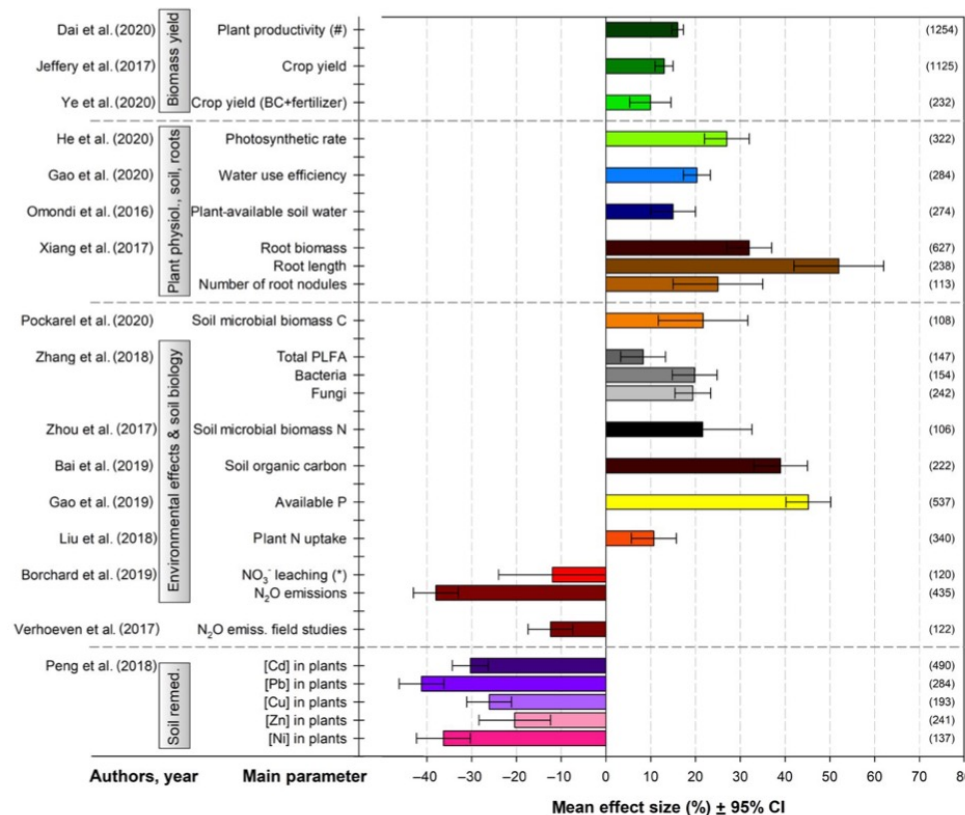


RESEARCH REVIEW

Biochar in agriculture – A systematic review of 26 global meta-analyses

Hans-Peter Schmidt¹  | Claudia Kammann² | Nikolas Hagemann^{3,4} |
 Jens Leifeld⁴  | Thomas D. Bucheli⁴ | Miguel Angel Sánchez Monedero⁵ |
 Maria Luz Cayuela⁵ 

- 1,500 independent studies
- 18.973 data sets
- 65 agronomic parameters



What to consider when evaluating soil/plant system responses to biochar:

- Feedstock
- Pyrolysis conditions (highest treatment temperature (HTT: 400°C-750°C), residence time at HTT)
- Physio-chemical properties of the biochar (C org., H/C ratio, P, ash content)
- Biochar storage, time since production, and water content

- What system constrains need to be addressed?
- Soil type & properties
- Treatments applied before or after pyrolysis (minerals, “binder” such as clay or starch, or mixing with inorganic fertilizer or compost -
> Nutrient enhanced biochar formulations!
- Application rates & mixing:
 - Low application rates <1 Mg ha⁻¹
 - High application rates 10-50 Mg ha⁻¹
- Biochar – soil/compost systems change over time!!! (1-3 weeks, 1-6 month, > 6 month)

