Biochar As Soil Amendment

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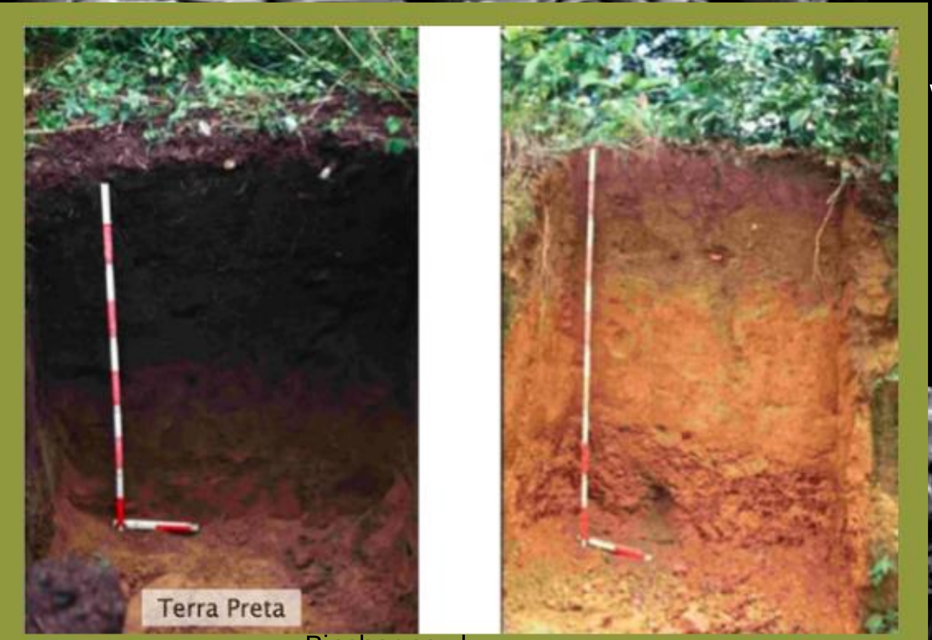
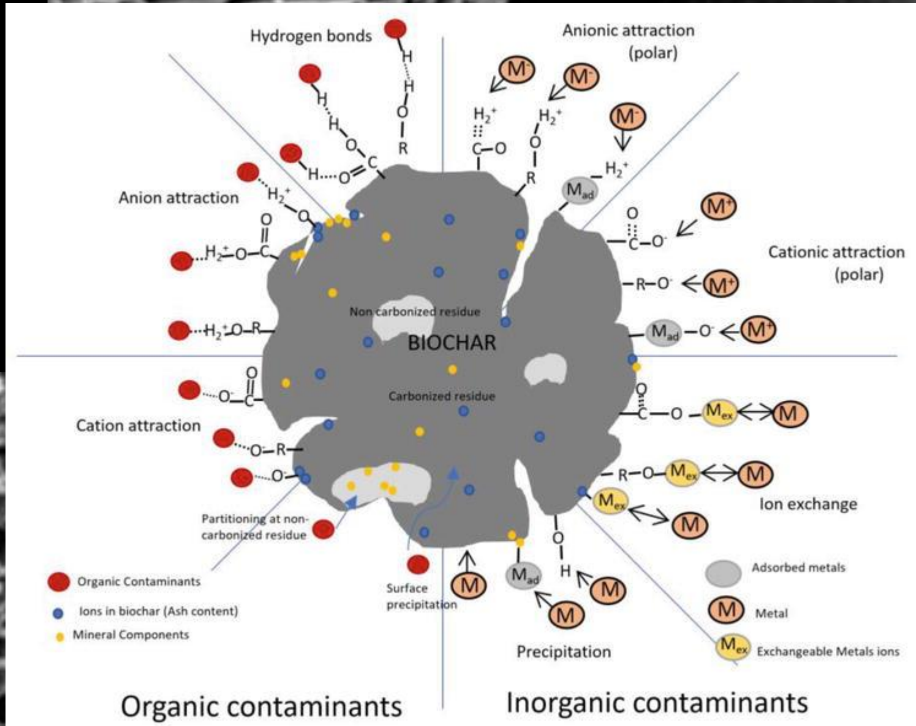
ASRS
41st Annual Meeting

June 4, 2024, Knoxville TN



Biochar.co.uk



What is Biochar: The Oldest New Material

Highly stable carbon-rich solid material produced by thermal decomposition of *biomass* in oxygen-limited environment (pyrolysis)

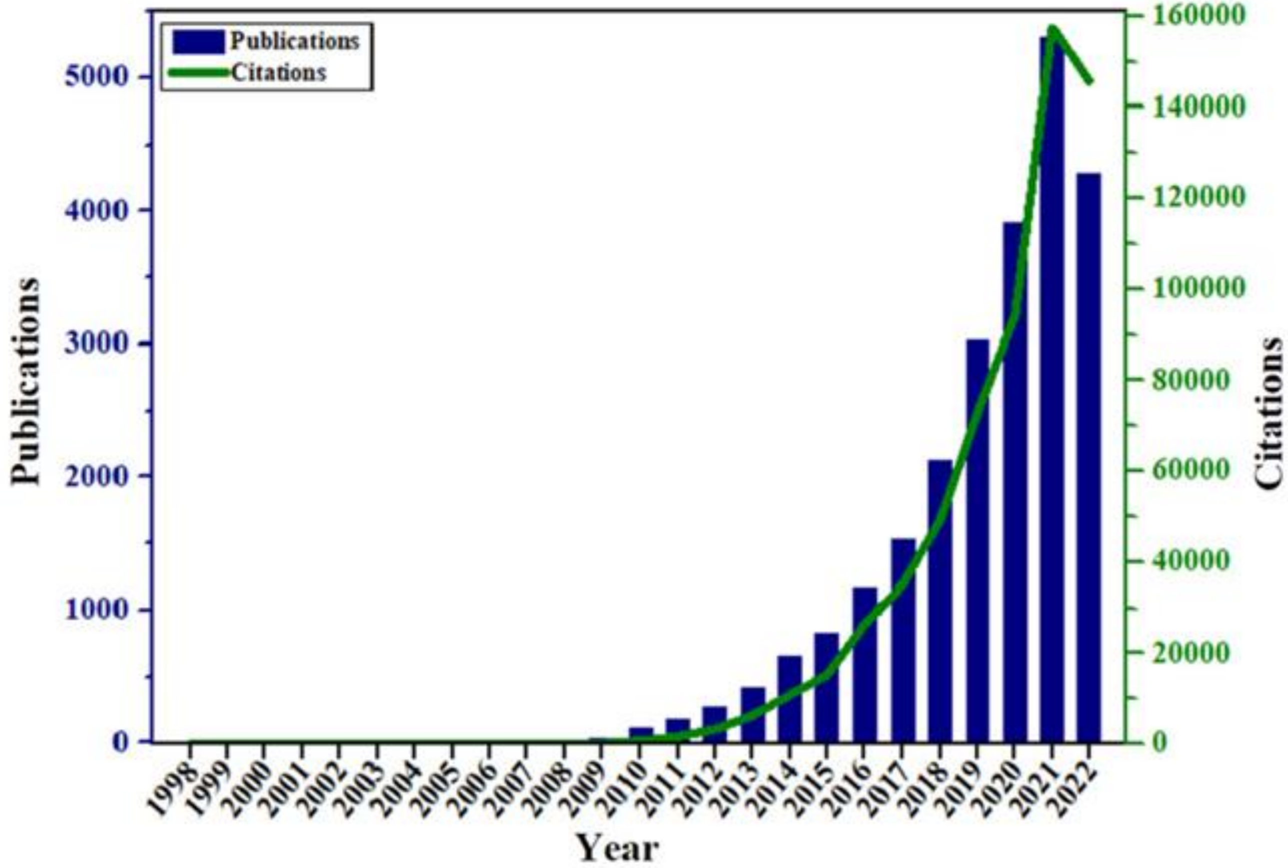


Fig. 1 Year-wise biochar publications with the number of citations

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Kumar et al. Biochar https://doi.org/10.1007/s42773-023-00207-z

Why Now? Why Soil? Why Biochar?

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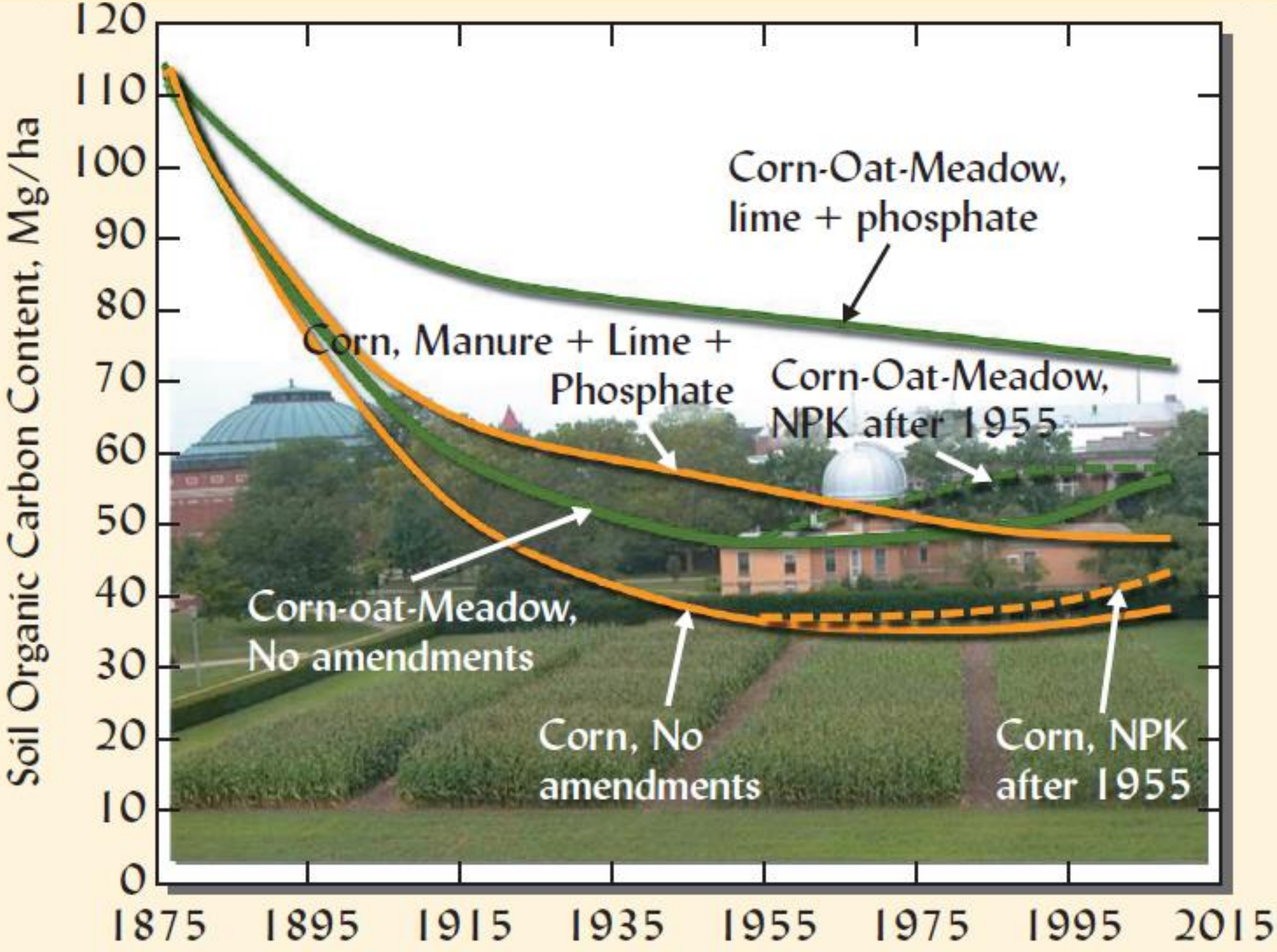
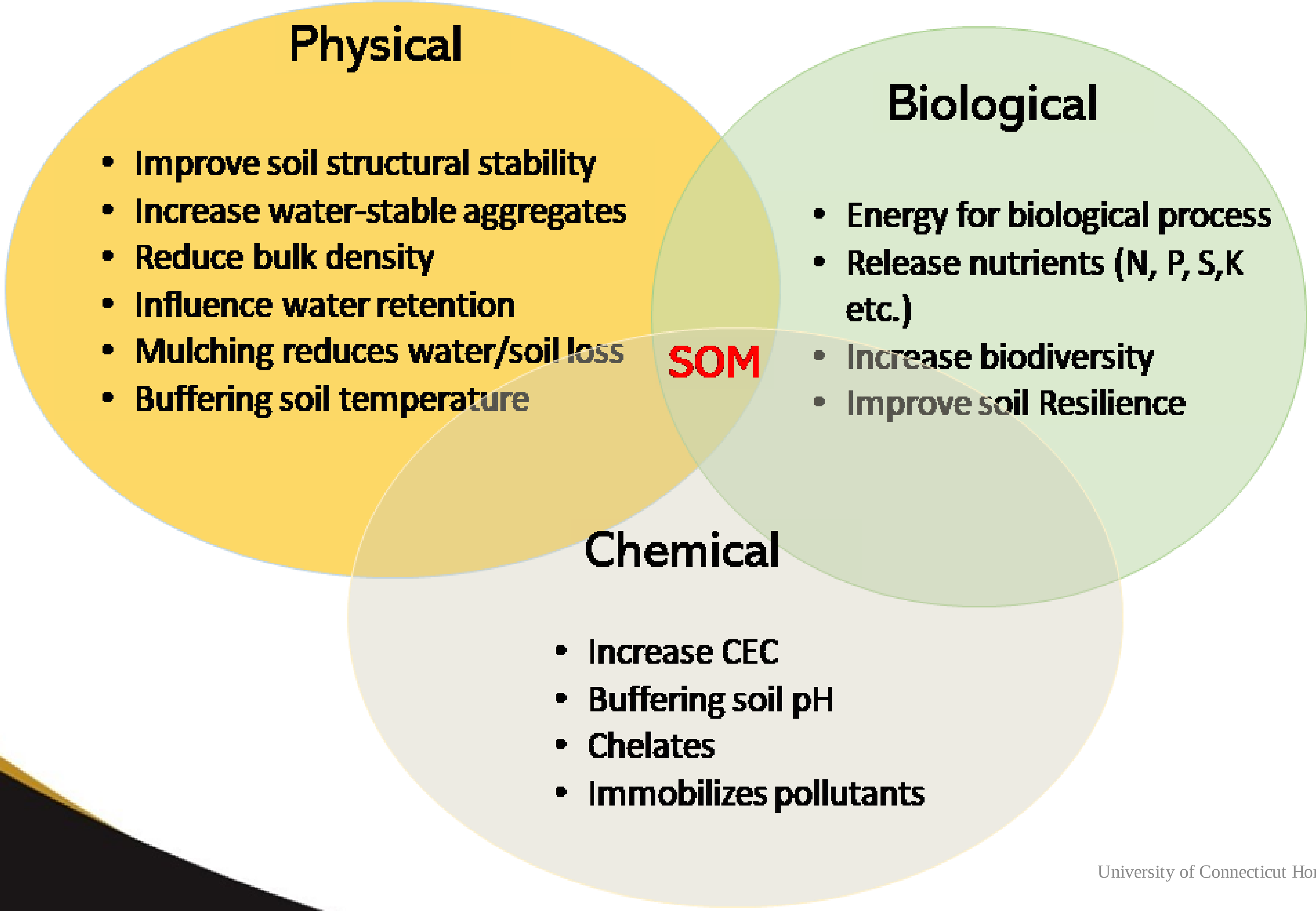
1876 – Virgin Grassland Soil (Morrow Plots, University of Illinois)



