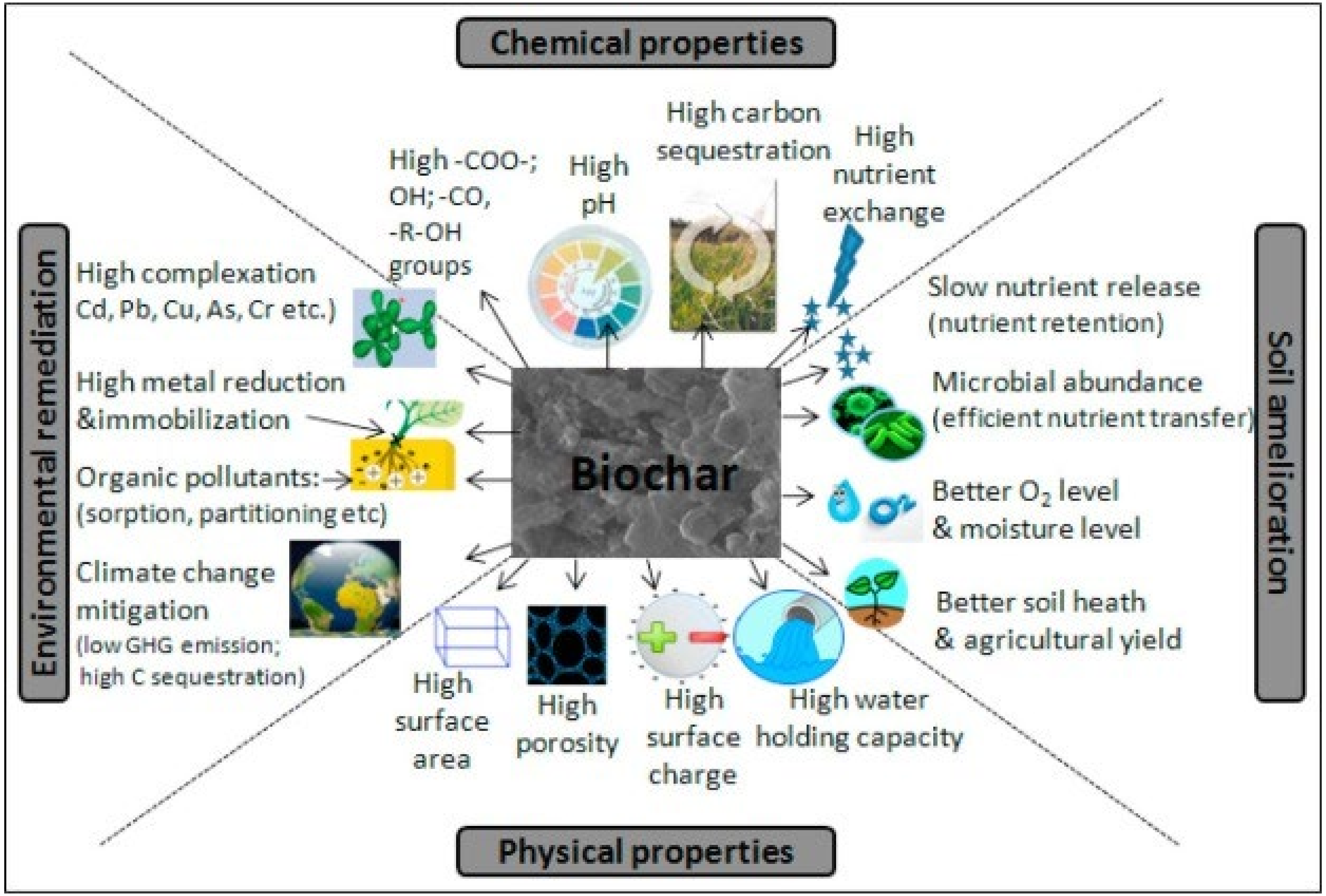
EBNet Working Group: Biochars for Pollution Prevention

Reviving bioremediation options and sustainability: Microbial enhanced biochar opportunities

Frederic Coulon

Biochar in Environmental Biotechnology: Webinar
12 February 2024

Relevance and application of biochar as tool for soil



Das et al., 2021; https://www.intechopen.com/chapters/76192

What are we still missing?

- ❑ Mechanisms of biochar-microbe interactions are poorly understood
- ❑ Match-making biochar with soil microbial degraders yields unpredictable outcome
- ❑ Can biochar alleviate the salinity effect on soil microbial community biodegradation activities?
- ❑ Can biochar provide us with the opportunity to increase sorption/decrease bioavailability of the chemicals, and increase surface contact of contaminants with the soil microbial community?

Biochar testing and selection

UK Biochar Research Centre
reducing and removing CO_2 while improving soils: a significant and sustainable response to climate change

Sewage Sludge Pellets (SSP)

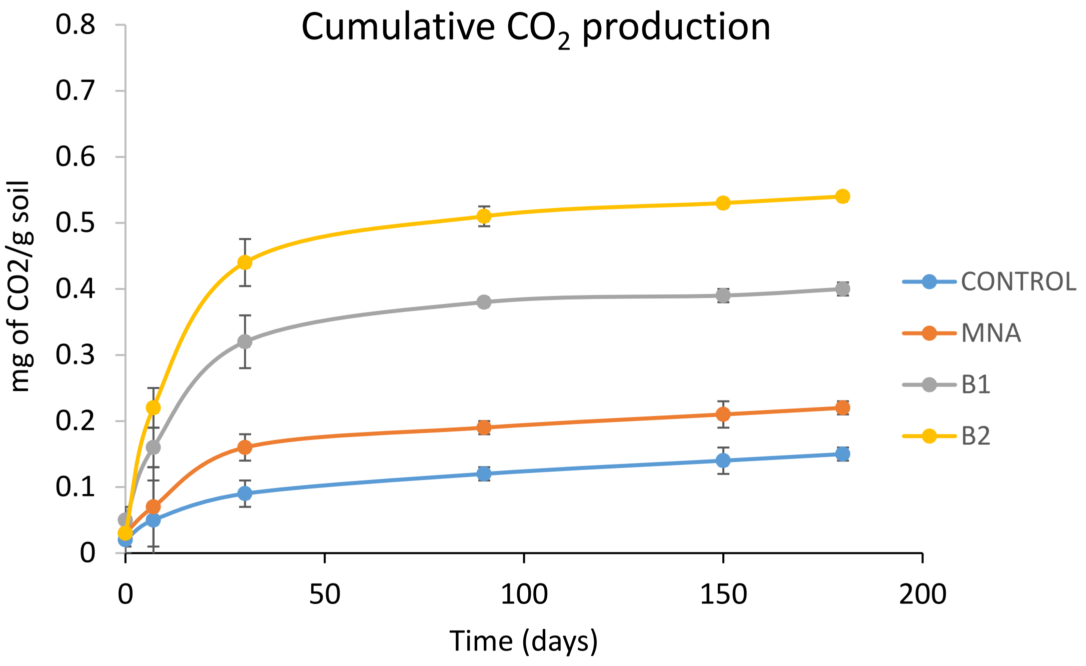
Basic Utility Properties		Mean	Run-to-Run Variation, SD(n)
Moisture[a]	wt.% (a.r.)	2.48	0.08 (2)
C_{tot}	wt.% (db.)	29.53	0.42 (2)
H	wt.% (db.)	1.33	0.07 (2)
O (by difference)	wt.% (db.)	6.50	0.47 (2)
$H:C_{tot}$	Molar ratio	0.54	0.03 (2)
$O:C_{tot}$	Molar ratio	0.17	0.01 (2)
C_{org}	wt.% (db.)	tbd	tbd
$H:C_{org}$	Molar ratio	tbd	tbd
Total ash[a]	wt.% (db.)	58.89	0.45 (2)
Total N	wt.% (db.)	3.75	0.08 (2)
pH	[-]	8.17	0.64 (2)
Electric conductivity	dS/m	280.80	15.3 (2)
Liming (if pH above 7)	% CaCO3	tbd	tbd
Biochar C stability[b]	% C-basis	84.40	0.04 (2)

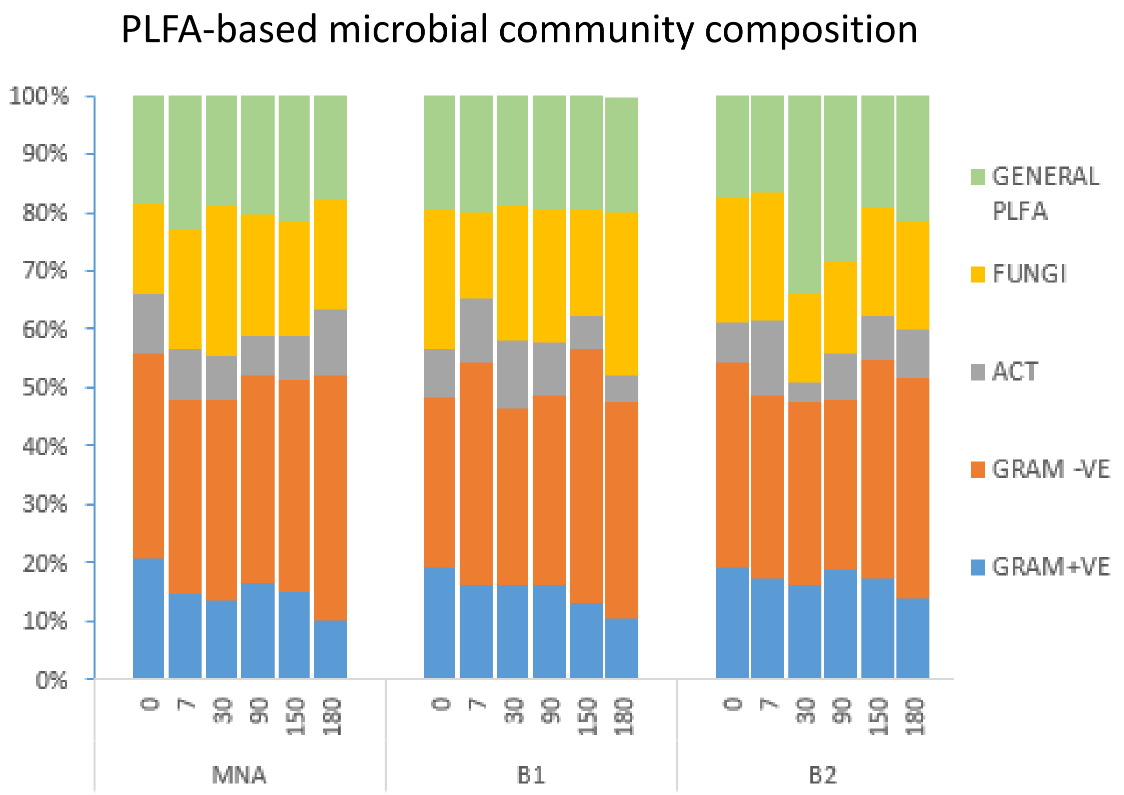
Wheat Straw Pellets (WSP)