Biochar as an additive in organic waste composting

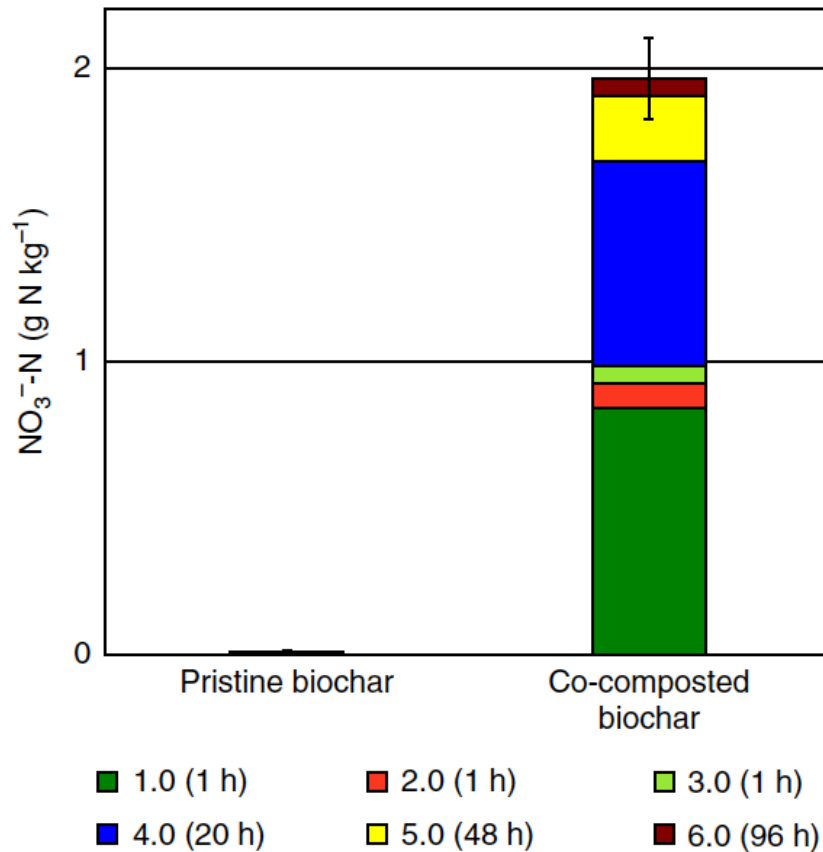


Pristine biochar

Co-composted biochar

“Slow release” of nitrate

Standard extraction procedures (2 M KCl, 1 h) underestimate NO_3^- content of co-composted biochar!