Role of Soil Organic Matter



University of Connecticut Home & Garden Education Center

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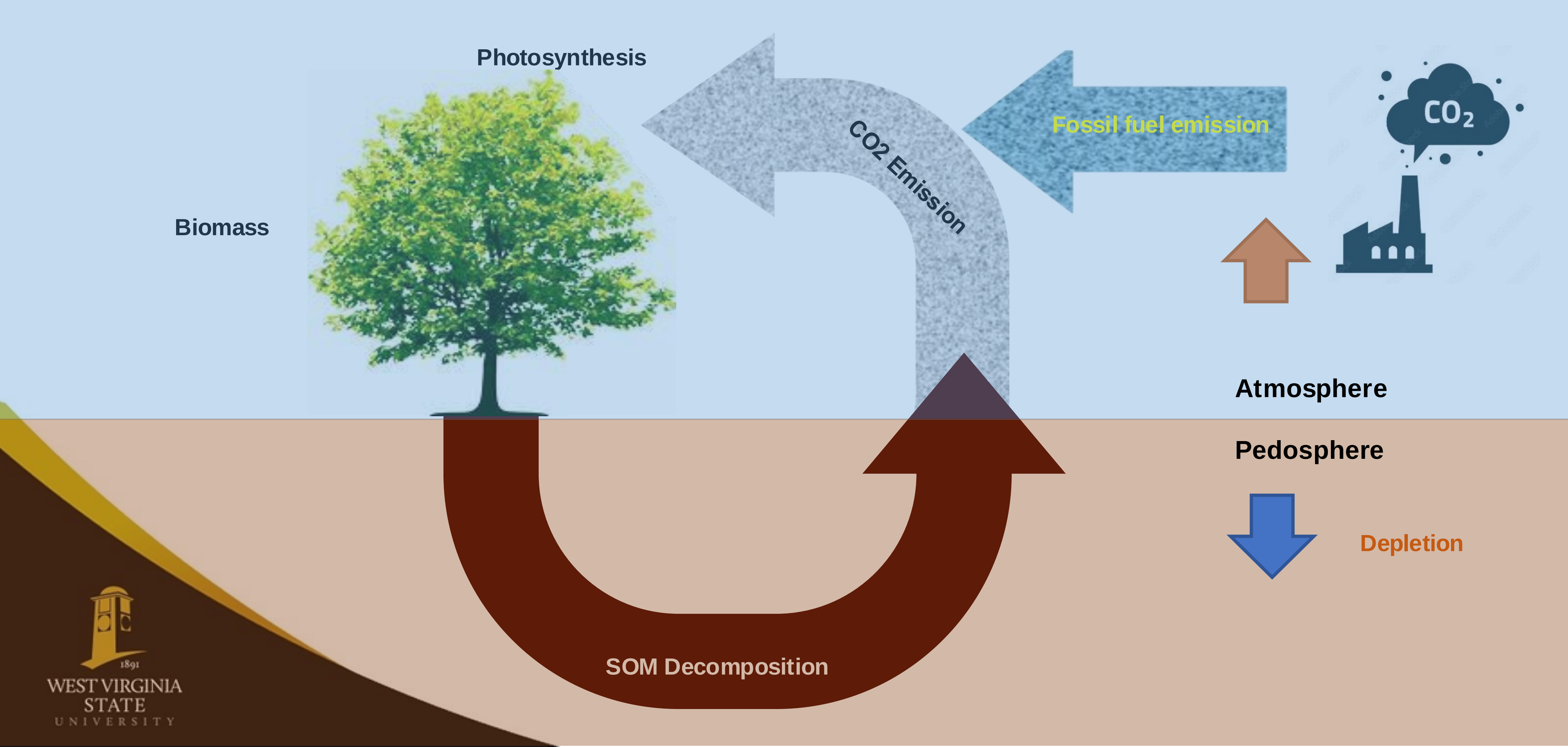
The Carbon Cycle



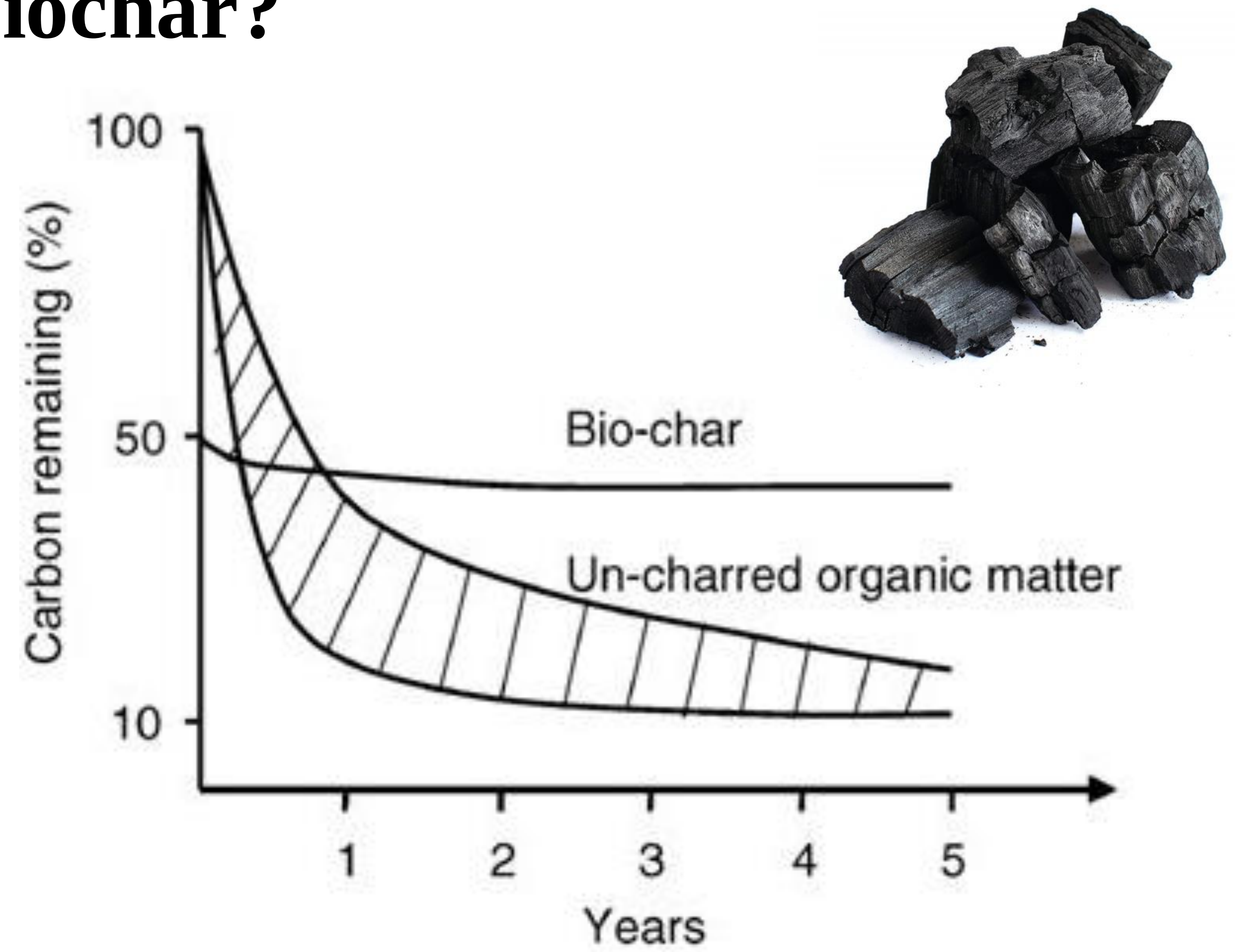

https://www.brookings.edu/articles/redefining-renewable-biomass-a-policy-change-with-cascading-outcomes/

Biomass

Pyrolysis

Biochar

Why Biochar?



Lehmann et al (2006)
Mitigation & Adaptation Strategies for Global Change 11: 403 - 427

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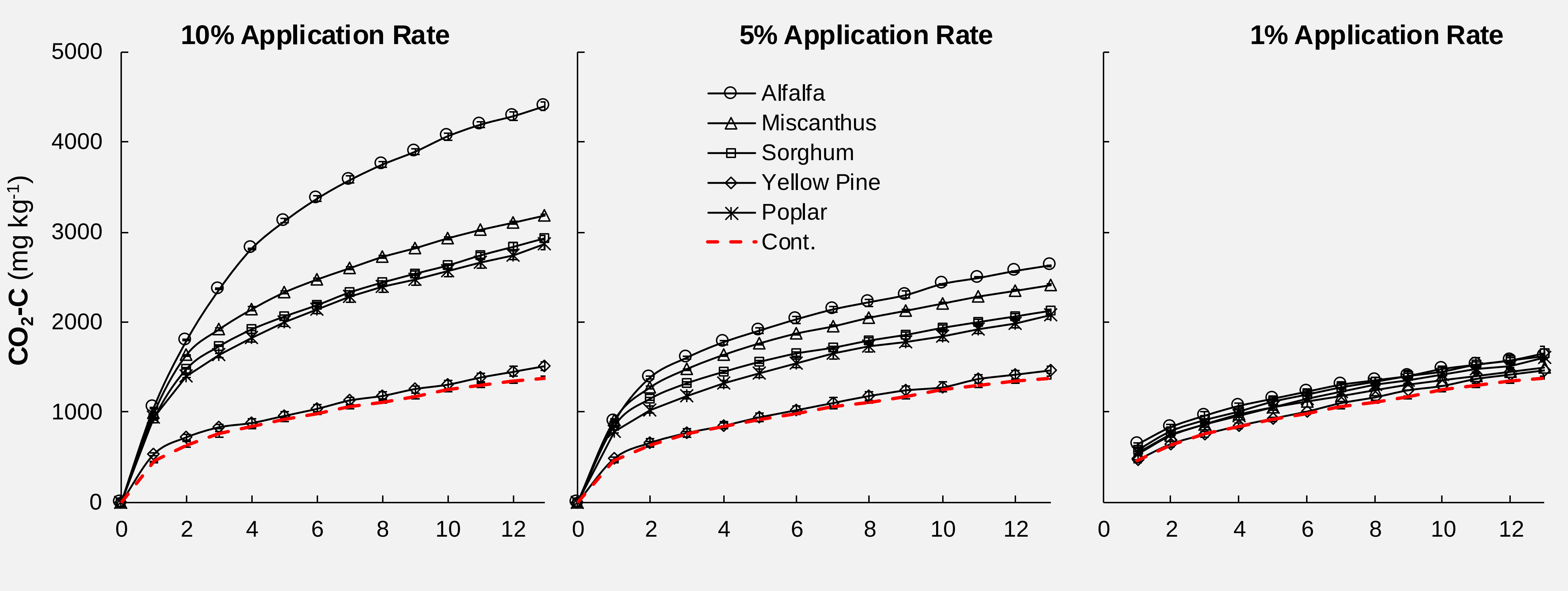
CO_2 Emission from Biochar Amended Soil – Feedstock and Application Rate Effect