Basic Utility Properties		Mean	Run-to-Run Variation, SD(n)
Moisture[a]	wt% (a.r.)	1.88	0.08 (7)
C_{tot}	wt% (d.b.)	68.26	1.10 (6)
H	wt% (d.b.)	2.10	0.25 (6)
O (by difference)	wt% (d.b.)	6.92	0.33 (6)
$H:C_{tot}$	Molar ratio	0.37	0.05 (6)
$O:C_{tot}$	Molar ratio	0.08	0.00 (6)
C_{org}	wt% (d.b.)	tbd	tbd
$H:C_{org}$	Molar ratio	tbd	tbd
Total ash[a]	wt% (d.b.)	21.25	1.09 (7)
Total N	wt% (d.b.)	1.39	0.10 (6)
pH	[-]	9.94	0.16 (4)
Electric conductivity	dS/m	1.70	0.43 (4)
Liming (if pH above 7)	% $CaCO_3$	tbd	tbd
Biochar C stability[b]	% C-basis	96.51	0.30 (5)

https://www.biochar.ac.uk/standard_materials.php

Microbial activity and dynamics





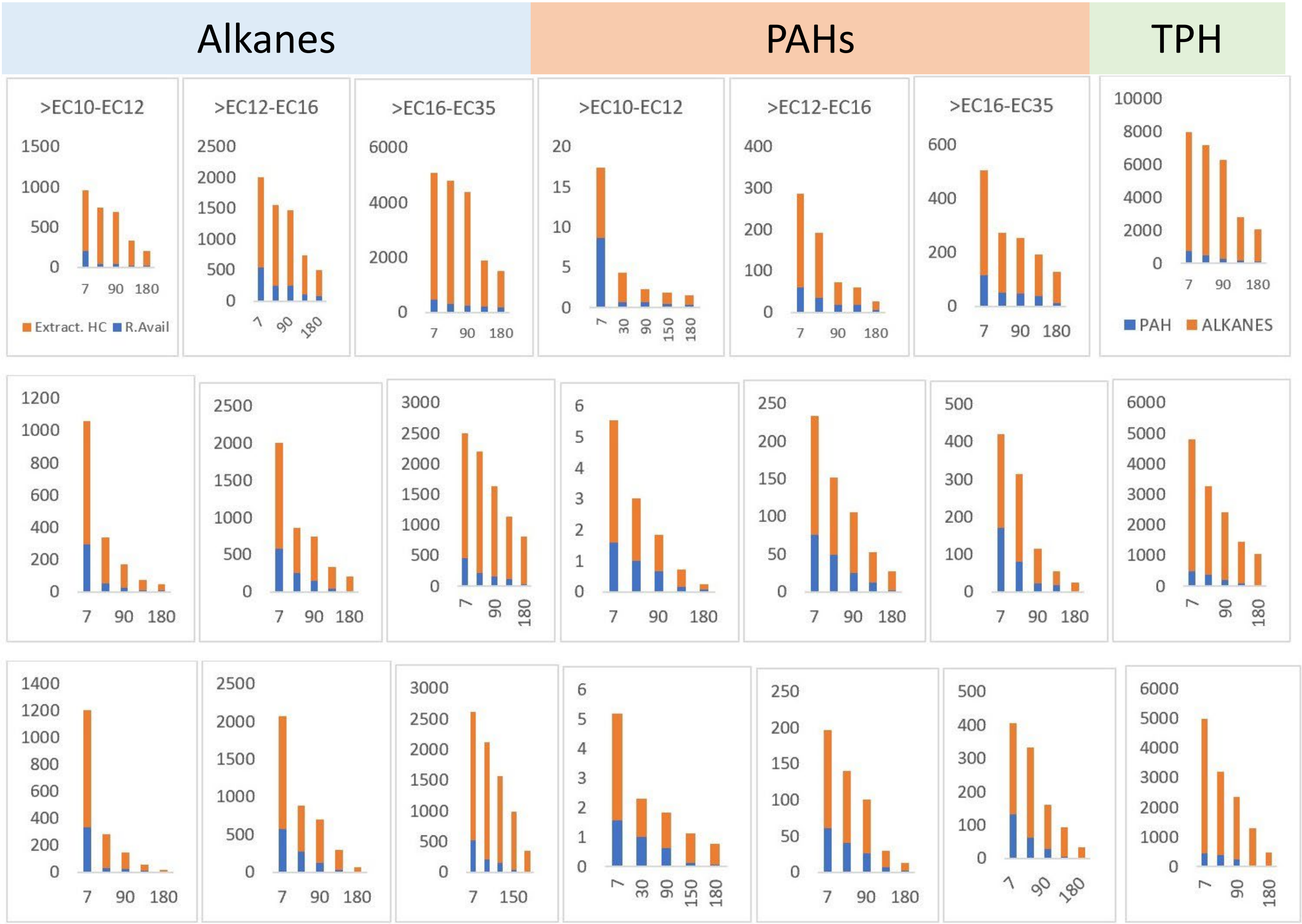
- Respiration increased up to 3 folds higher with SSP compared to MNA (B1).
- Respiration with addition of WSP (B2) 1.3 times greater than SSP (B1)

- Biomass increase by 22% with B1 after 30 days compared to MNA
- Biomass increase by 25% with B2 after 30 days compared to MNA

Azuazu et al., 2024, Cranfield PhD thesis

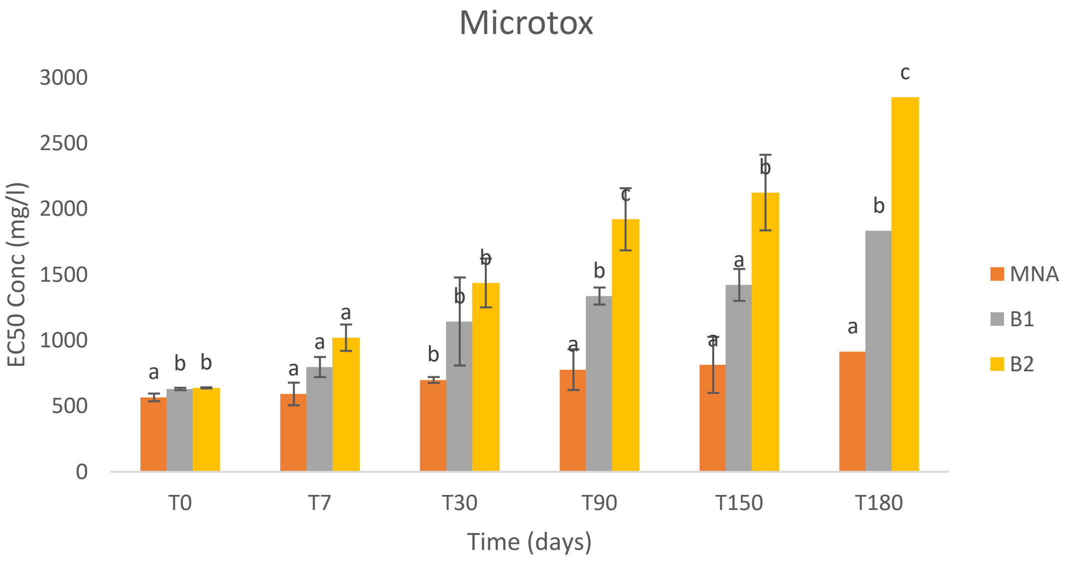
Hydrocarbons degradation

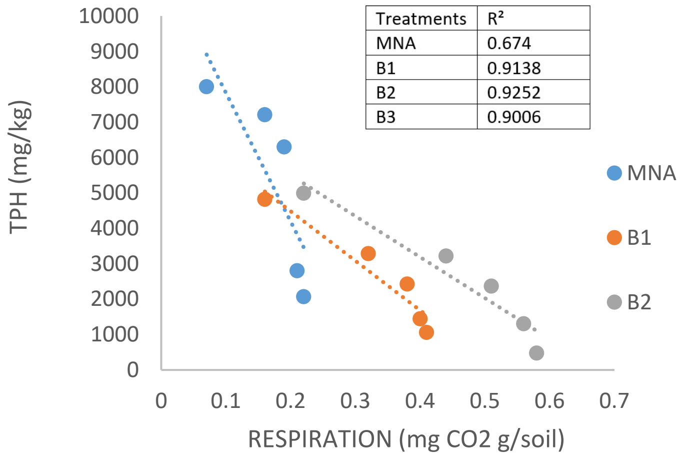
- TPH degradation
  - 39% MNA
  - >76% B1 and B2
- Aliphatic $EC_{16–35}$ degradation
  - 45% MNA
  - 49% B1
  - 76% B2
- Aromatics $EC_{16–21}$ degradation
  - 10% MNA
  - 28% B1
  - 32% B2
- TPH rate 2.1 – 2.3 times faster (71-78 mg kg^{-1}/day) compared to MNA (34 mg kg^{-1}/day)



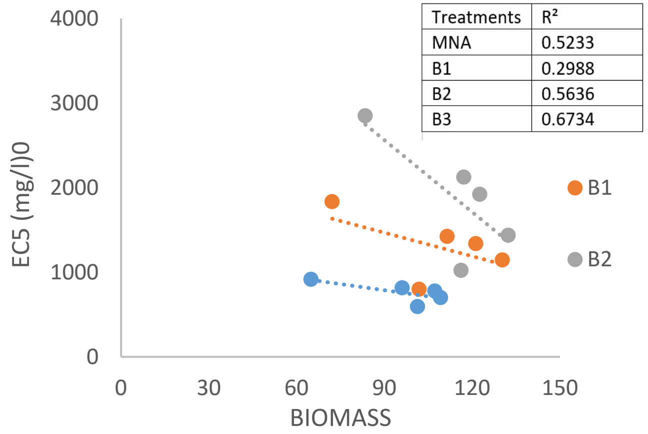
Azuazu et al., 2024, Cranfield PhD thesis