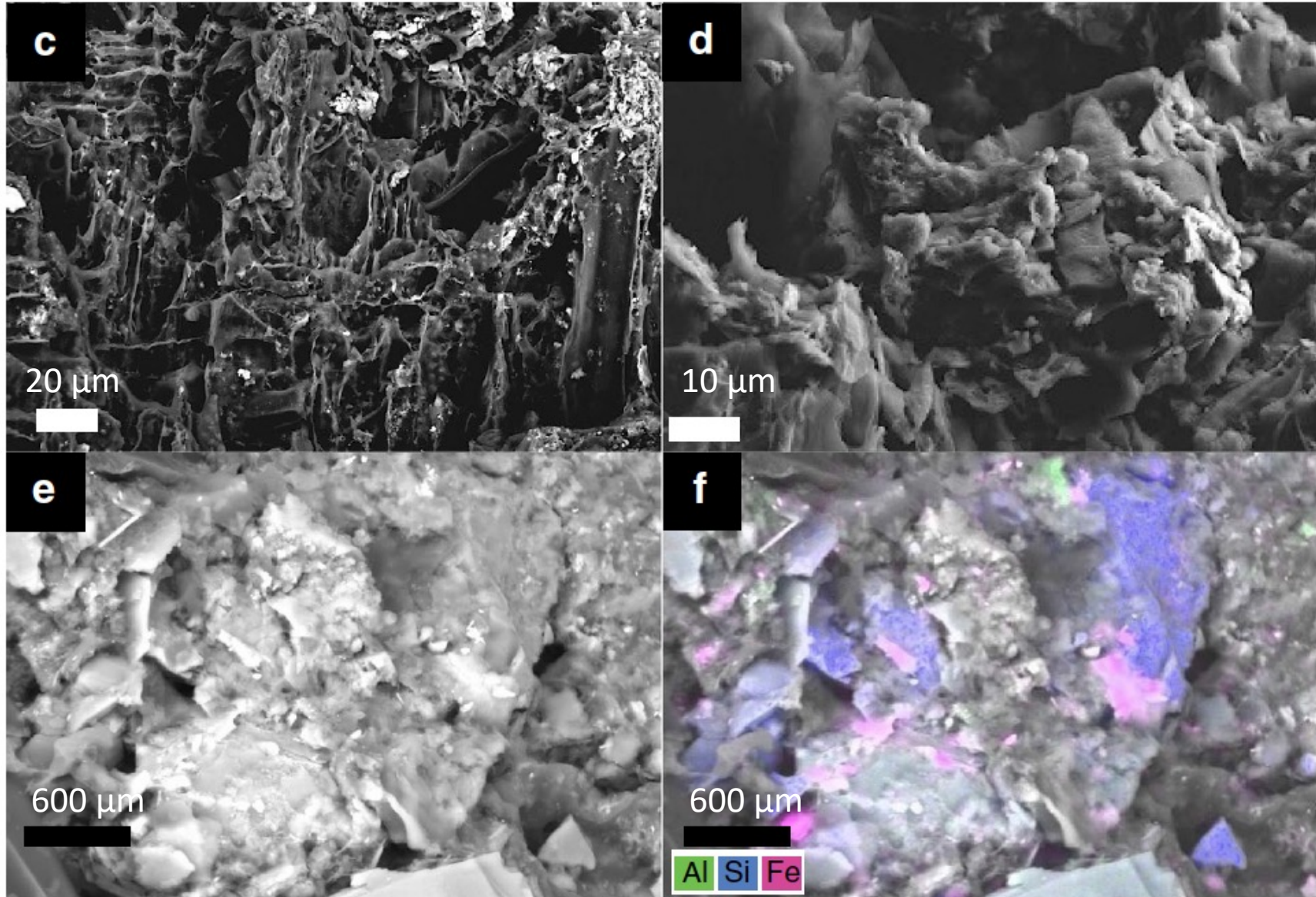
“Slow release” is...

- Abiotic process
- Caused by biochar (up to 5 g N kg⁻¹ biochar)
- Is present also in soil-aged biochar (when soaked in NO_3^- solution)