Weeks of incubation

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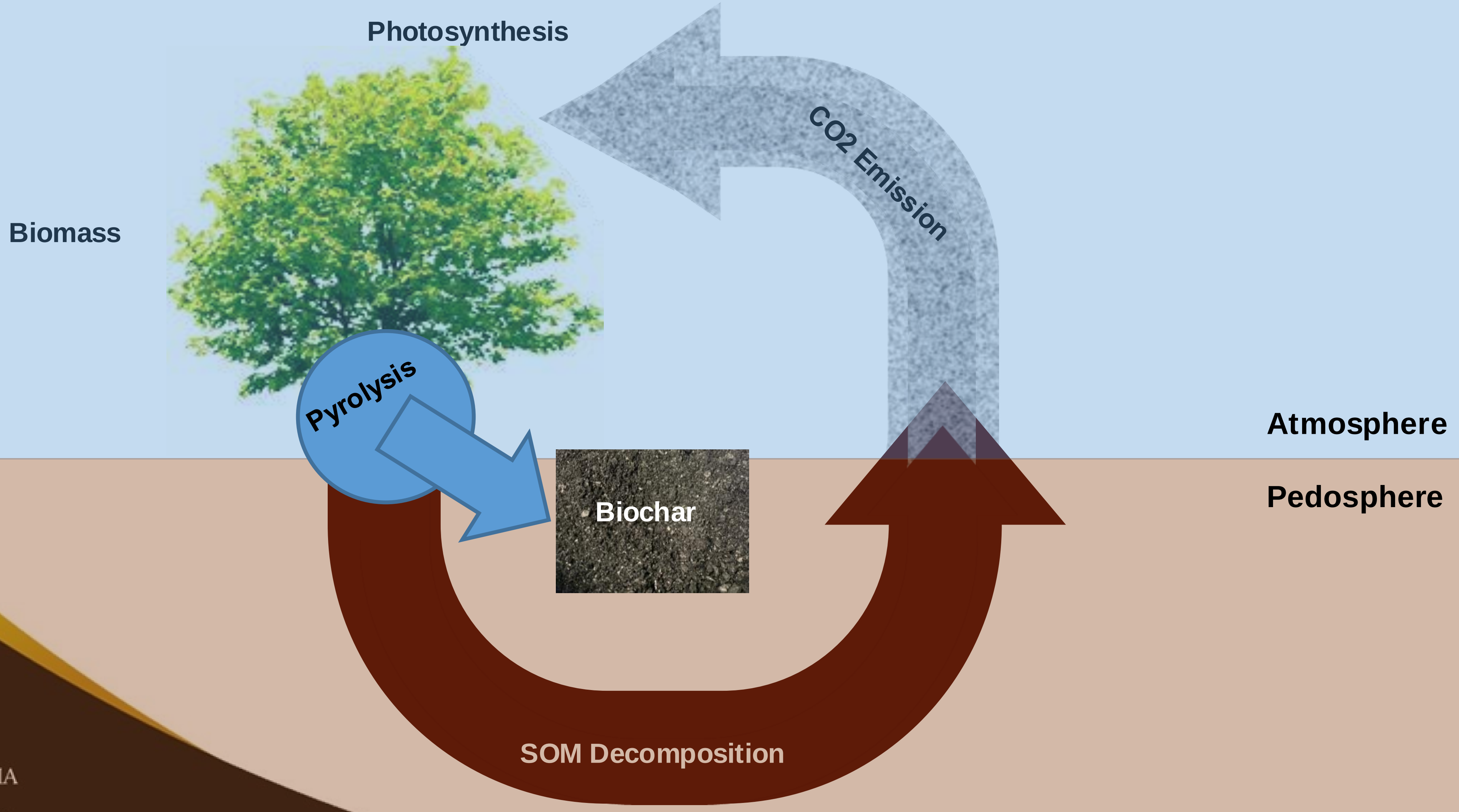
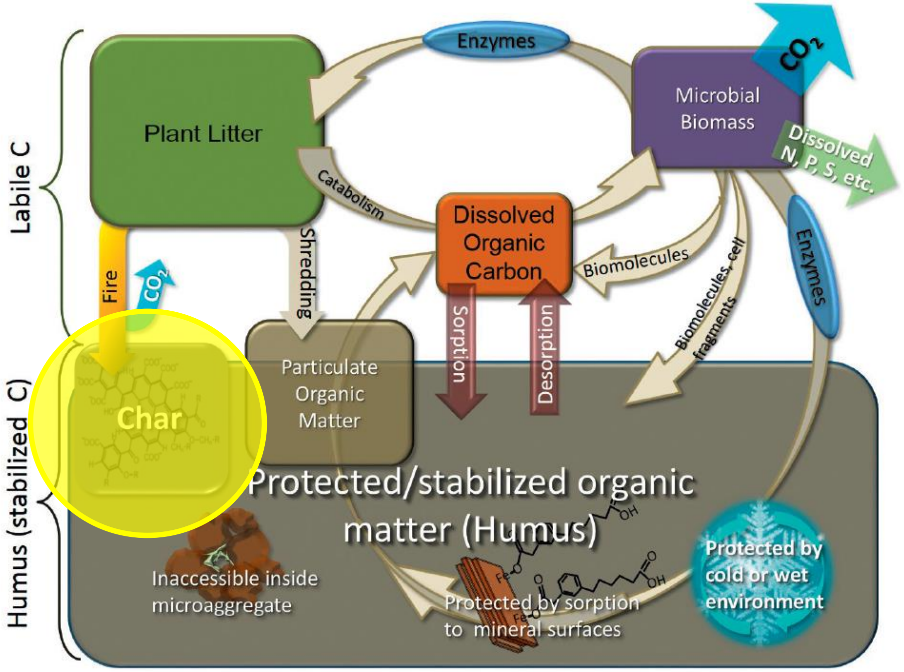
The Carbon Cycle



Why Biochar?

Terra Preta soils

The ancient soil that could help agriculture and the climate today



Biochar.co.uk

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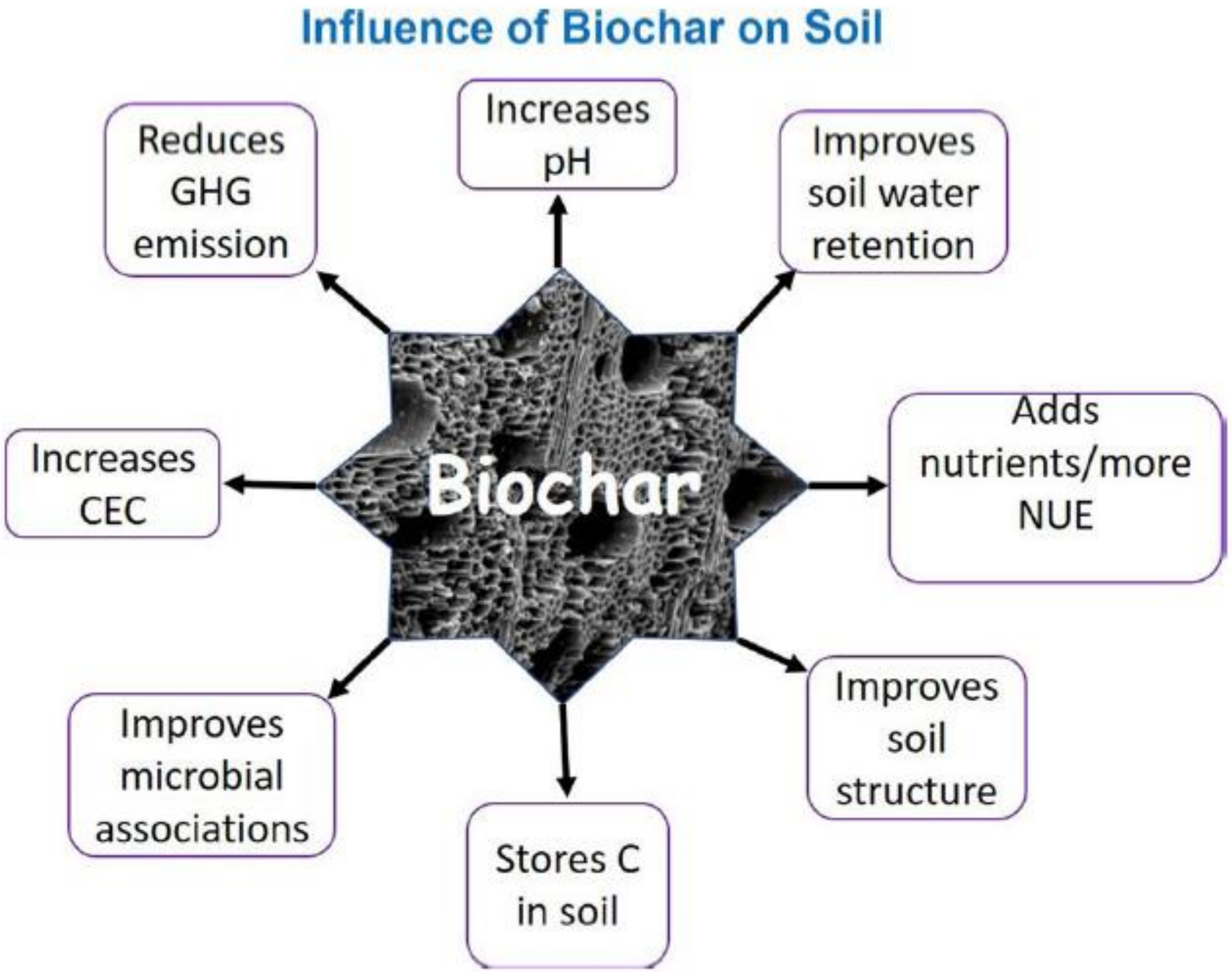

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Hossain et al., 2020; https://doi.org/10.1007/s42773-020-00065-z

United States Department of Agriculture

336-CPS-1

Natural Resources Conservation Service

CONSERVATION PRACTICE STANDARD

SOIL CARBON AMENDMENT

CODE 336

(ac)

DEFINITION

Application of carbon-based amendments derived from plant materials or treated animal byproducts.

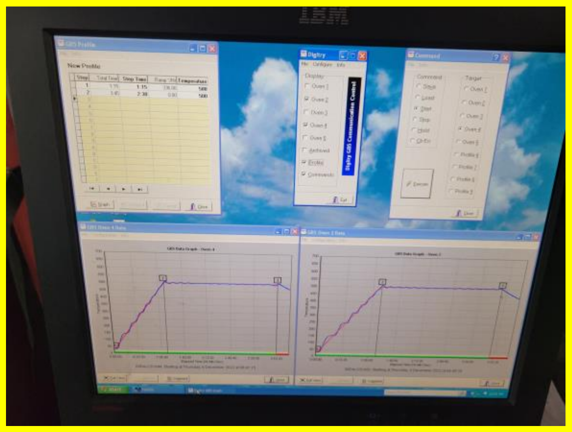
PURPOSE

Use this practice to accomplish one or more of the following purposes:

- Improve or maintain soil organic matter.
- Sequester carbon and enhance soil carbon (C) stocks.
- Improve soil aggregate stability.
- Improve habitat for soil organisms.

Conservation Practice Standard Soil Carbon Amendment (Code 336) (usda.gov)

Biochar/Charcoal Production



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Biochar Production Using ‘The Ring-of-Fire’