Ecotoxicological assays and correlations

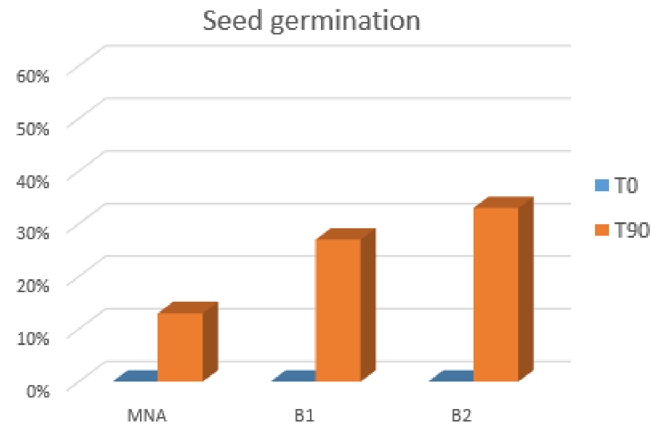


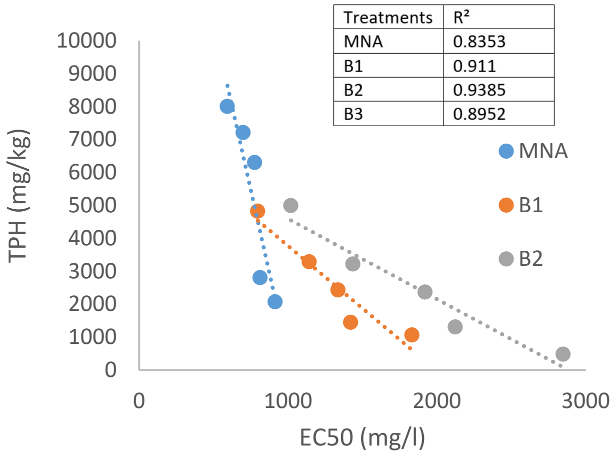


Treatments	R²
MNA	0.674
B1	0.9138
B2	0.9252
B3	0.9006

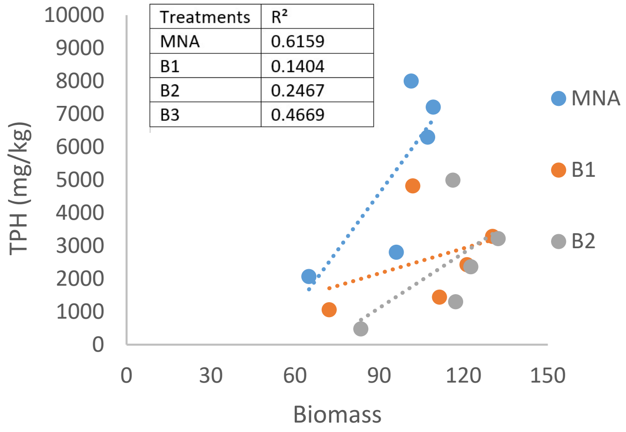


Treatments	R²
MNA	0.5233
B1	0.2988
B2	0.5636
B3	0.6734





Treatments	R²
MNA	0.8353
B1	0.911
B2	0.9385
B3	0.8952



Treatments	R²
MNA	0.6159
B1	0.1404
B2	0.2467
B3	0.4669

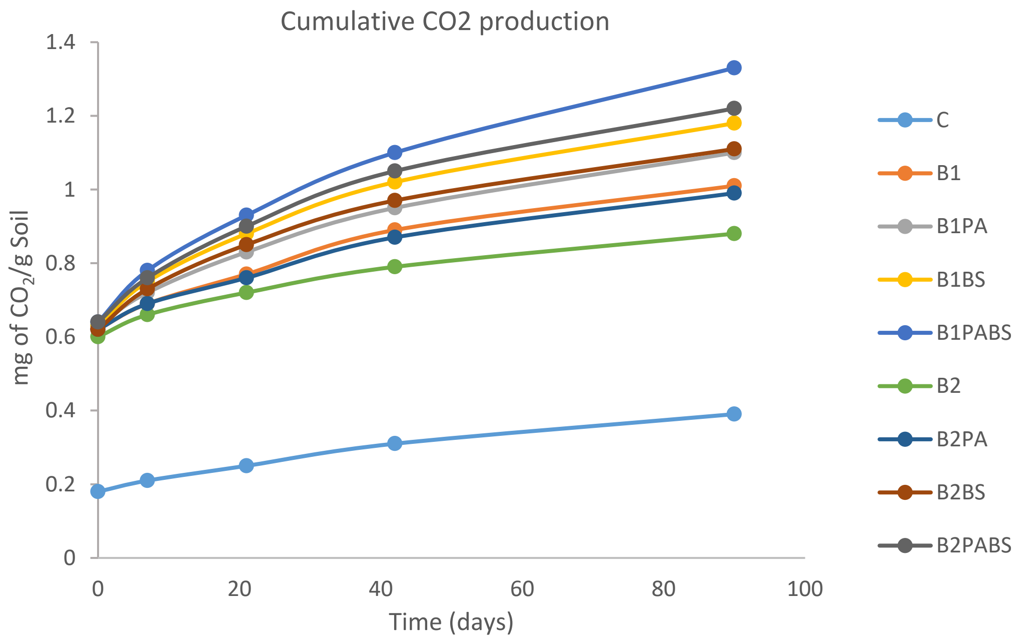
Azuazu et al., 2024, Cranfield PhD thesis

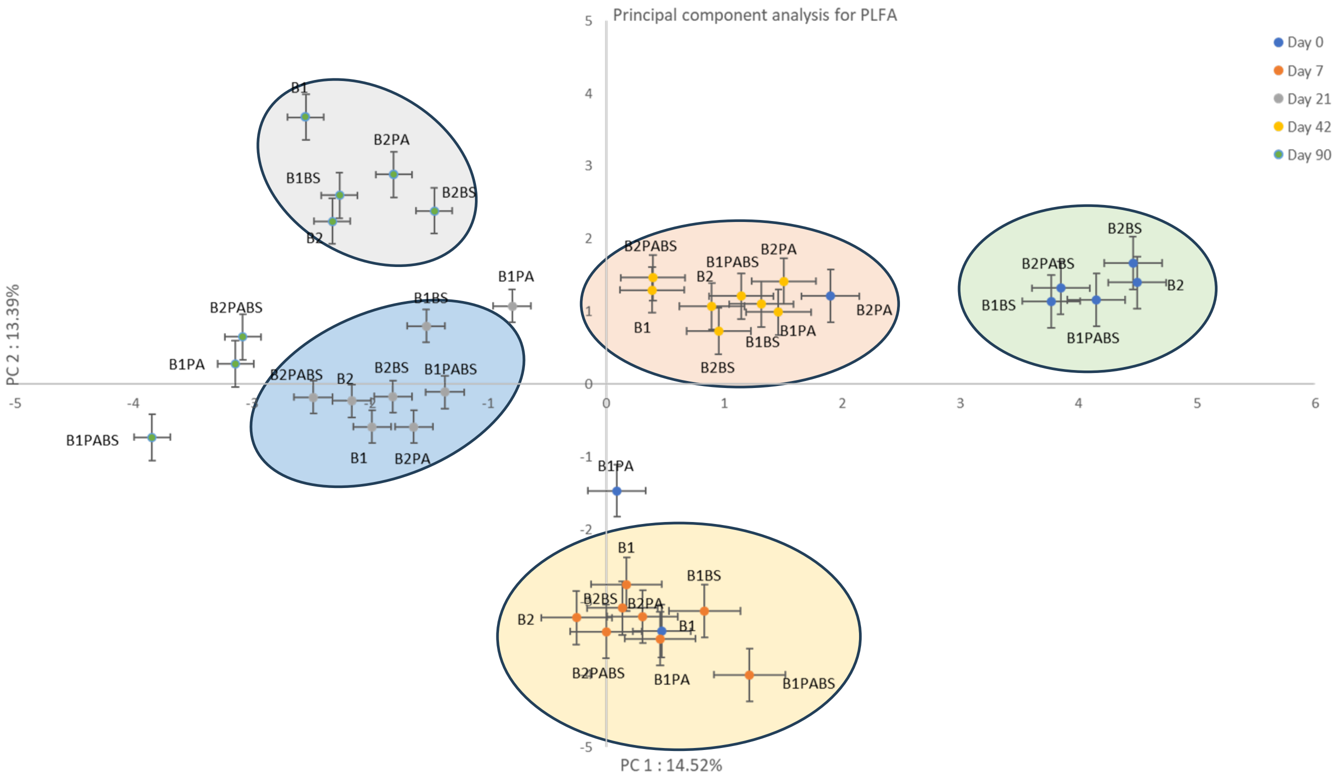
Assessing the performance of bioaugmented biochar for recurring oil contaminated soils

Soil mesocosm (2 kg) incubated for 90 days at room temperature	
C	Control
Biochar 1 (B1)	Crude oil remediated soil + spiked again with 10,000 mg kg^{-1} crude oil + 10% (w/w) WSP biochar
Biochar 1 + PA (B1PA)	Crude oil remediated soil + spiked again with 10,000 mg kg^{-1} crude oil + 10% (w/w) WSP biochar + *Pseudomonas aeruginosa*
Biochar 1 + BS (B1BS)	Crude oil remediated soil + spiked again with 10,000 mg kg^{-1} crude oil + 10% (w/w) WSP biochar + *Bacillus sonorensis*
Biochar 1 + PA + BS (B1PABS)	Crude oil remediated soil + spiked again with 10,000 mg kg^{-1} crude oil + 10% (w/w) WSP biochar + *Pseudomonas aeruginosa* + *Bacillus sonorensis*
Biochar 2 (B2)	Crude oil remediated soil + spiked again with 10,000 mg kg^{-1} crude oil + 10% (w/w) SSP biochar
Biochar 2 + PA (B2PA)	Crude oil remediated soil + spiked again with 10,000 mg kg^{-1} crude oil + 10% (w/w) SSP biochar + *Pseudomonas aeruginosa*
Biochar 2 + BS (B2BS)	Crude oil remediated soil + spiked again with 10,000 mg kg^{-1} crude oil + 10% (w/w) SSP biochar + *Bacillus sonorensis*
Biochar 2 + PA + BS (B2PABS)	Crude oil remediated soil + spiked again with 10,000 mg kg^{-1} crude oil + 10% (w/w) SSP biochar + *Pseudomonas aeruginosa* + *Bacillus sonorensis*