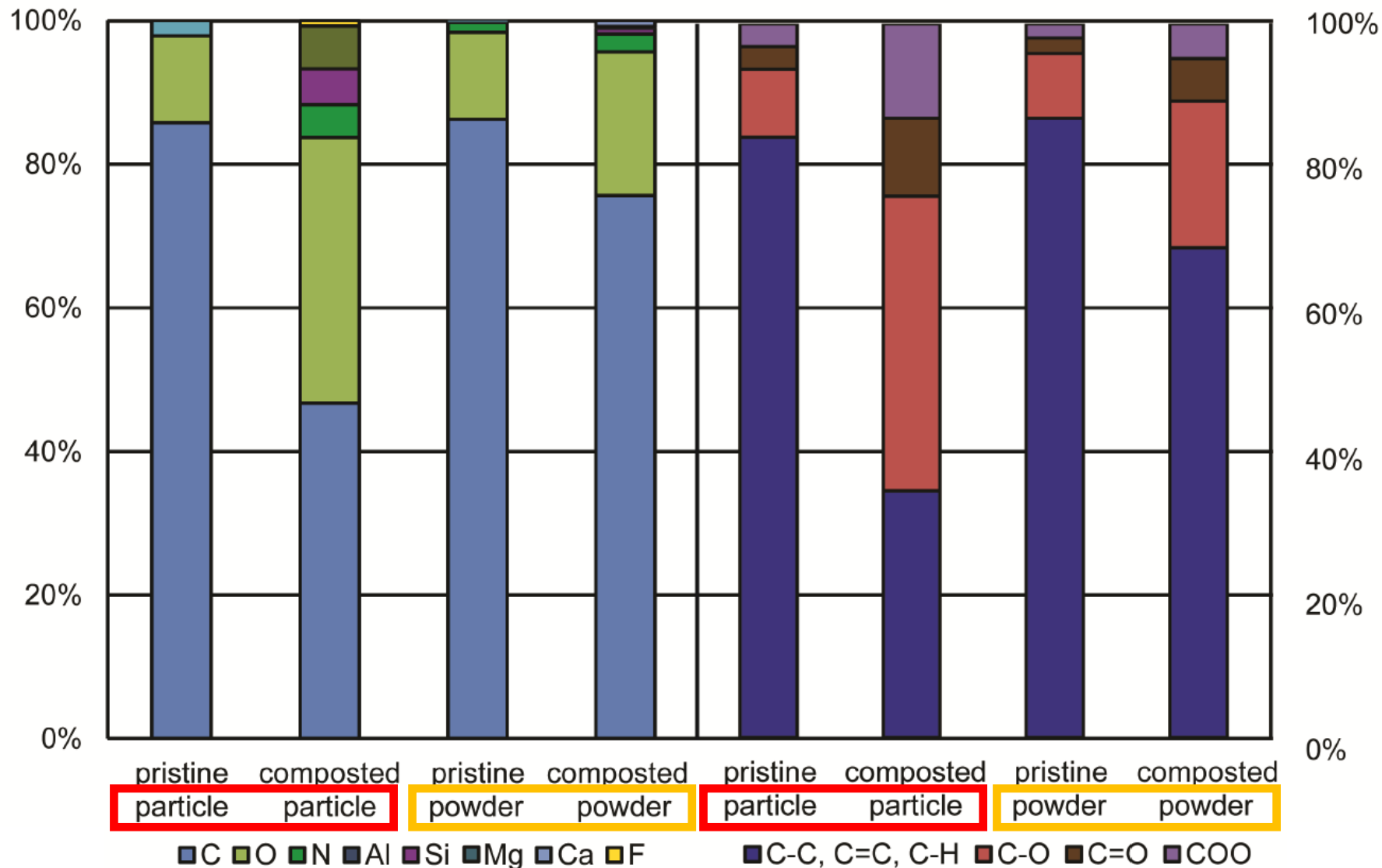
Co-composting of biochar increases the affinity to NO_3^-

Hagemann *et al.*, PLoS One, 2017