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Biochar/Charcoal Production

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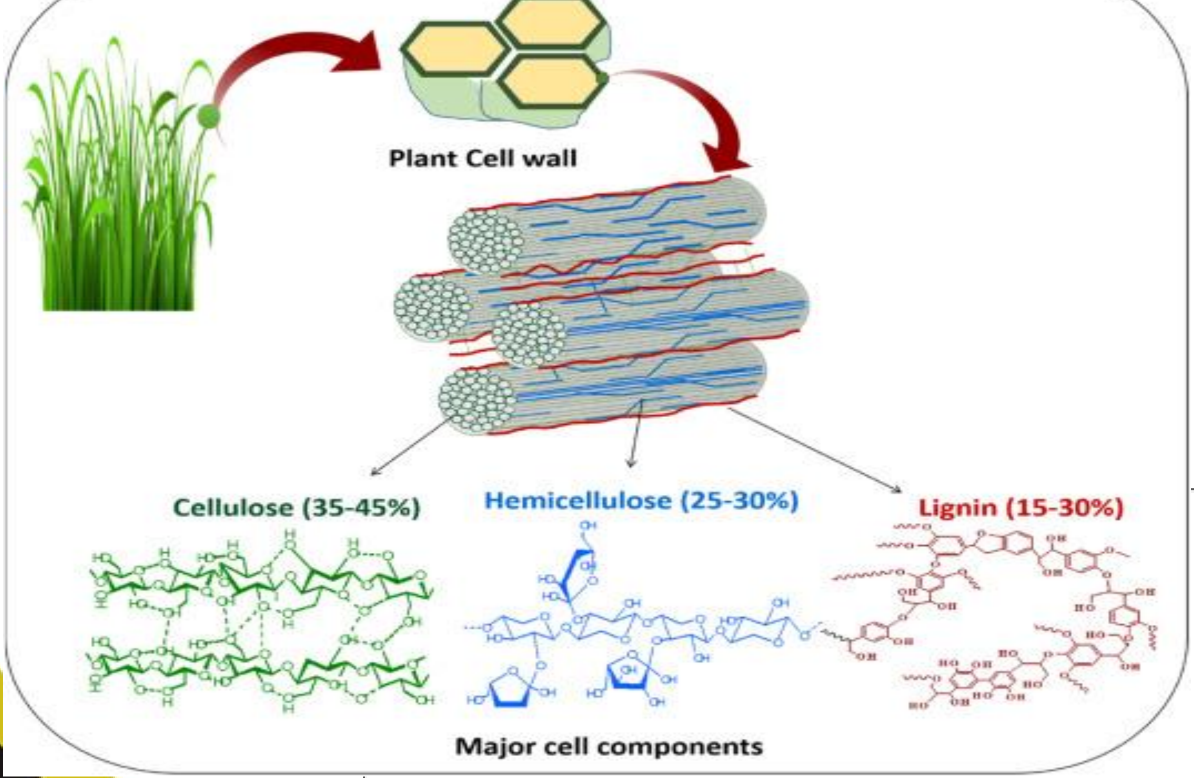
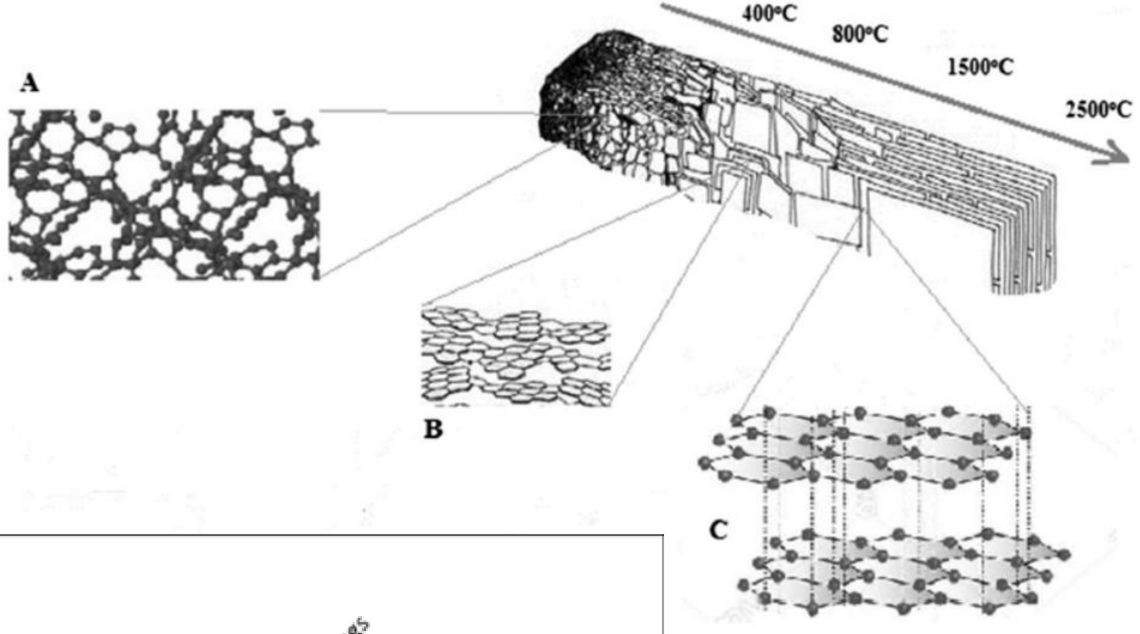
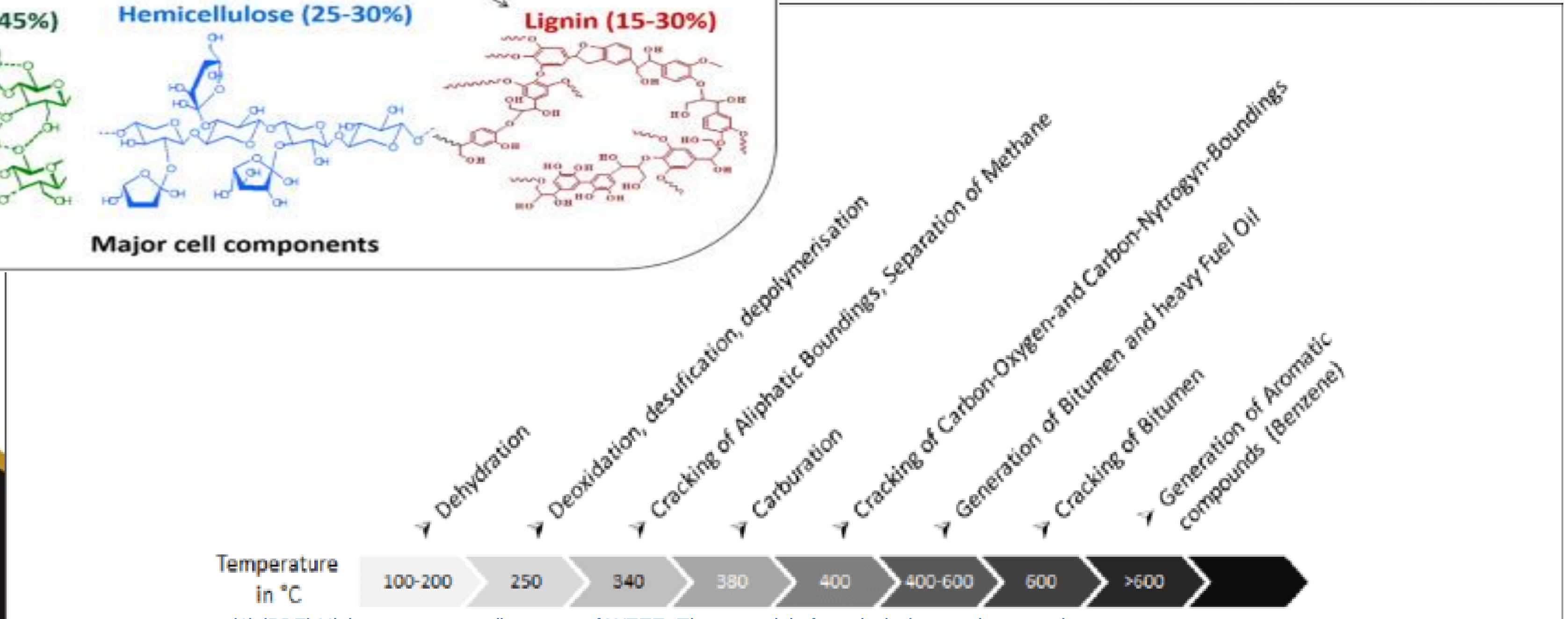
Transformation During Pyrolysis

https://doi.org/10.1016/j.rser.2022.112130



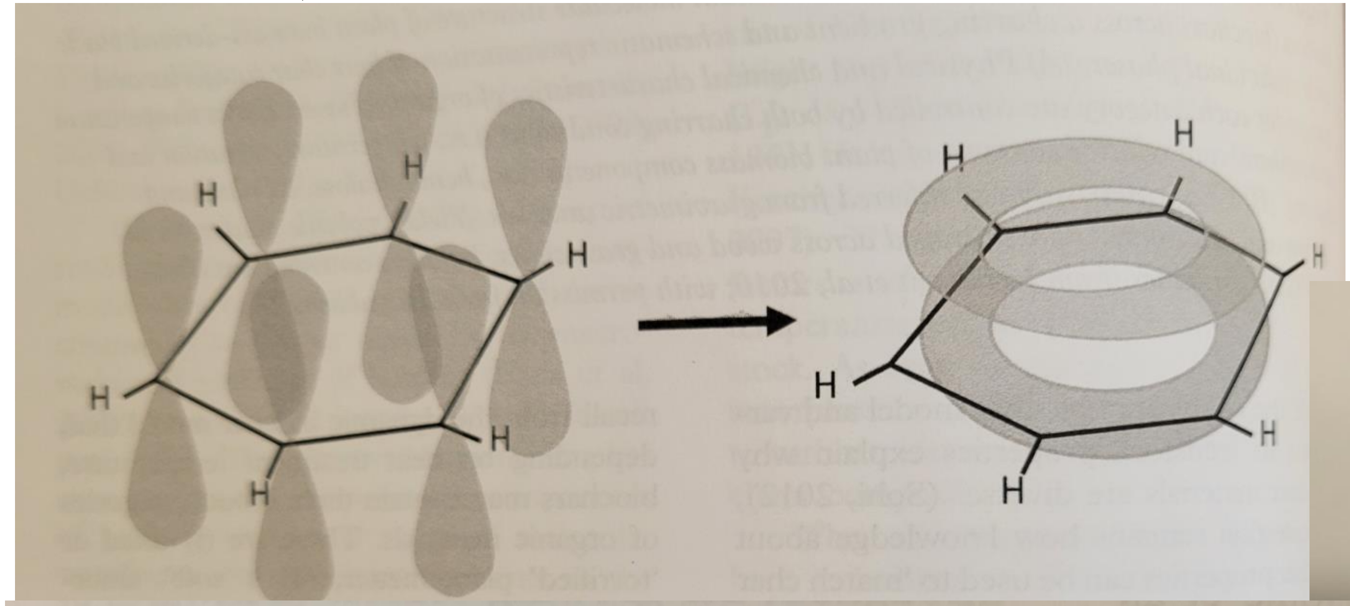


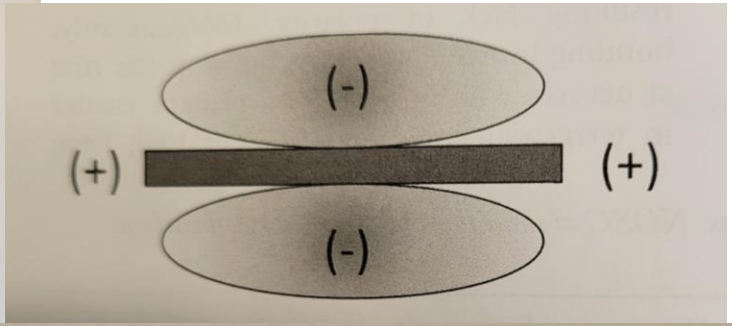
Tomczyk20 Biochar physicochemical properties

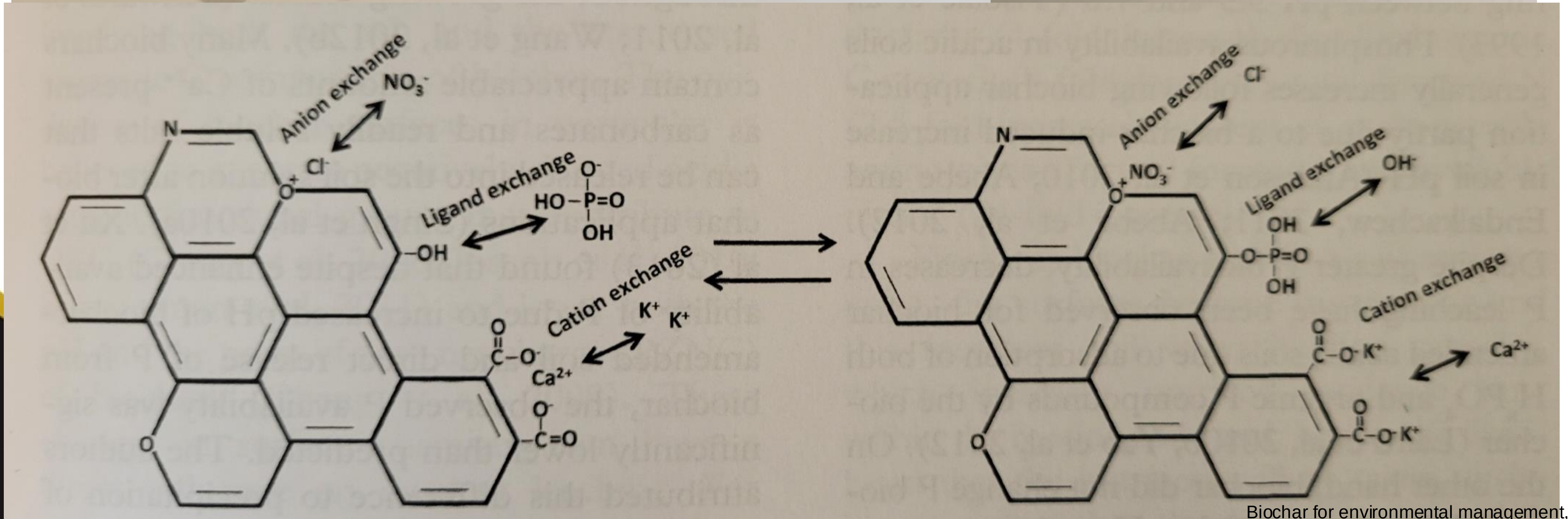


[(1) (PDF) High recovery recycling route of WEEE: The potential of pyrolysis (researchgate.net)]()