Azuazu et al., 2024, Cranfield PhD thesis

Influence of biochar and bioaugmentation on respiration and soil community



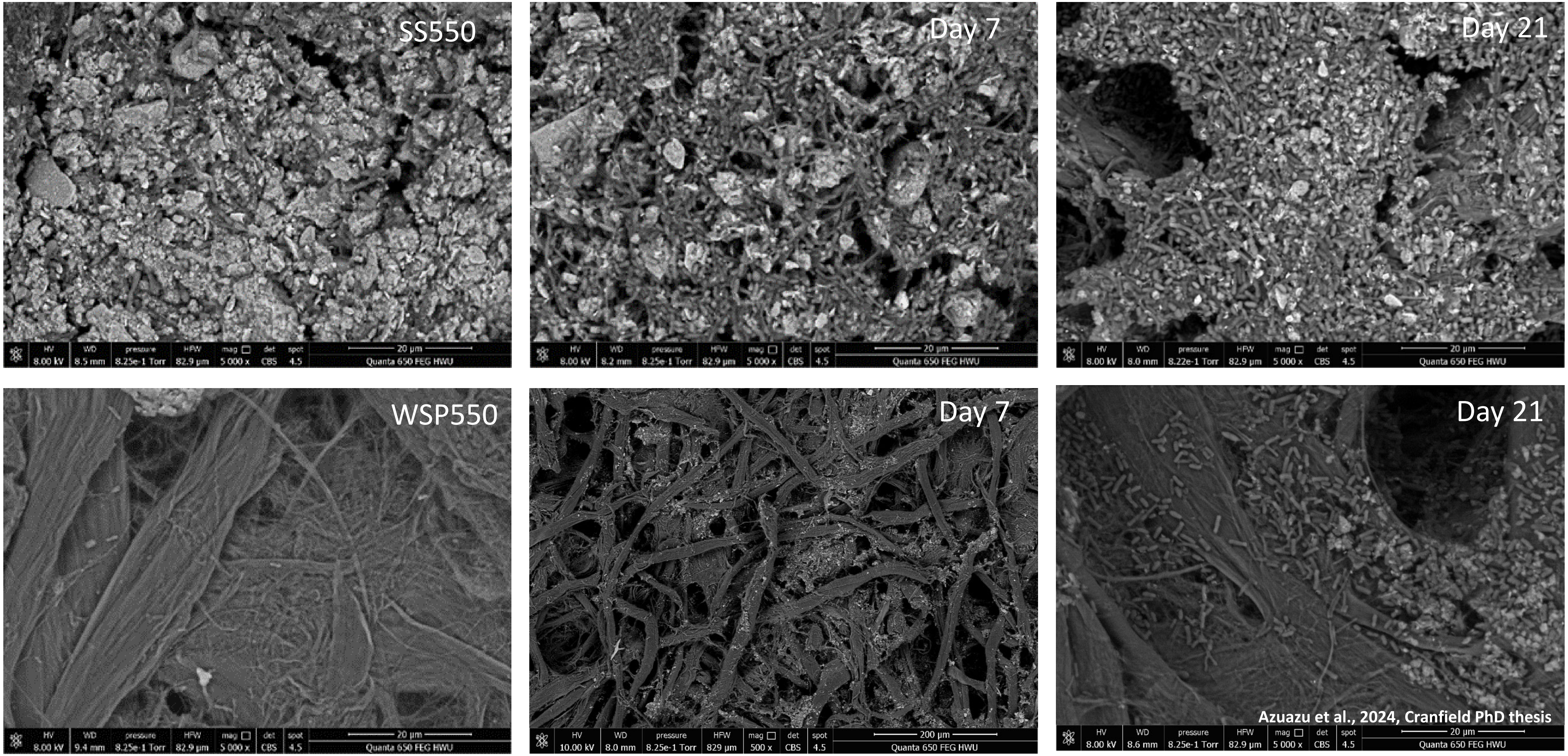


- CO_2 production increased up to 3.5 times compared to control
- CO_2 production increased up to 2 folds for combined bioaugmentation strategies compared to either biochar application

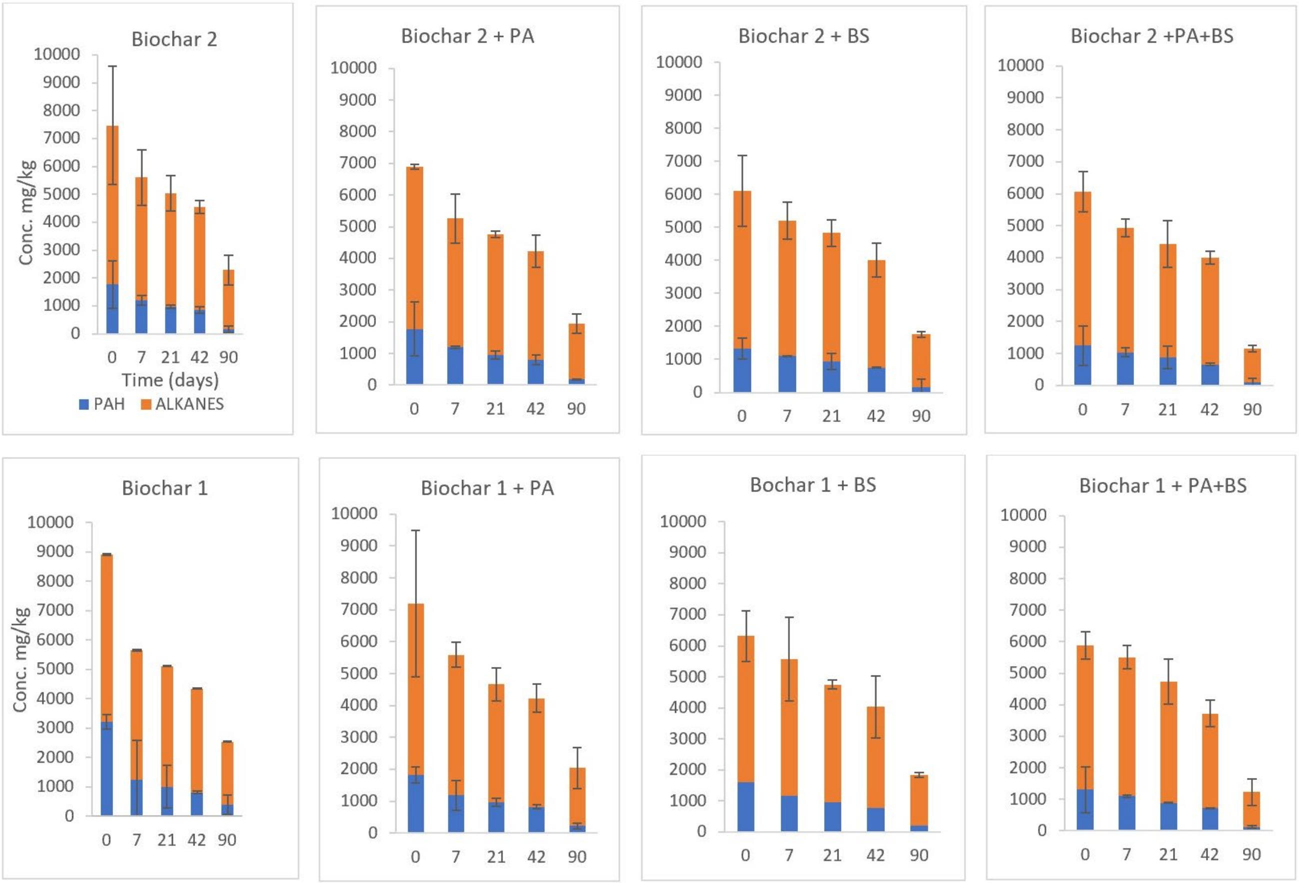
- Rapid temporal shifts in microbial community structure in response to TPH, with patterns of convergence and divergence indicating adaptability.
- Biochar type and bacterial strain directly influence the microbial community structure and its TPH degradation capability.

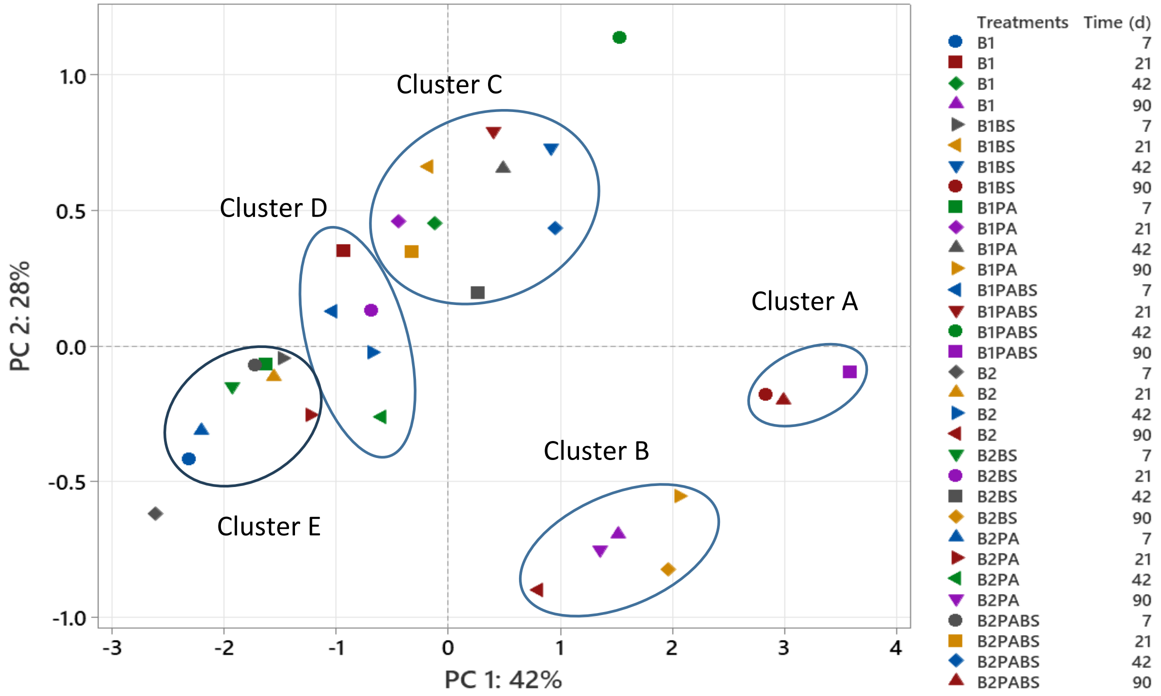
Azuazu et al., 2024, Cranfield PhD thesis

Scanning electron microscopy images of immobilized bacteria on Sewage Sludge Pellet biochar (SSP550) and Wheat Straw Pellets biochar (WSP550)