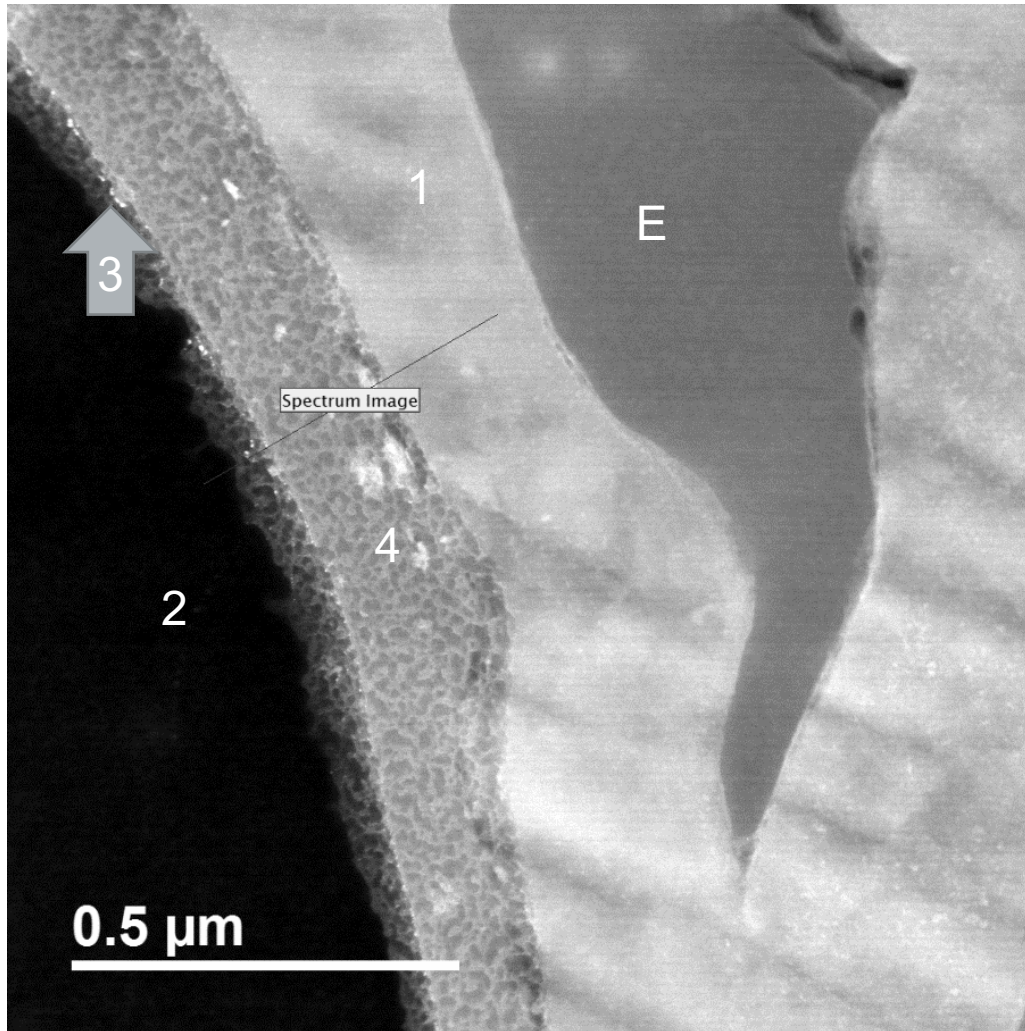
Identification of biochar surface modifications induced by co-composting using SEM and EDS mapping