(Condensed) Aromatic Structure







Biochar for environmental management, Routledge, 2015

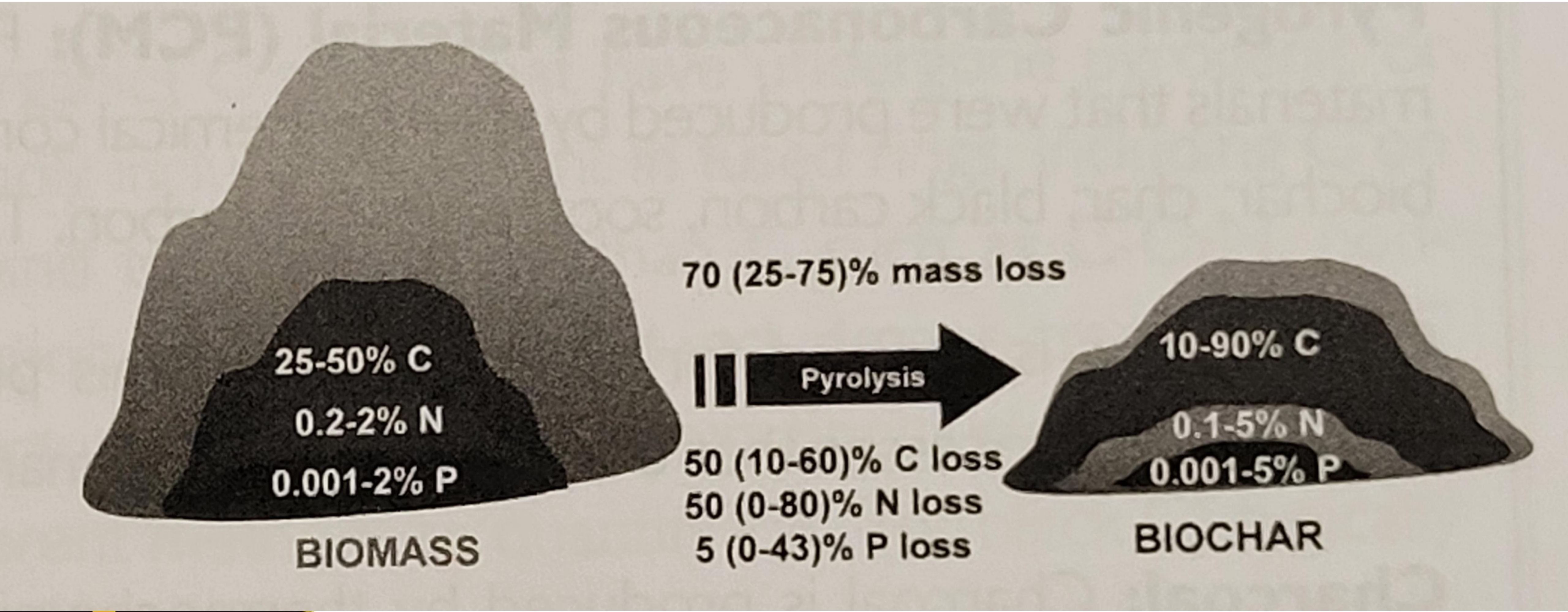
Peak Temperature Effect on Biochar Properties

Table 7.6 *Average biochar pH, calcium carbonate equivalent (CCE), surface area and cation exchange capacity (CEC) based on pyrolysis temperature, pyrolysis type and pyrolysis temperature by type*

Source†	pH	CCE (%)	Surface Area ($m^2 g^{-1}$)	CEC ($mmol_c kg^{-1}$)
Pyrolysis temperature†				
<300°C	5.01	7.95	1.686	327
300–399°C	7.60	13.7	65.36	371
400–499°C	8.10	17.2	83.98	191
500–599°C	8.71	15.6	111.8	283
600–699°C	9.00	---‡	217.0	126
700–799°C	9.83	21.0	176.2	39.0
>800°C	10.8	---	213.8	44.0
Pyrolysis type†				
Fast	8.38	---	69.38	28.8
Slow	8.50	14.9	124.4	250

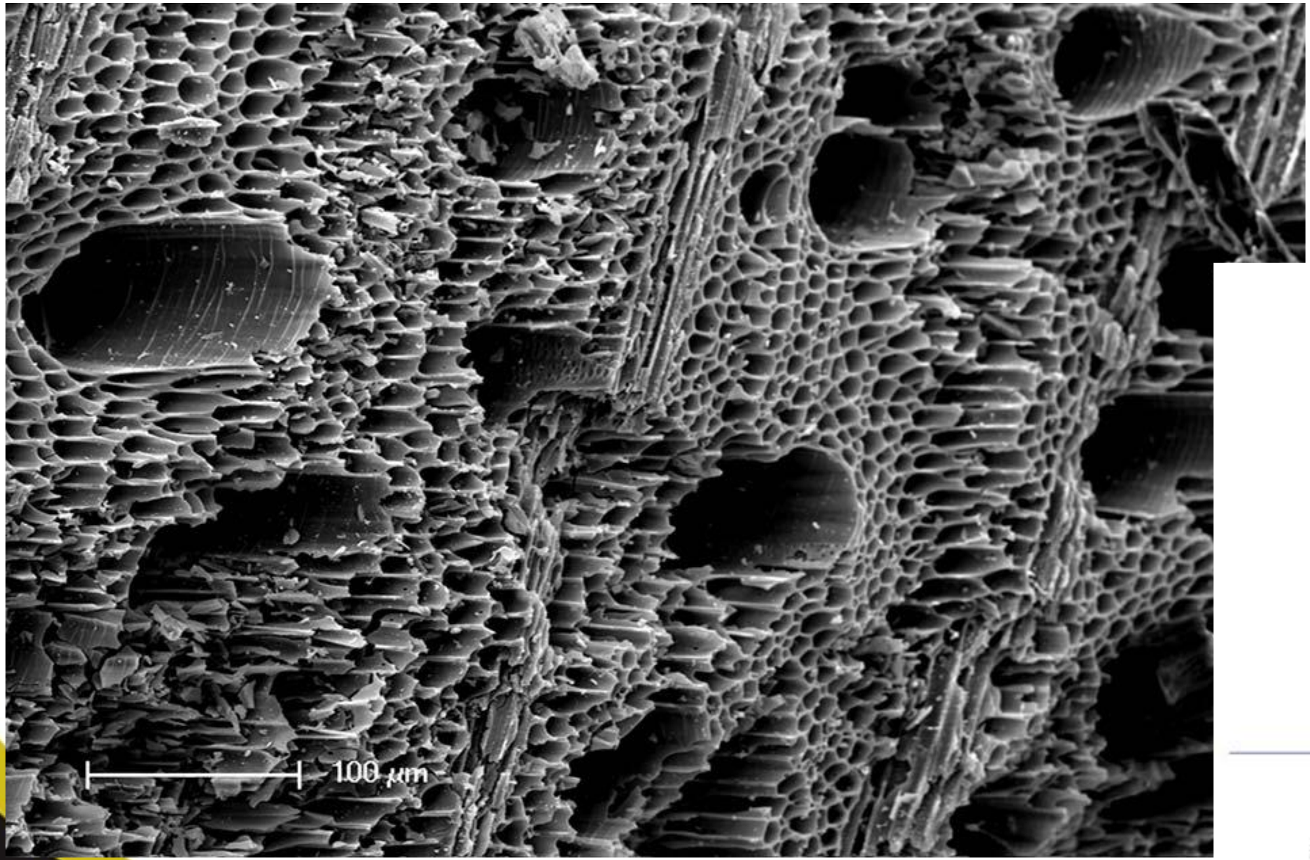
Biochar for environmental management, Routledge, 2015

Pyrolysis - Conversion Efficiency of C, N, P



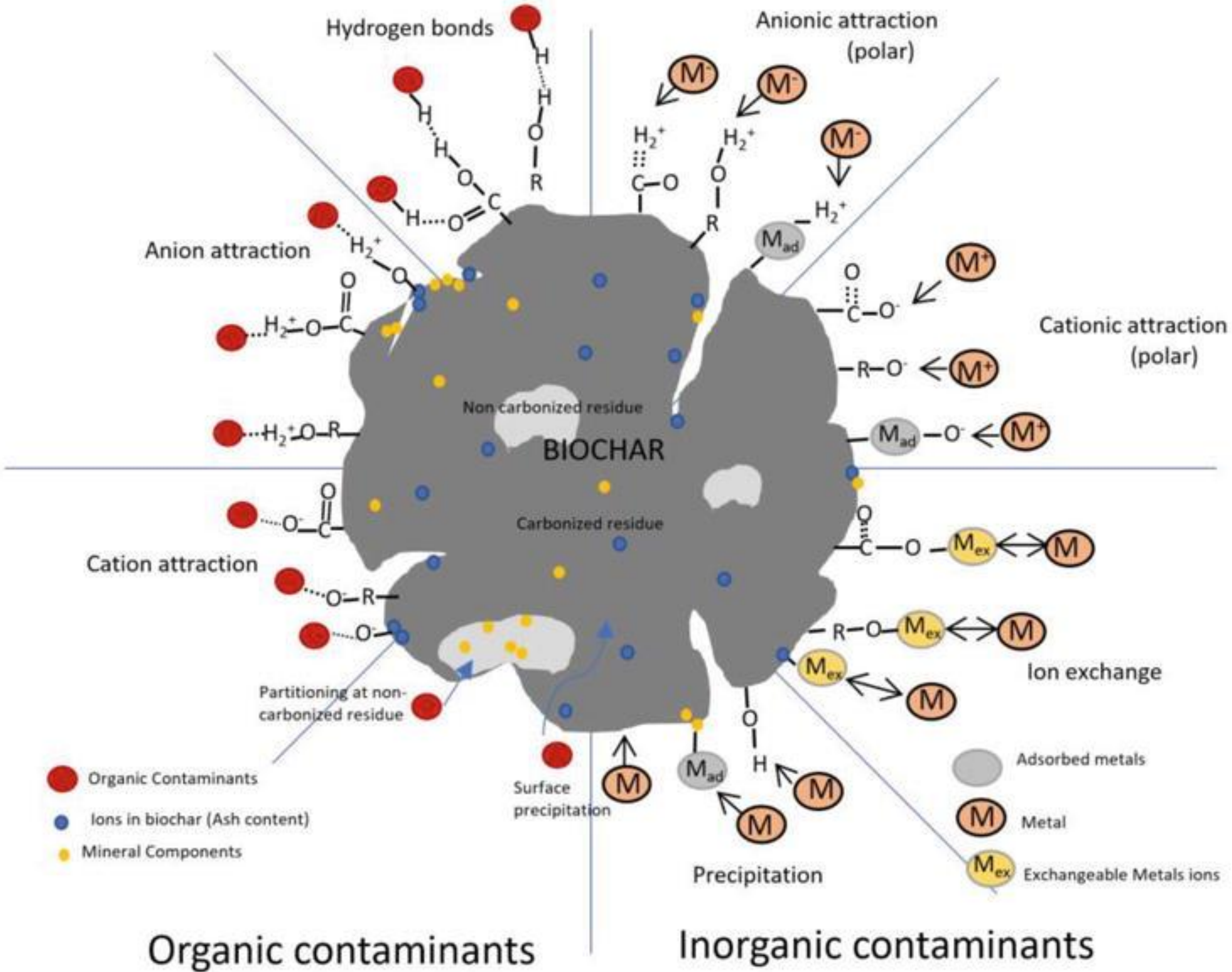
Biochar for environmental management, Routledge, 2015

Biochar Properties



Porous, Stable Carbon-Rich Material of High Surface Area

Heterogeneous composition of functional groups



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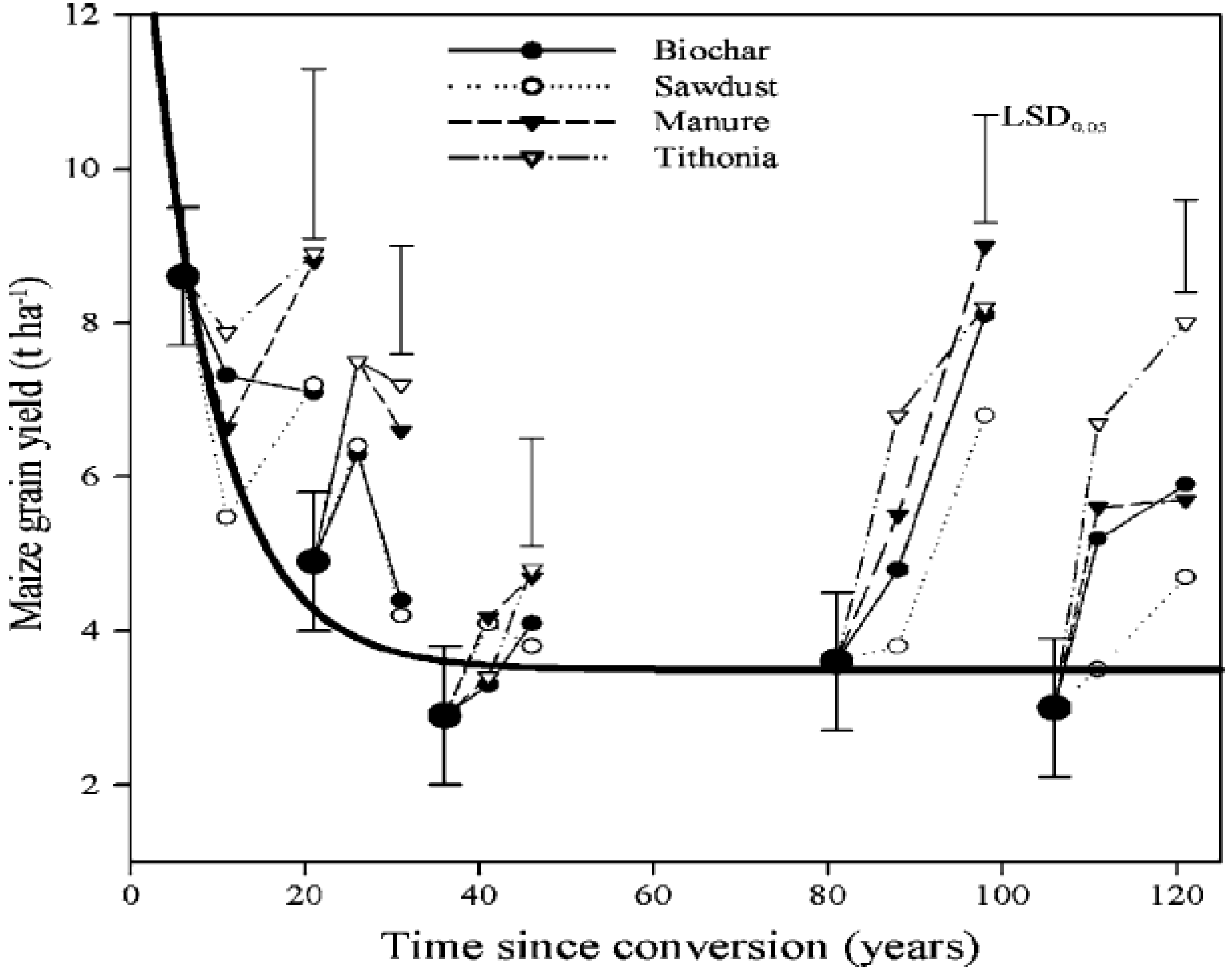
Biochar & Soil Productivity