Hydrocarbons and community dynamics

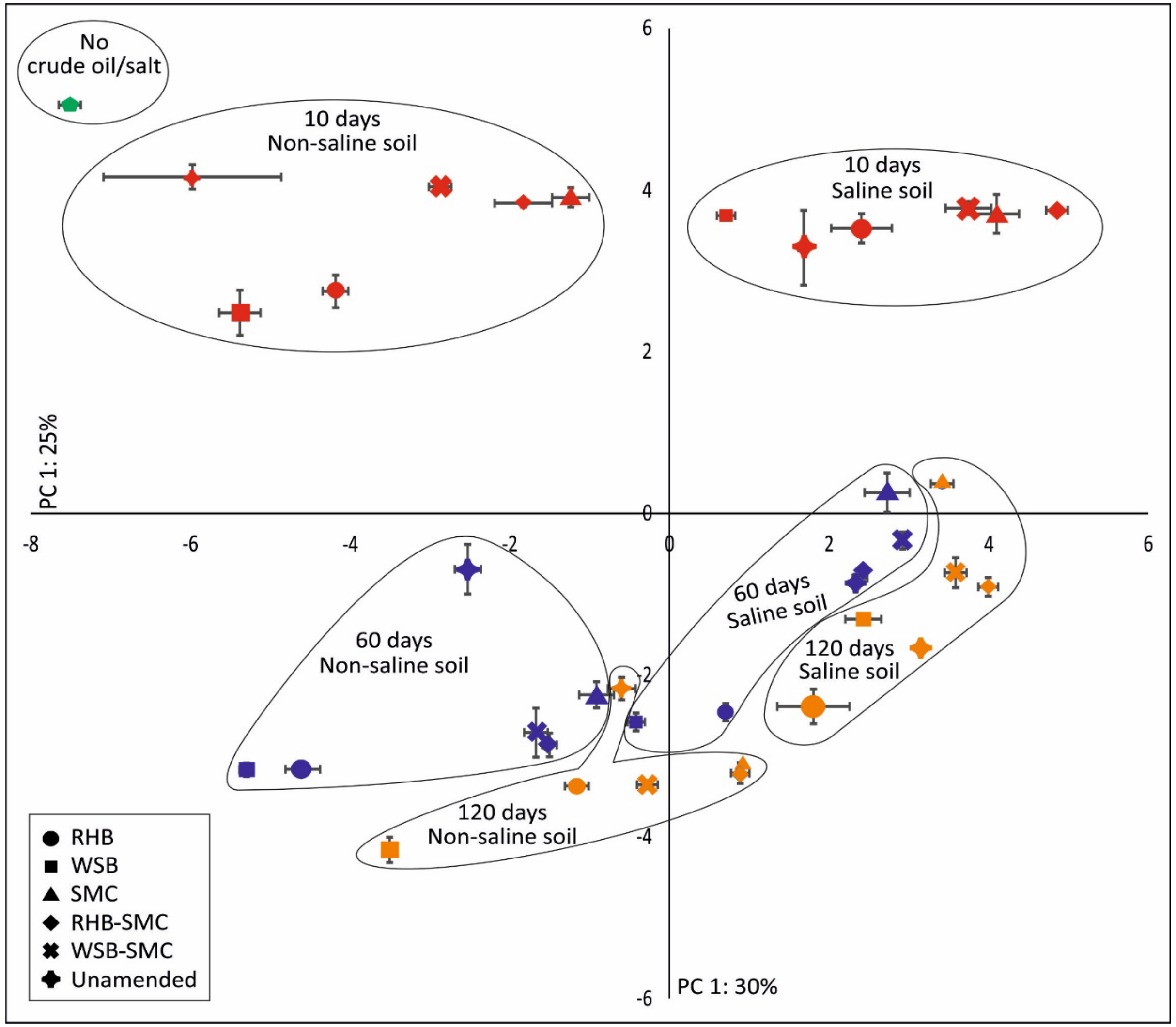


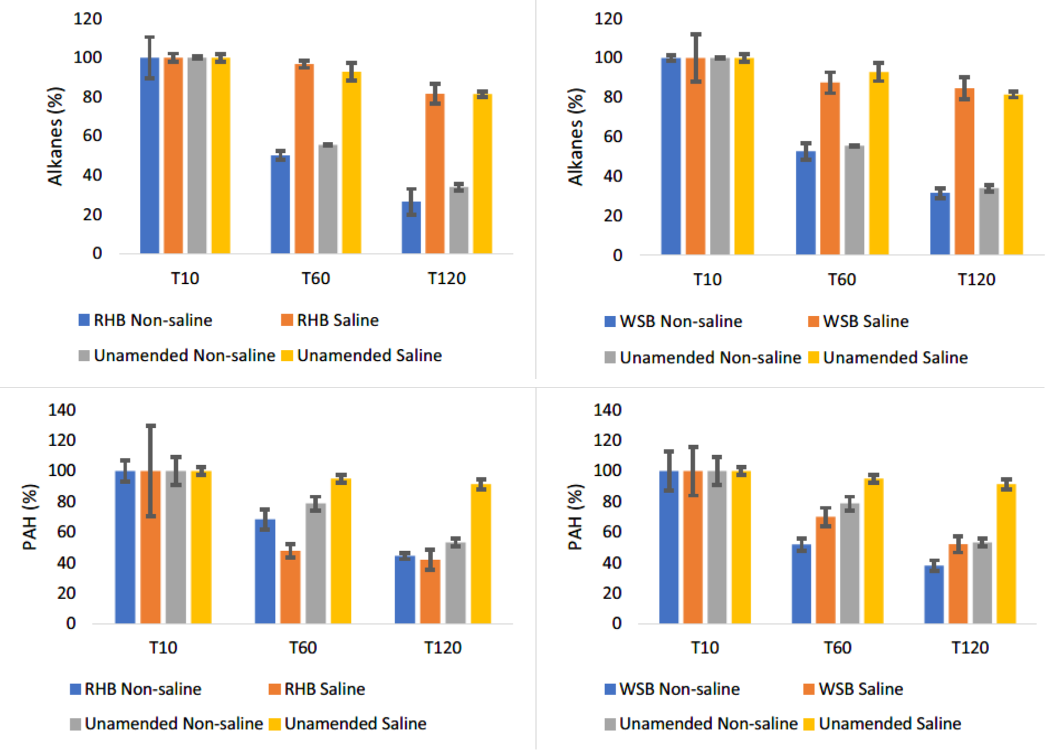


- Decrease in TPH content of 85% - 95% across treatments
- Combined strategies (Biochar and PA+BS) had higher TPH degradation than the single (Biochar 1 or Biochar 2) strategy
- Degradation for the recurring spill was 2 times faster than the initial spill on day 90

Azuazu et al., 2024, Cranfield PhD thesis

Influence of biochar on microbial community dynamics oil contaminated saline soils

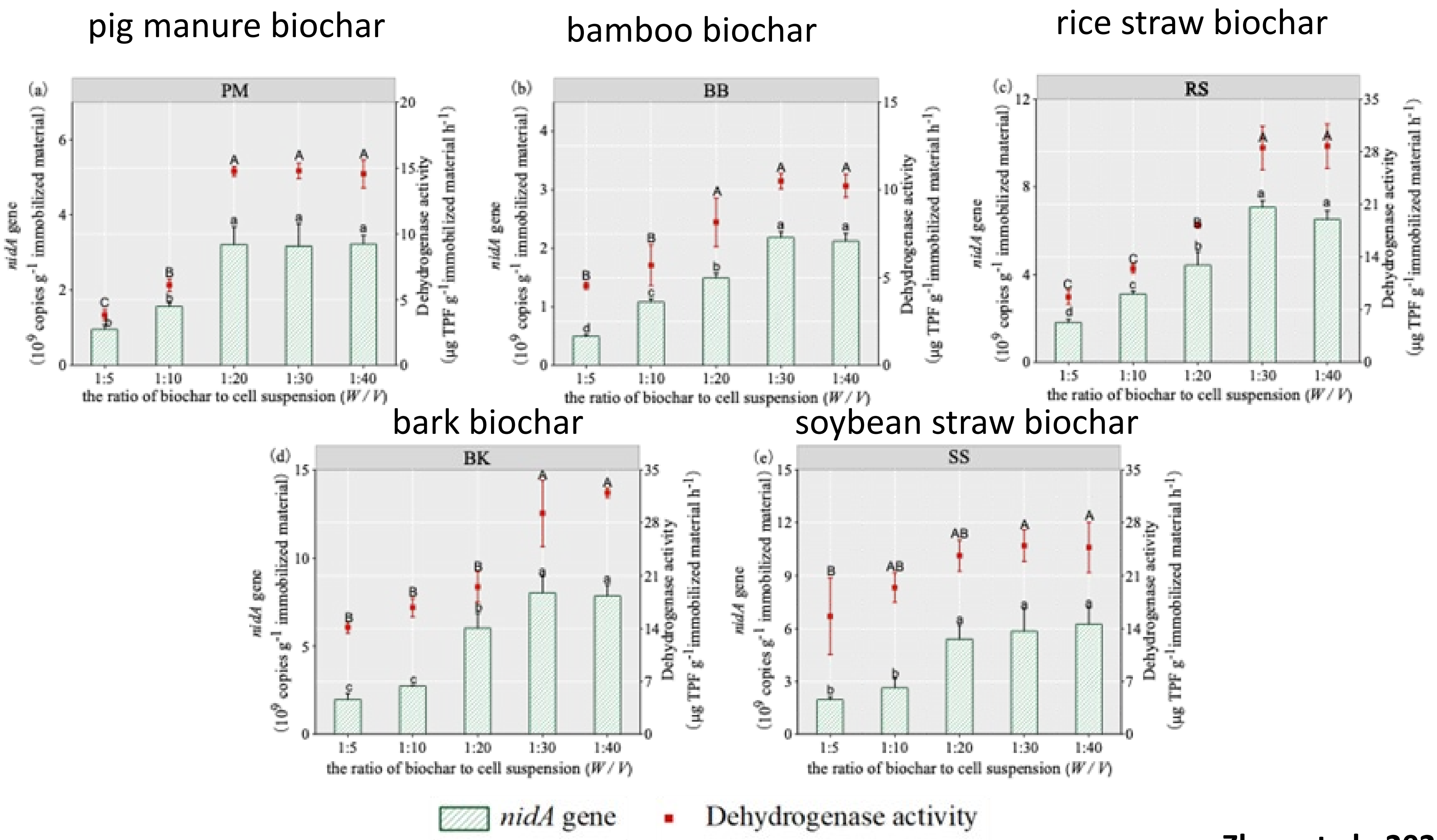




- Microbial communities shift due to oil contamination
- Distinct community between non-saline and saline soil.
- Biochar(s) may have contributed to mediate the community shift and contribute to alleviate salinity effect on petroleum hydrocarbons degradation