Identification of biochar surface modifications by X-ray Photoelectron Spectroscopy (XPS)

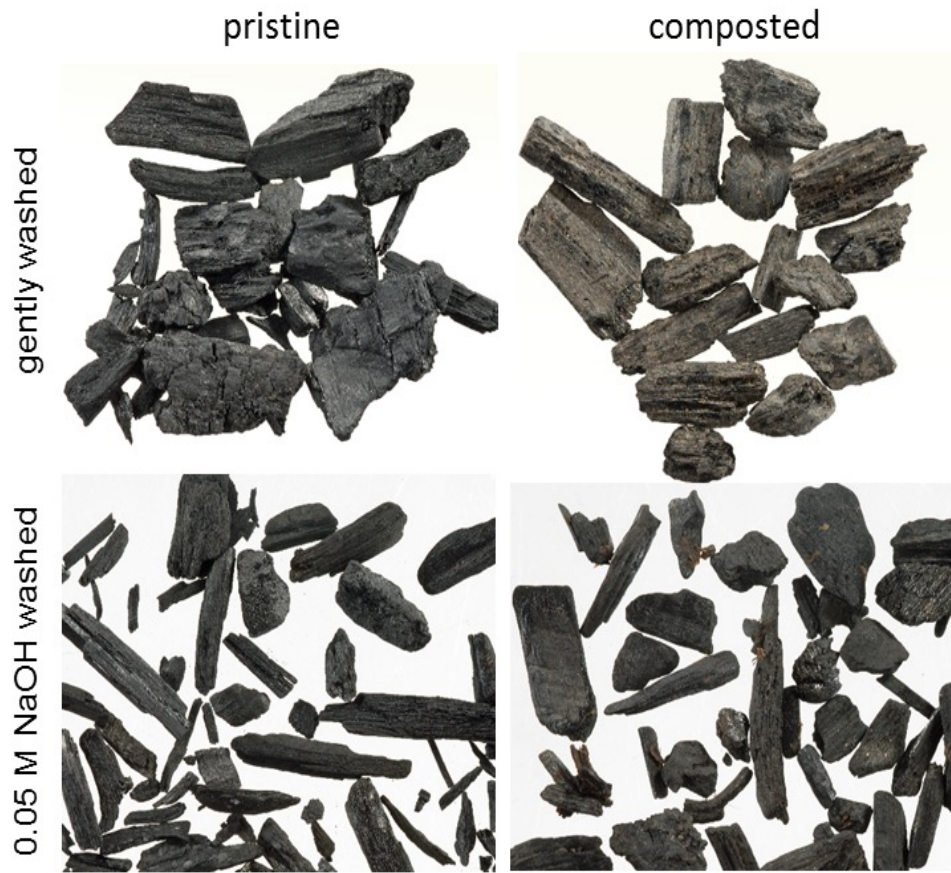


STEM micrograph of co-composted biochar with organic coating



- (1) Biochar, no N or O
- (2) Resin
- (E) Empty pore: resin did not penetrate this pore
- (3) Gold, just in trace amounts, this surface was “hidden” in a pore
- (4) Porous coating contains N and O

Washing with 0.05 M NaOH



Co-composted biochar higher in nitrate, OC, carbonate, Ca, K

- entirely new C species
- sorption of compost/ soil OM

Co-composted washing solution contains...

- compost organic carbon
- biochar nano-particles

Organic coating has higher *Electron Exchange Capacity* than both compost and biochar (per mol of C)!

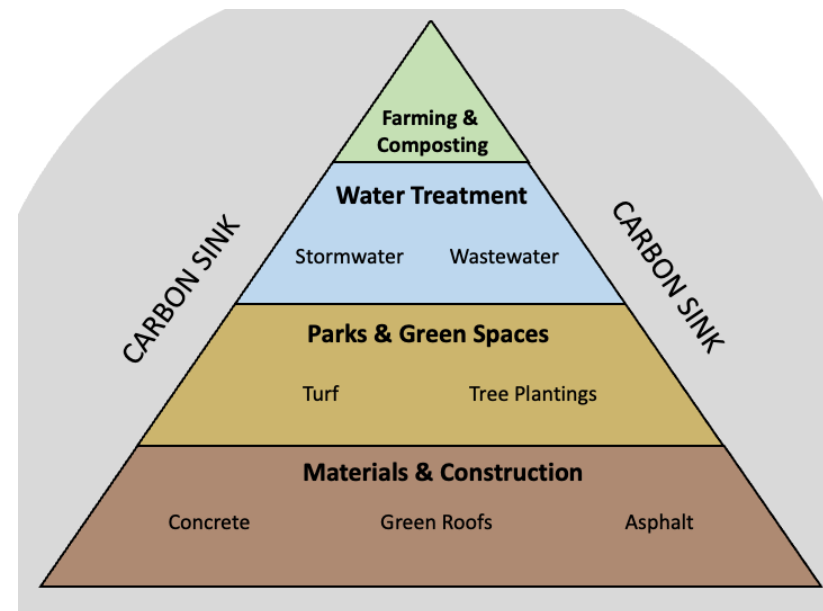
Conclusions



- Co-composting coats biochar in organo-mineral layer that increases nitrate retention
- Formulations combining biochar with fertilizer (inorganic or as compost mixture) at low application rates show positive effect on plant yield independent on climatic zones or soil type
- Nutrient-enriched biochars are likely to be the most cost-effective approach for broadacre cropping in temperate climate zones.
- Besides increased plant yield positive biochar effects stretch beyond one growing season by impacting soil carbon storage, fertilizer use efficiency, causing less nutrient loss and consequential environmental harm

Future research needs

- Biochar-soil-plant interactions in the field over the longer term
- Effect of biochar properties on microbial nutrient cycling in soil and compost
- Biochars can be produced for specific applications and to meet environmental constraints
- Guidelines and safety standards on producing and selecting the “best” biochar/ biochar-compost formulations to meet the needs and/or environmental constraints of specific applications (e.g. soils, stormwater, remediation).