Well, it depends…



- Feedstock
- Crop type
- Application rate
- Soil pH
- Soil Texture
- Co-application
- Pyrolysis temp
- …

Kimetu et al., 2008. Ecosystems DOI: 10.1007/s10021-008-9154-z

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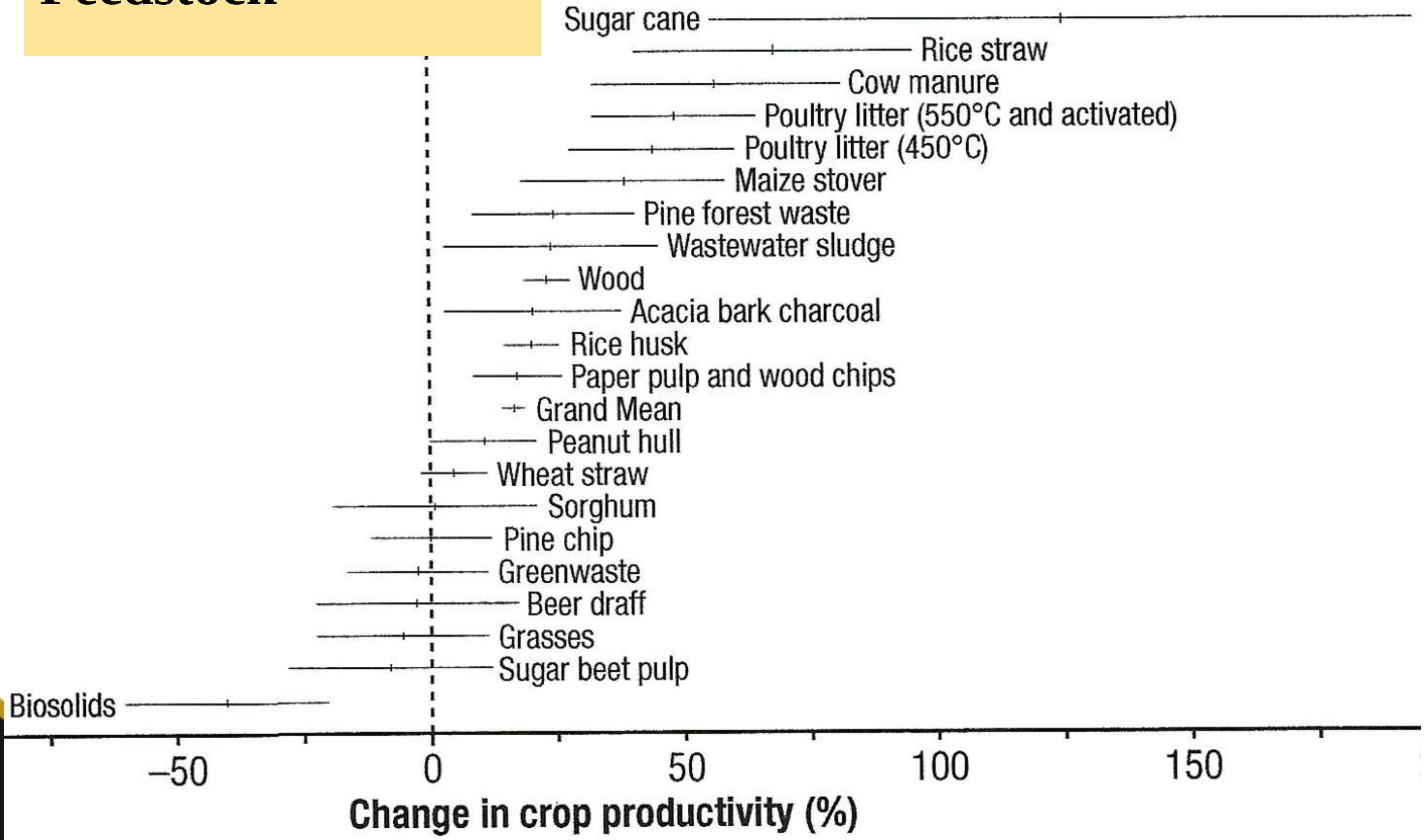
Biochar & Soil Productivity

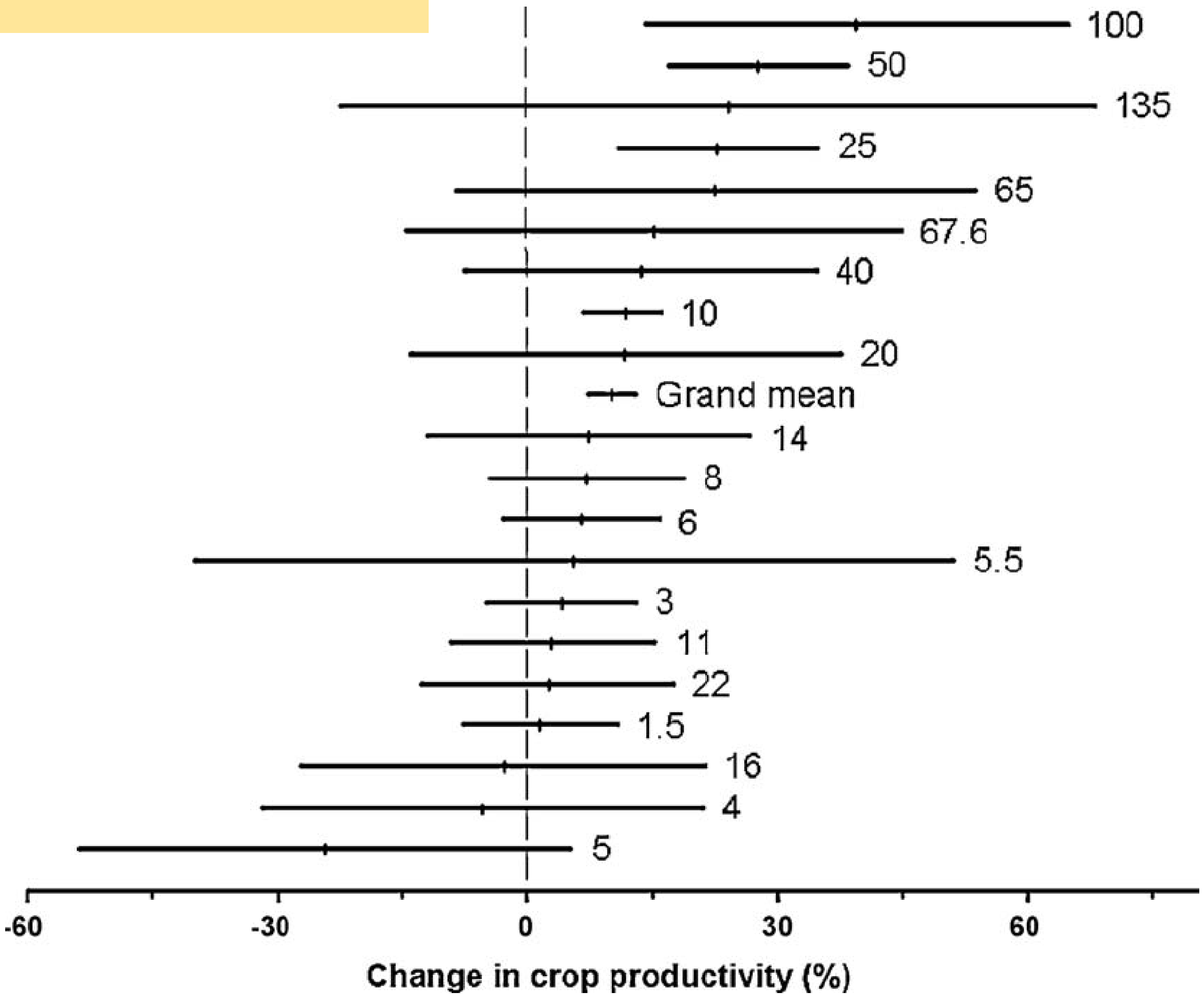
Feedstock



Jeffery et al., 2015. Biochar effect on crop yield

Biochar & Soil Productivity

Application Rate



S. Jeffery et al. / Agriculture, Ecosystems and Environment 144 (2011) 175–187

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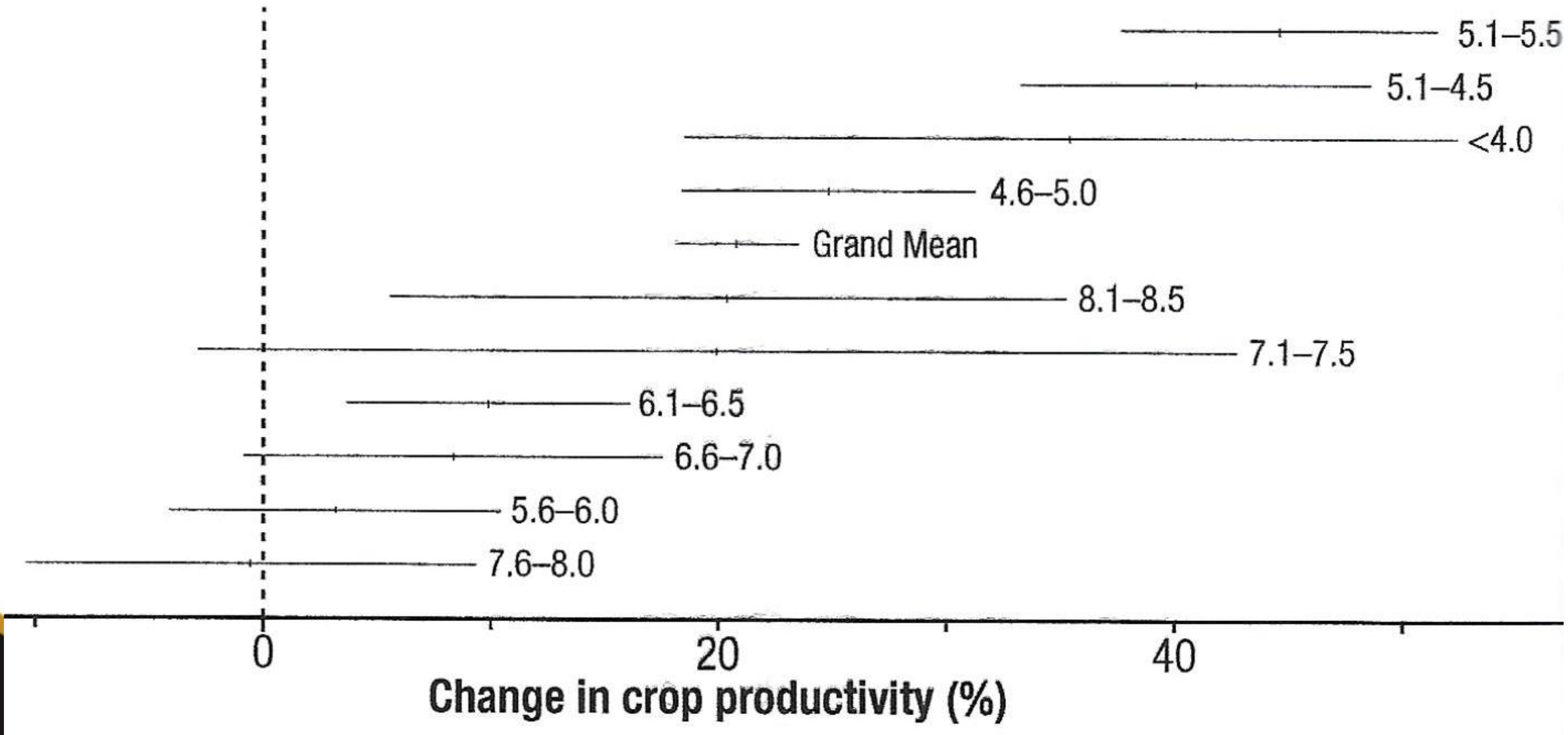
Biochar & Soil Productivity