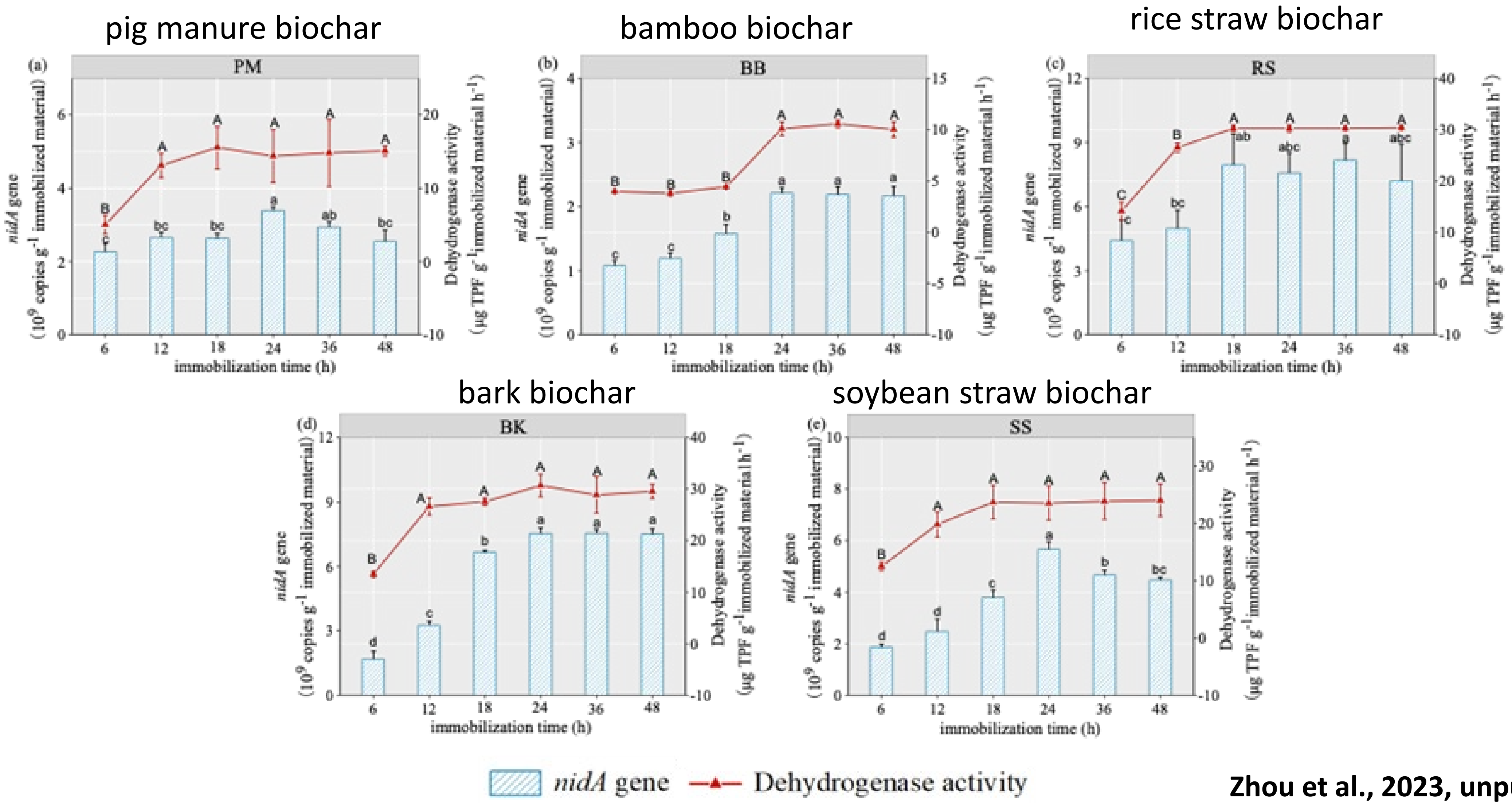
Atai et al., 2023 STOTEN, 892, 164720

Effect of biochar to cell ratio (w/v) on the immobilization capacity of different biochars for *Mycobacterium* ZL-7



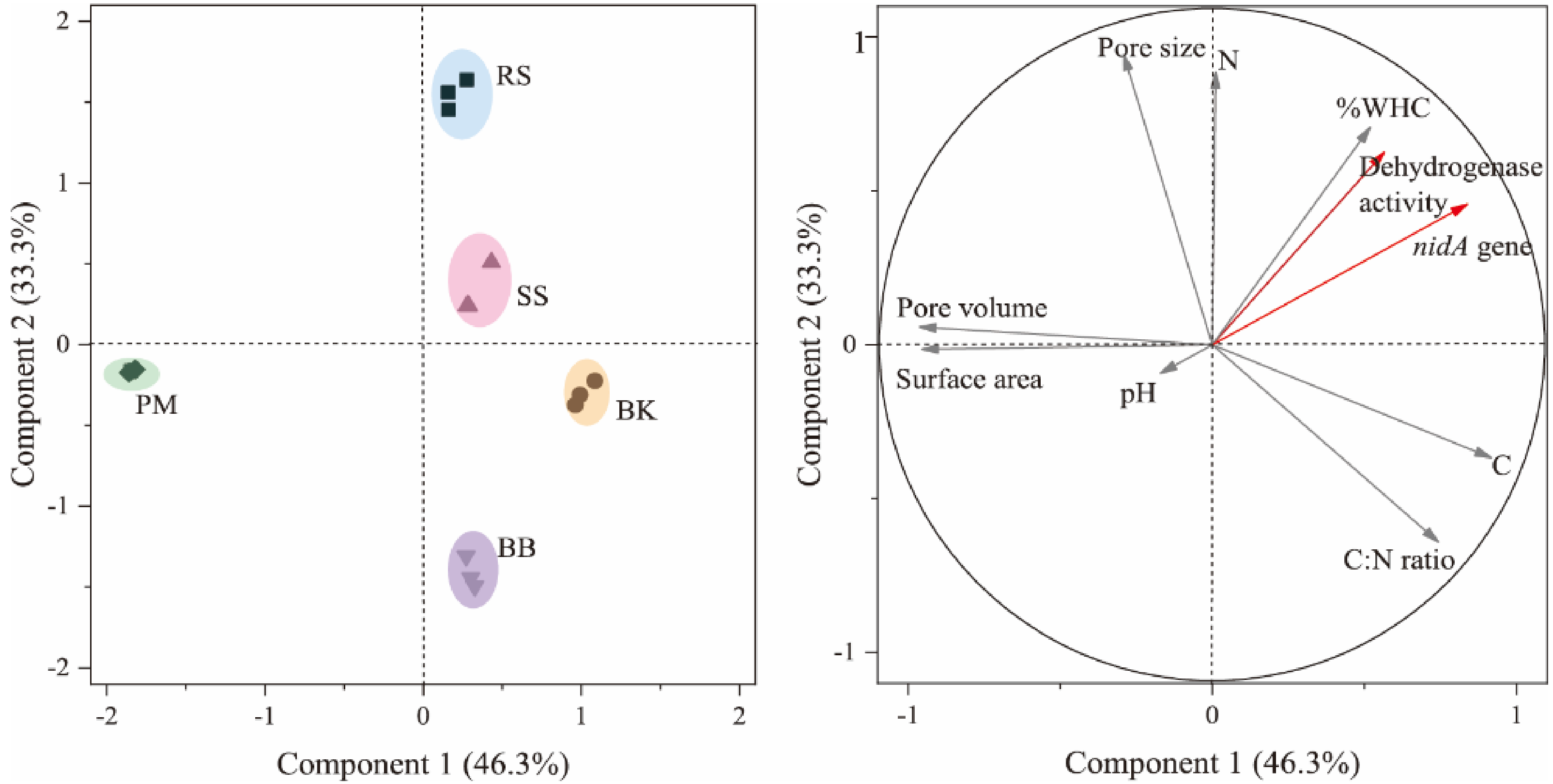
Zhou et al., 2023, unpublished

Effect of time on the capacity of different biochars of immobilizing a PAH degrader, *Mycobacterium* ZL-7



Zhou et al., 2023, unpublished

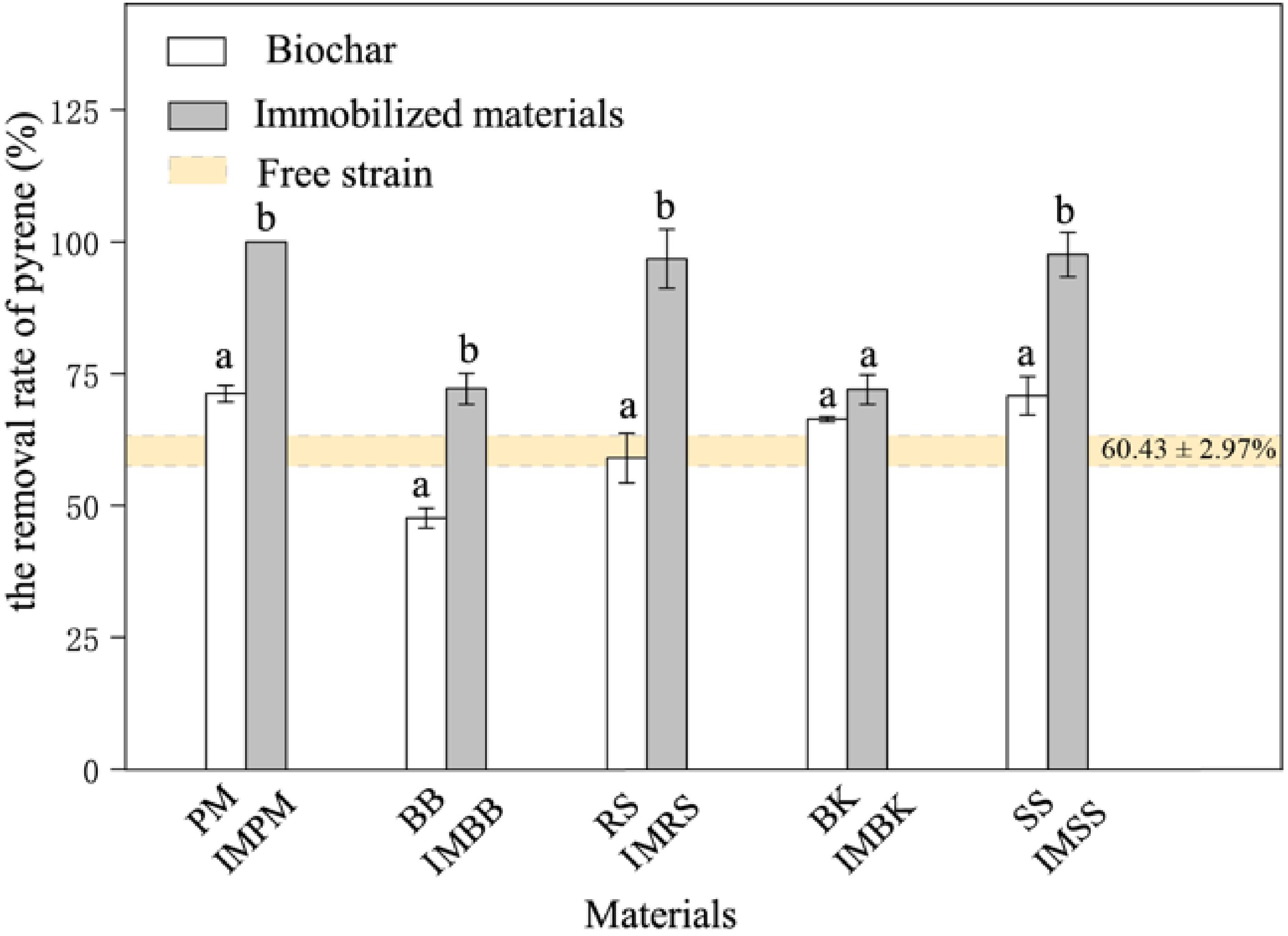
Comparison of the physico-chemical characteristics of the biochars and their immobilization capacity