Experimental Setup

- Compost feedstock: cow, pig, horse and poultry manure
- 4 windrows of 20 m³
 - 3 biochar treatments (4.4 % w/w DM char)
 - 1 control treatment w/o additive
- Triplicates (not randomized)
- Composting according to Swiss Guidelines for high grade compost:
 - Daily turning / mechanical aeration during first 4 weeks
 - Subsequent turning / aeration every 3rd day
 - Maturation after 7 to 8 weeks



Biochar – soil/compost systems change over time - > 3 Stages

Stage 1 (1-3 weeks)

Initial reaction of pure or nutrient-enriched biochar in soil, effects on germination or seedlings -> Dominated by dissolution of compounds from biochar

Stage 2 (1-6 months)

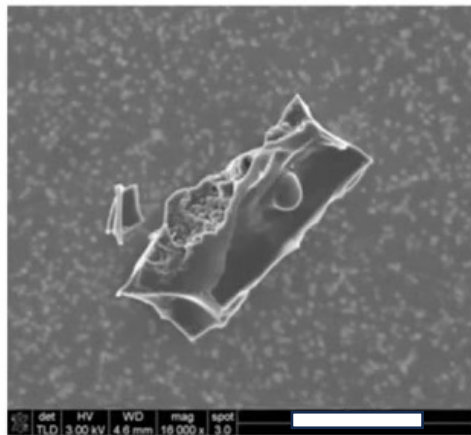
Soil-biochar interactions change the reactive surfaces on biochar, effects on plant growth from seedling to harvest -> plant root intercept and interact with biochar; plant root hairs enter biochar pores, roots wrap around biochar, and very small biochar particles can attach to root surfaces. Biochar affects the abundance of specific microorganisms especially in the rhizosphere

Stage 3 (> 6 months)

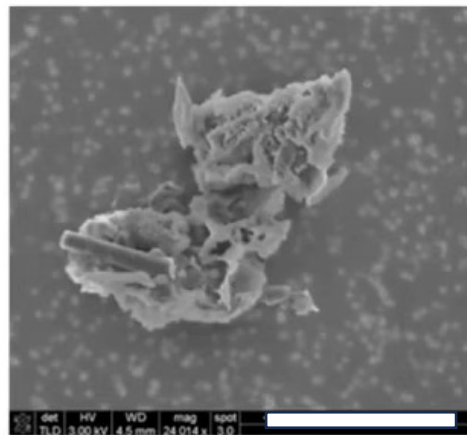
Biochar “ages” in soil, physical disintegration long term chemical alteration of the biochar surface, effects on subsequent crop cycles

Who knows what biochar is?

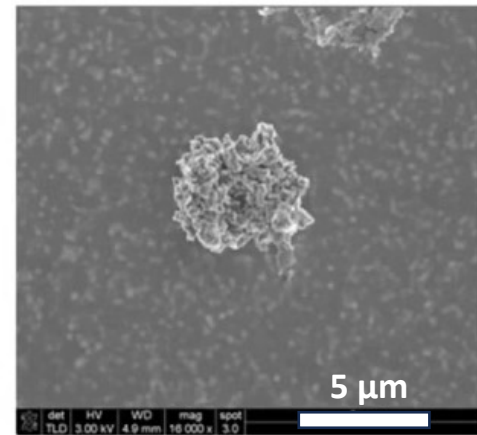
Physicochemical properties					
Sample	pH	Electrical Conductivity ($\mu\text{s}/\text{cm}$)	WHC ^a (%)	Ash Content (%) (750° C)	S _{BET} ^b ($\text{m}^2 \text{g}^{-1}$)
	S.D.	S.D.	S.D.	S.D.	S.D.
Wood	10.4 ± 0.0	1183 ± 205	266 ± 16	10.6 ± 0.2	407.2 ± 5.2
Paper-Sludge	10.4 ± 0.1	336 ± 46	233 ± 14	25.1 ± 1.0	116.9 ± 2.0
Sewage-Sludge	6.7 ± 0.2	162 ± 57	27 ± 5	69.5 ± 0.3	67.3 ± 1.3



Wood



husk & paper



biosolid

One possible definition of biochar (European Biochar Certificate):

- Biochar is a porous, carbonaceous material
- That is produced by pyrolysis of biomass
- Biochar is applied in a way that the contained carbon remains stored as a long-term C sink
- It can replace fossil carbon in industrial manufacturing
- It is not made to be burnt for energy generation (which sets it apart from charcoal)

Very broad and somehow vague