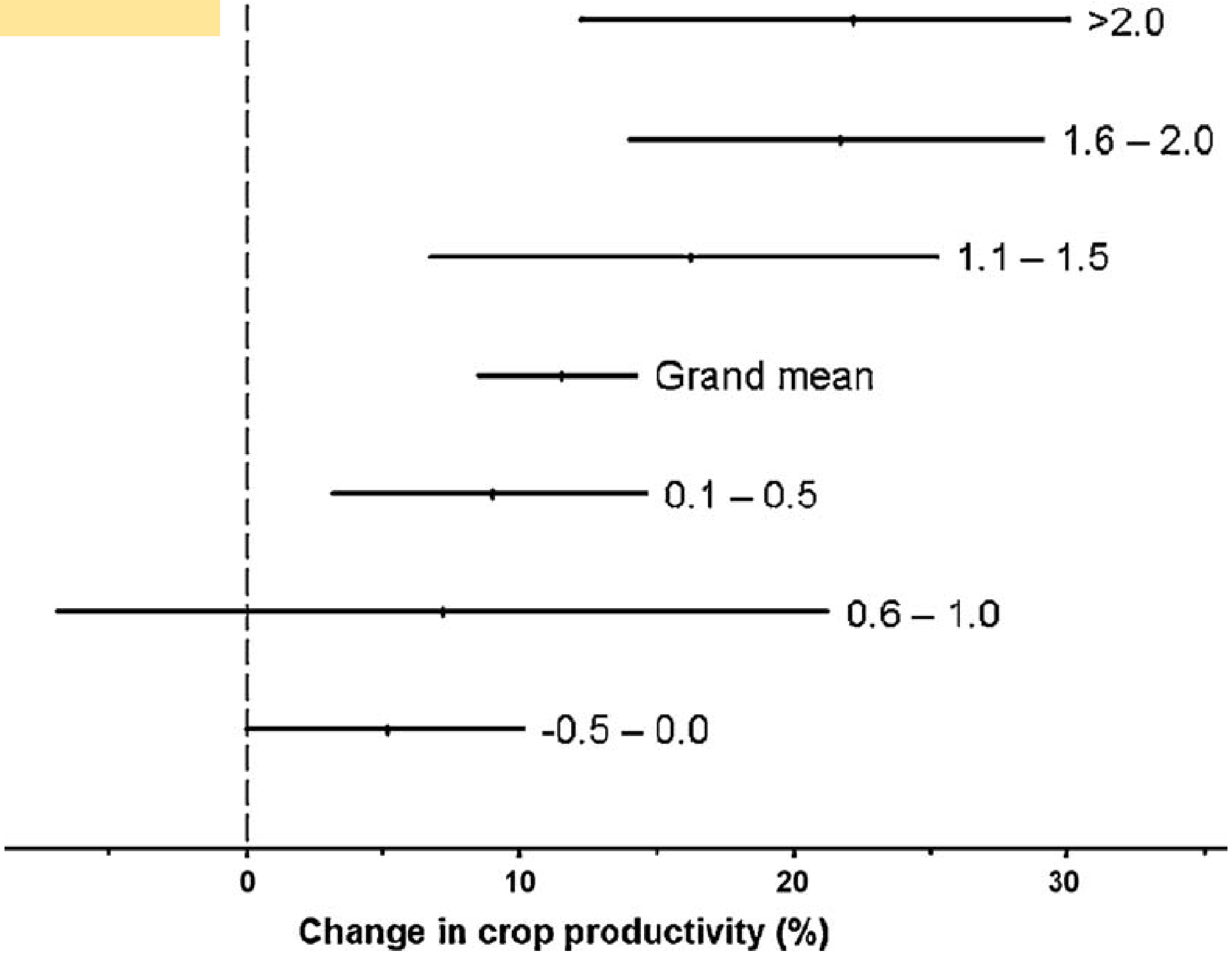
Soil pH



Jeffery et al., 2015. Biochar effect on crop yield

Biochar & Soil Productivity

Soil pH ***(ΔpH)***



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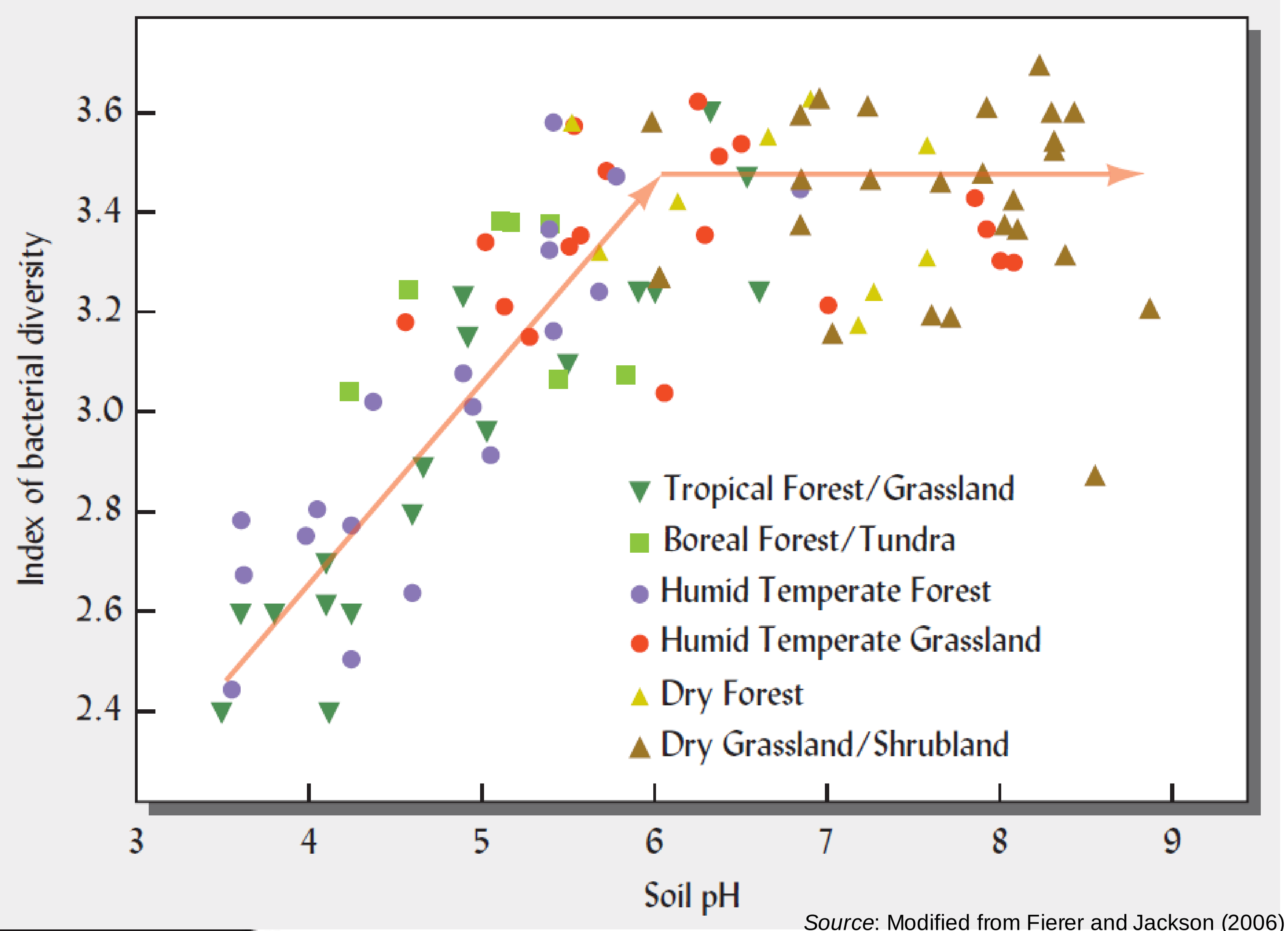
Soil pH Greatly Influences Microbial Diversity



Source: Modified from Fierer and Jackson (2006)

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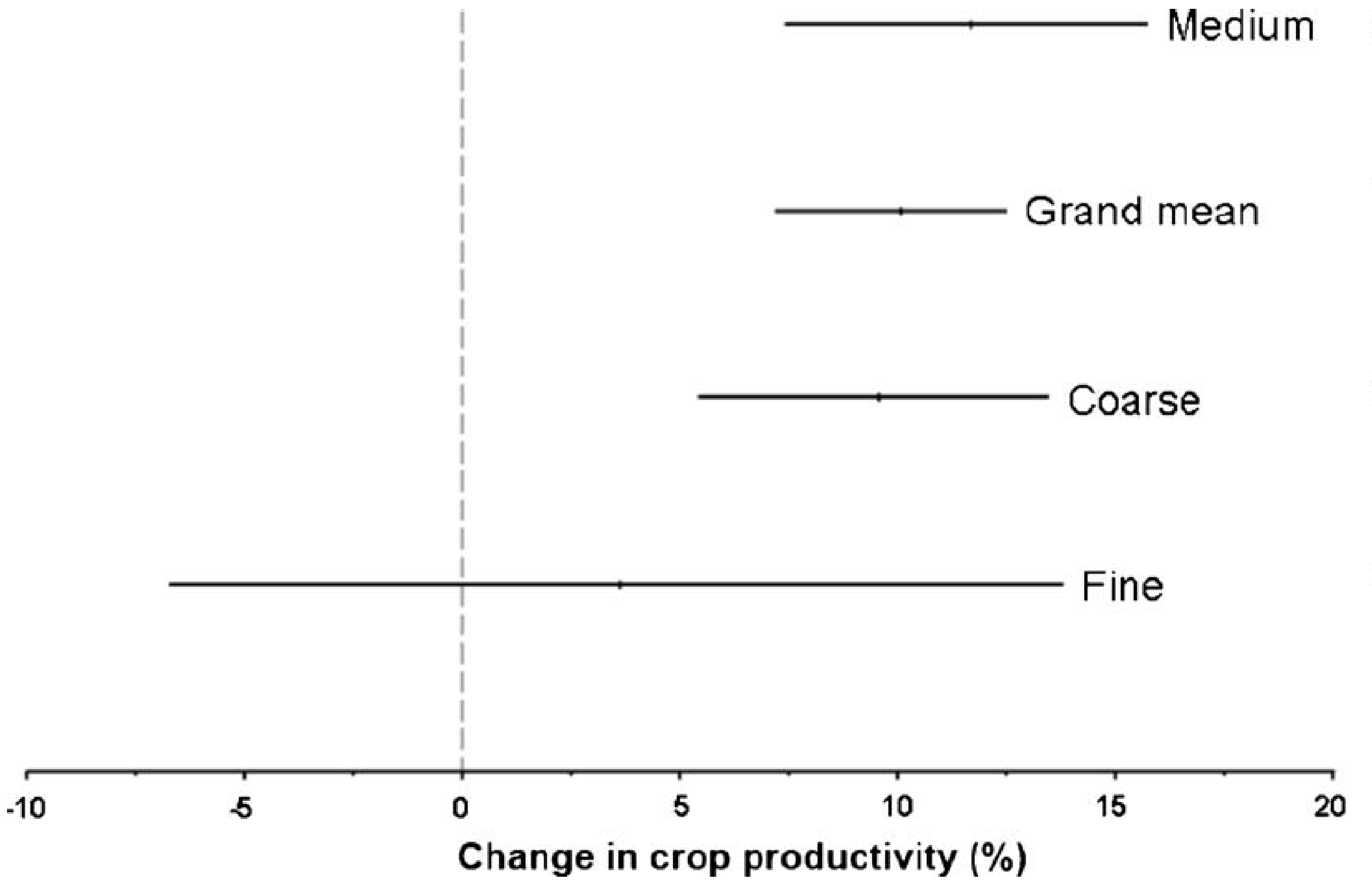
Biochar & Soil Productivity