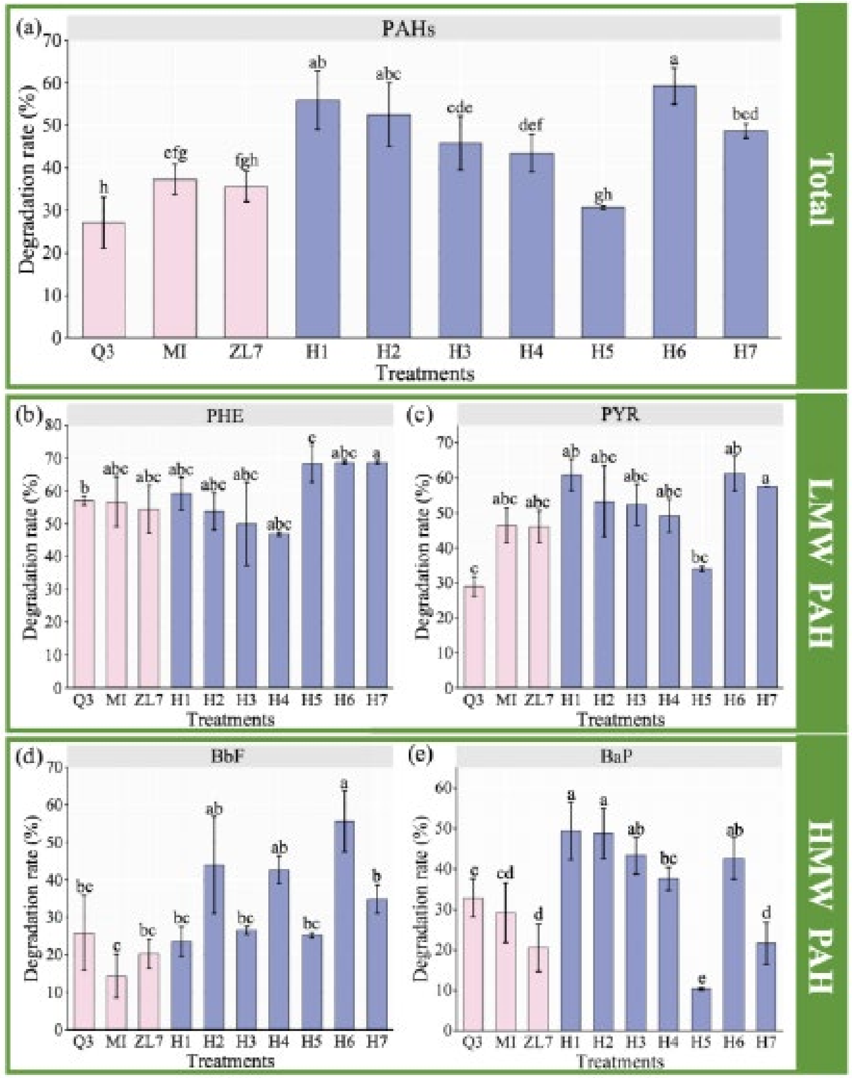


- %WHC, C and N significant positive relationships with the immobilized capacity of biochars (RS, SS and BK) = higher immobilized capacities than other types of biochar.
- Pore volume, surface area and pH significantly negatively correlated with the immobilized capacity of biochars.
- Pore size and C: N ratio had little effects on the immobilized capacity of biochar.

Zhou et al., 2023, unpublished

Removal rate of pyrene in solution

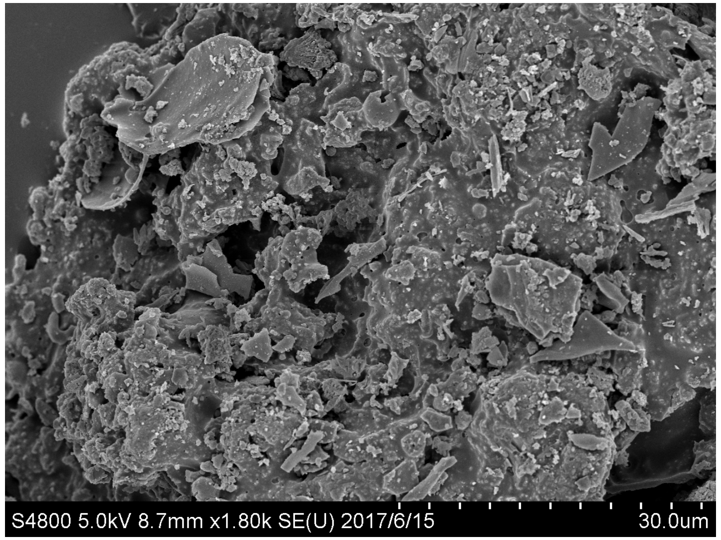




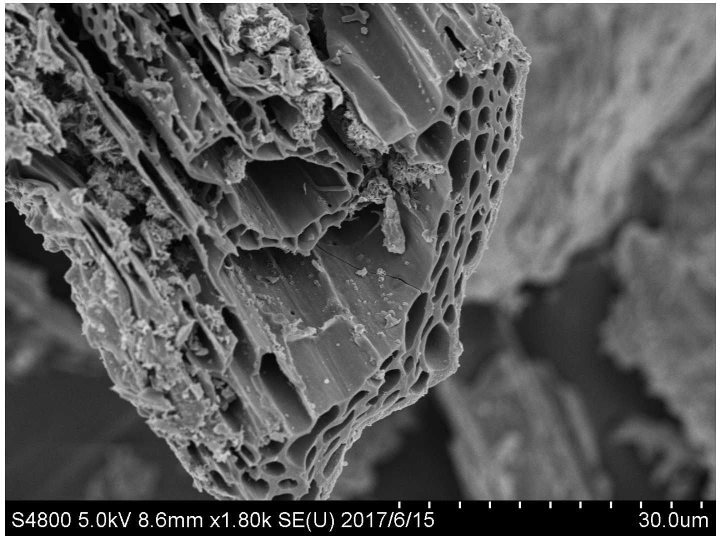
Zhou et al., 2023, IJRPH, 20,1766

Field verification of low-level biochar applications

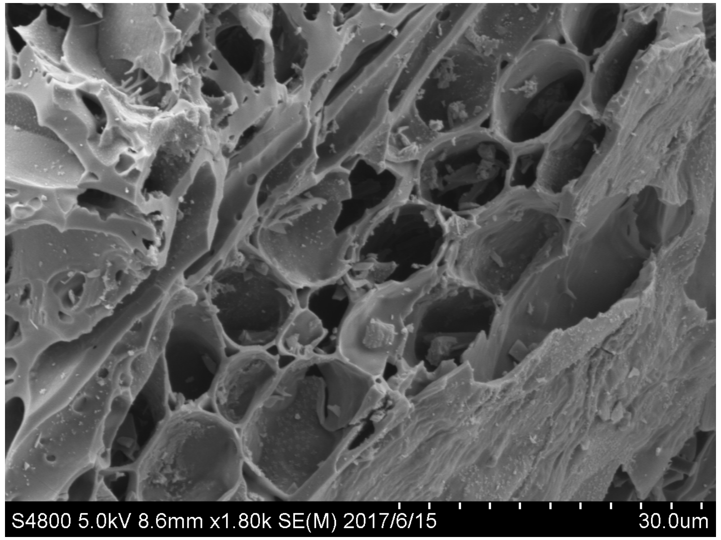
- To date little information and guidance on field-scale in situ applications of biochar.
- Field trial results are often inconsistent due to variable field conditions and contrasting biochar properties.
- Field experiment was conducted on an upland farm located in Zhouzai village, Zhangzhou city, Fujian province in southern China, with low level of [Cd] = 0.38 mg/kg (regulatory limit = 0.30 mg/kg in plants growing in contaminated soils)



Pig Manure Biochar (PMB)



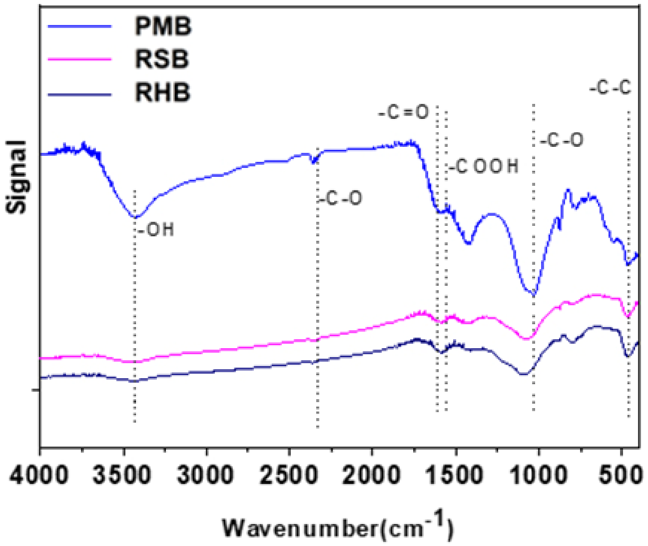
Rice Straw Biochar (RSB)

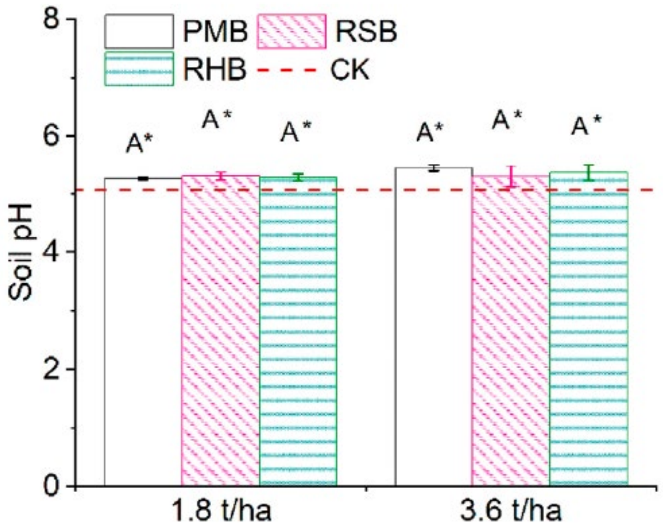


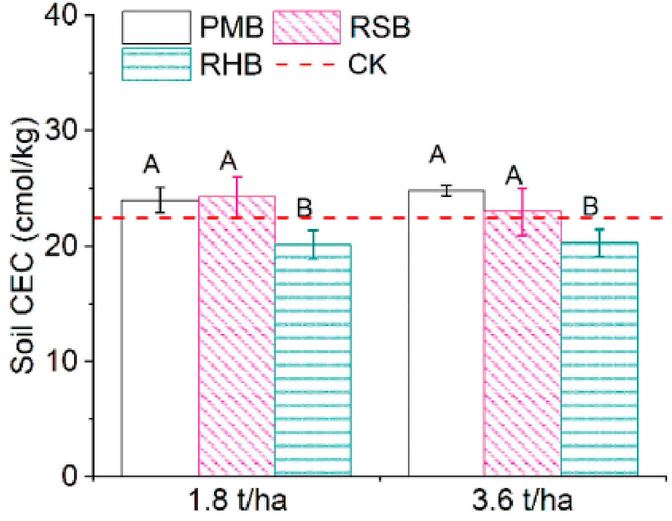
Rice Husk Biochar (RHB)

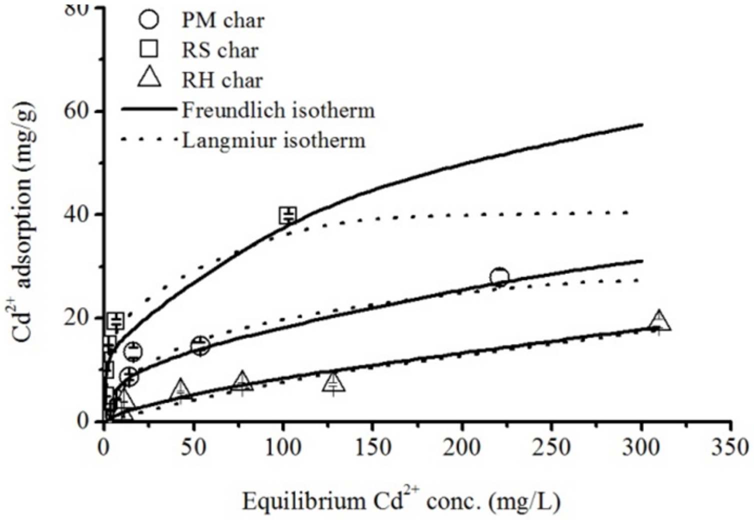
Zhang et al., 2023, Front. Environ. Sci., 10,1114335

Field verification of low-level biochar applications





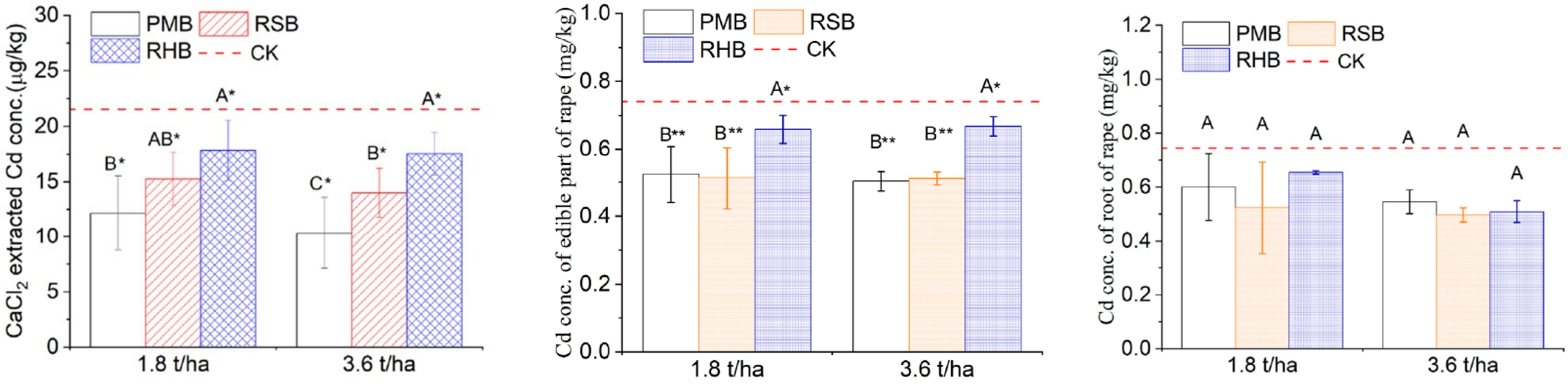




- **Surface area**: RSB > PMB >> RHB
- **Av. pore volume**: PMB = RSB >>> RHB.
- **RSB** (high pH, high carbon content and high surface area) **hypothesised as the best for Cd immobilization**
- **Adsorption Cd capacity** (Freundlich isotherm: RSB > PMB > RHB

Zhang et al., 2023, Front. Environ. Sci., 10,1114335

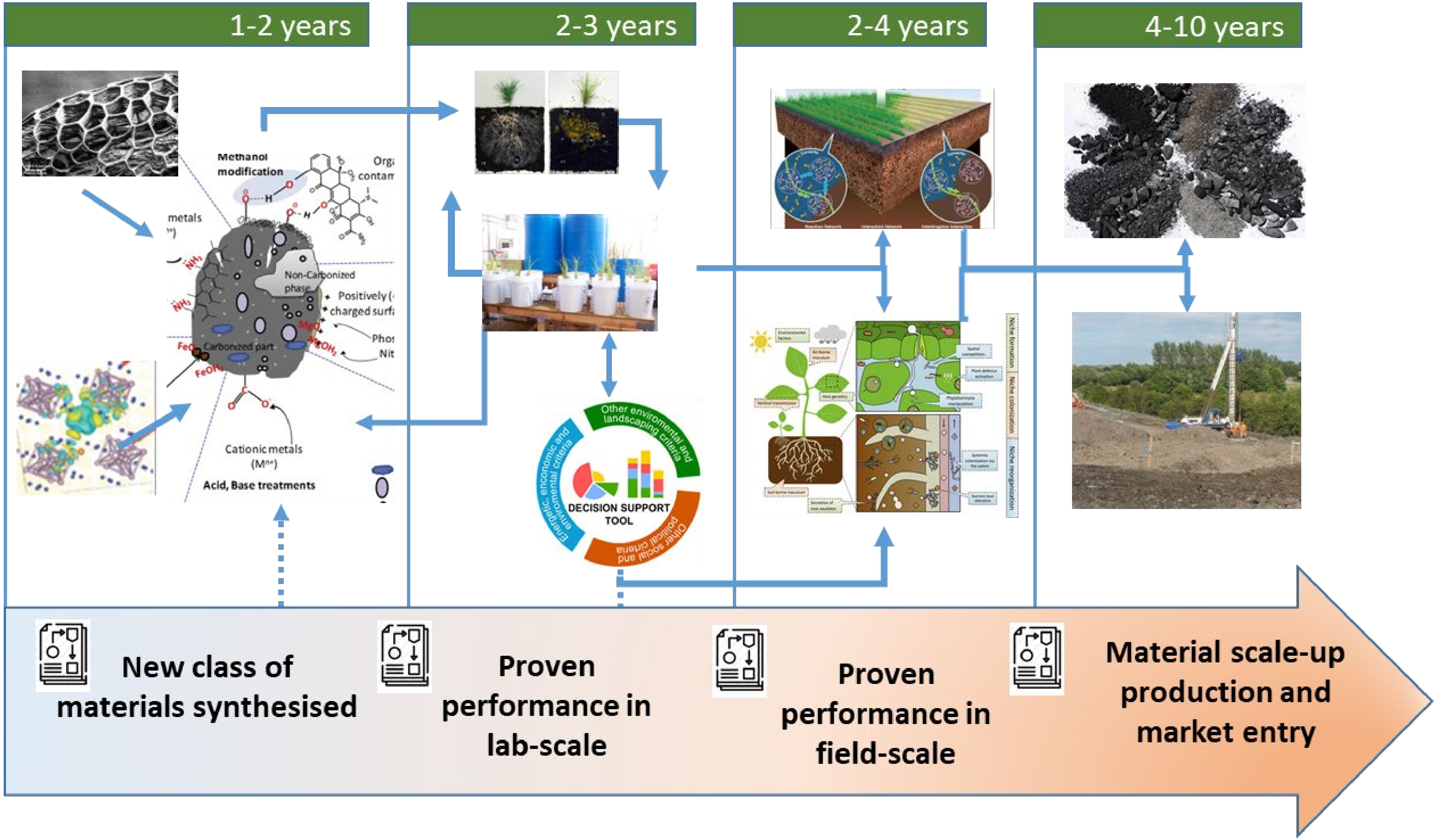
Field verification of low-level biochar applications



- Biochars performance in batch adsorption ≠ real soil systems. No significant difference in [Cd] in rape plants between RSB and PMB
- Doubling field application rates increased Cd immobilization by 10%
- Using a pyrolysis system capacity of 20 ton/year. Thus, assuming an application rate of 2 t/ha = 10 ha/year.
- Such scale of production, and low application rates, represents a realistic approach to support the production of biochar in quantities that would allow for meaningful field scale application.

Zhang et al., 2023, Front. Environ. Sci., 10,1114335

So where are we and what is next?



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- Research lead Water-Environment-Health Nexus
- EBNet Co-I and Co-lead of the Pollutants and Media theme

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