Soil Texture



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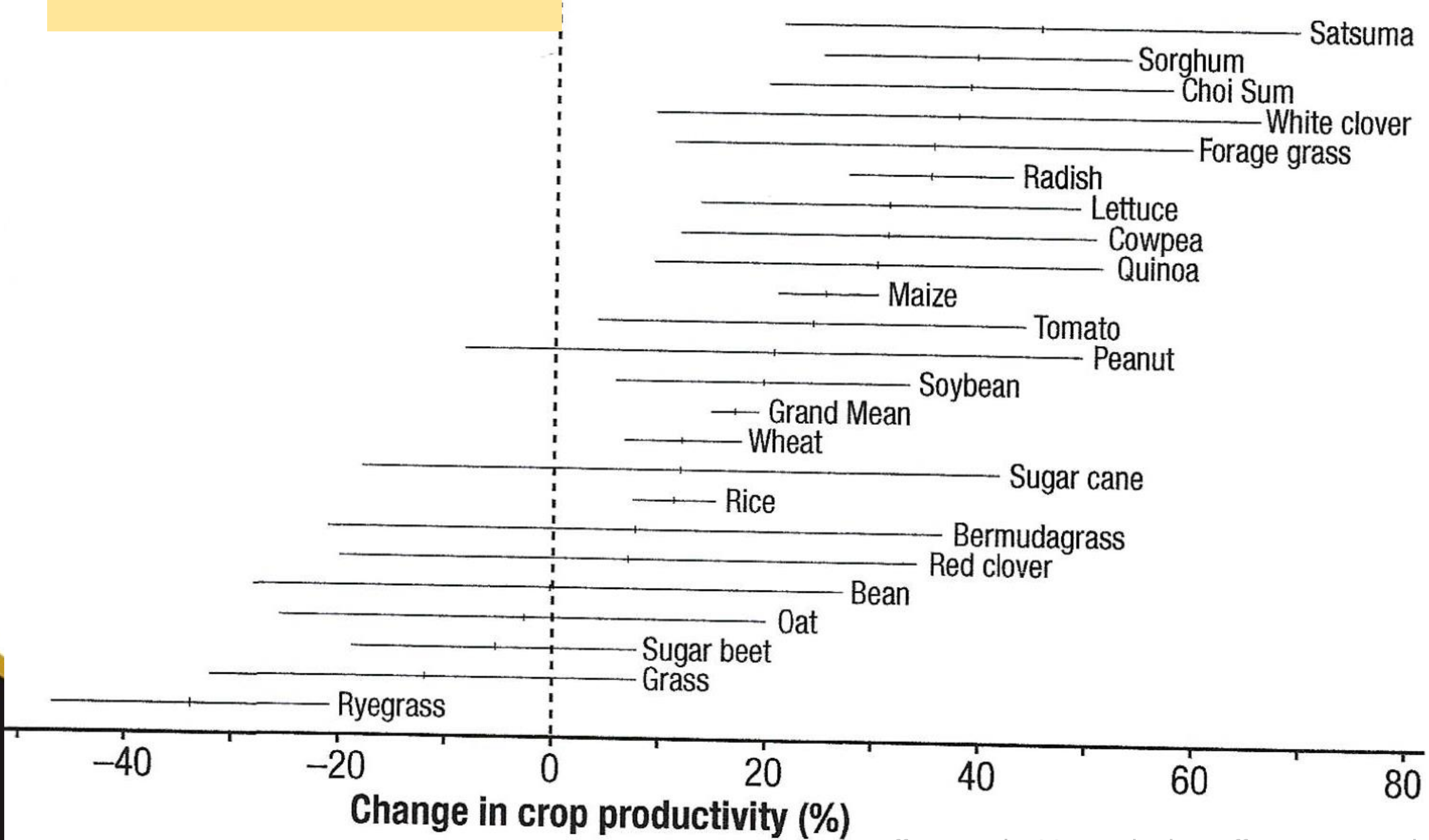
Biochar & Soil Productivity

Crop



Jeffery et al., 2015. Biochar effect on crop yield

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Biochar Bulk Density (BD) and Effect on Soil

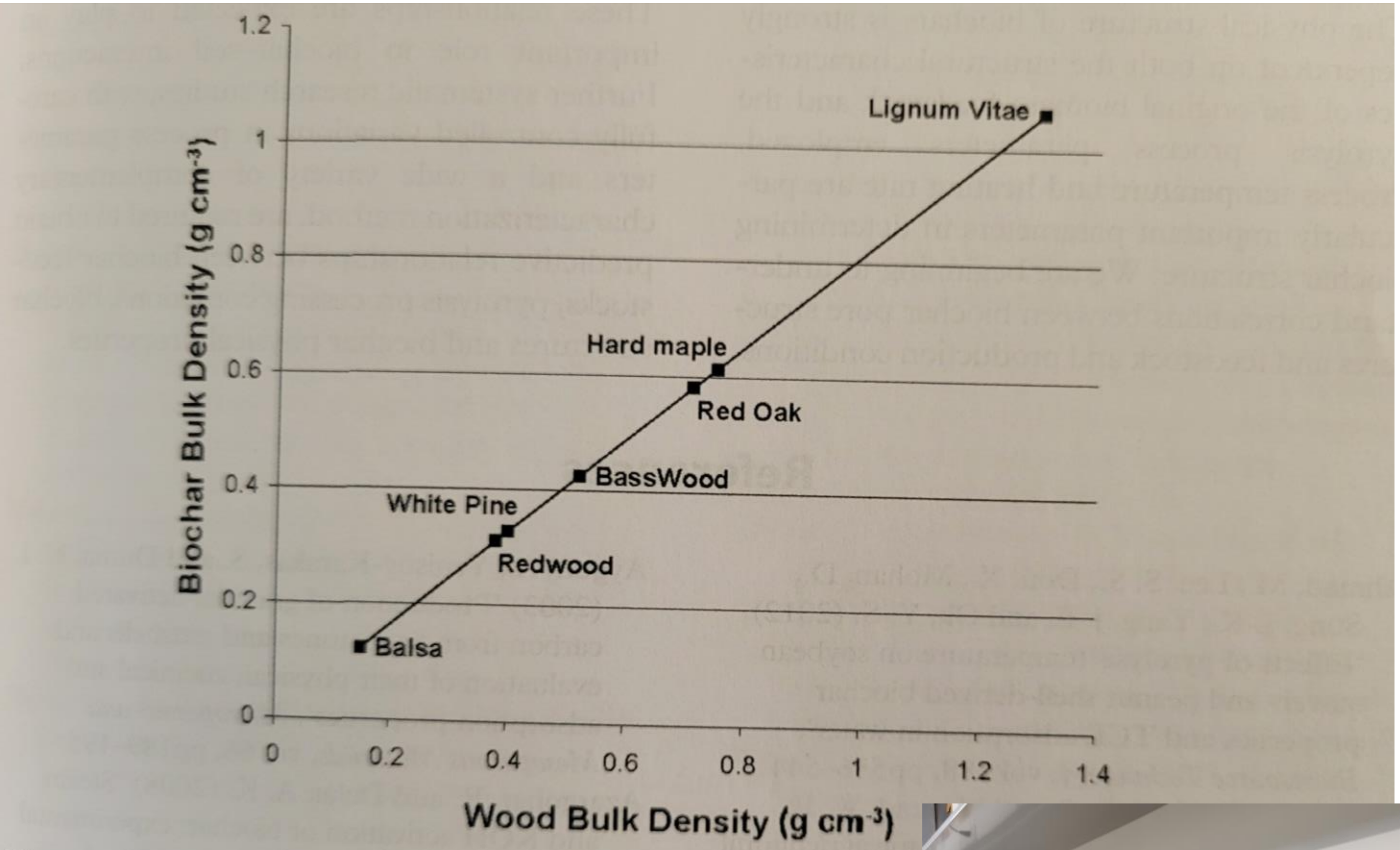
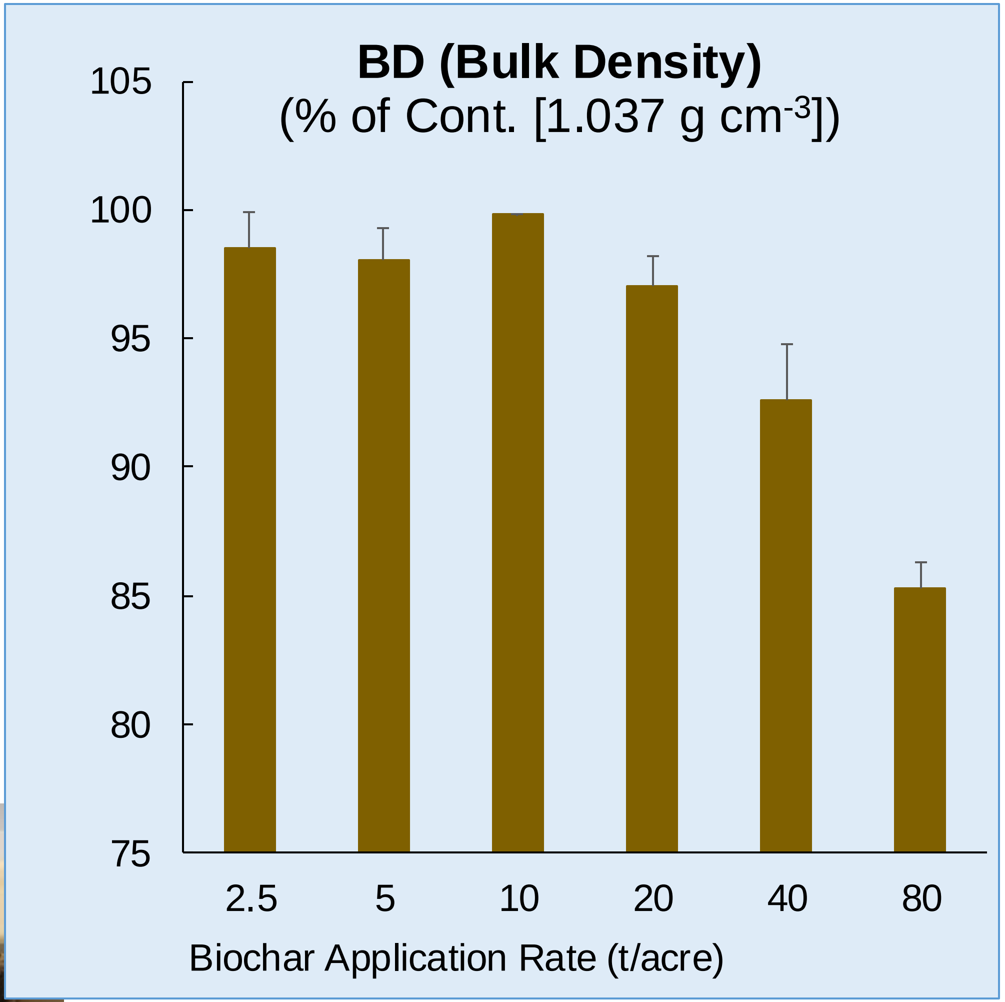
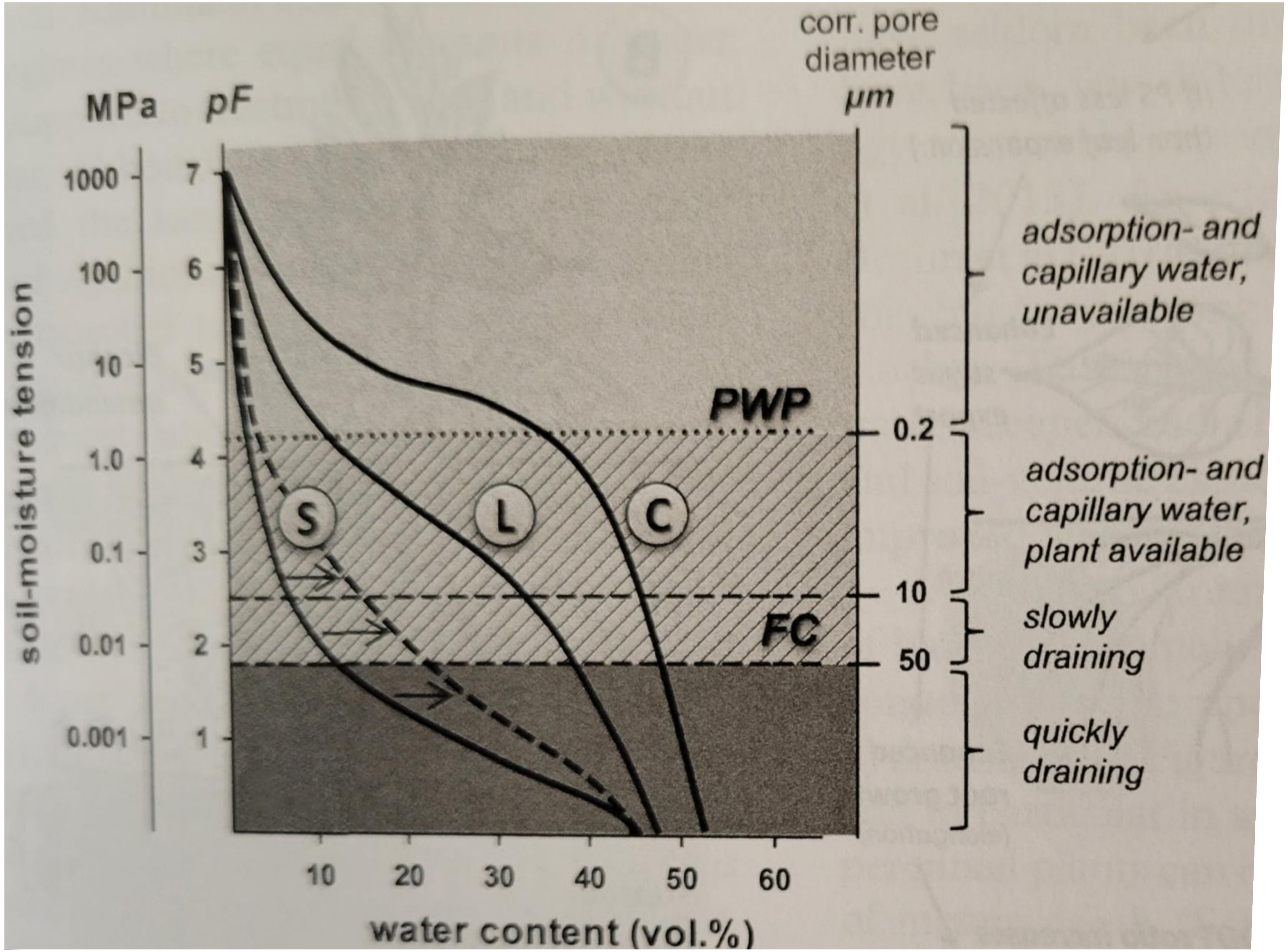
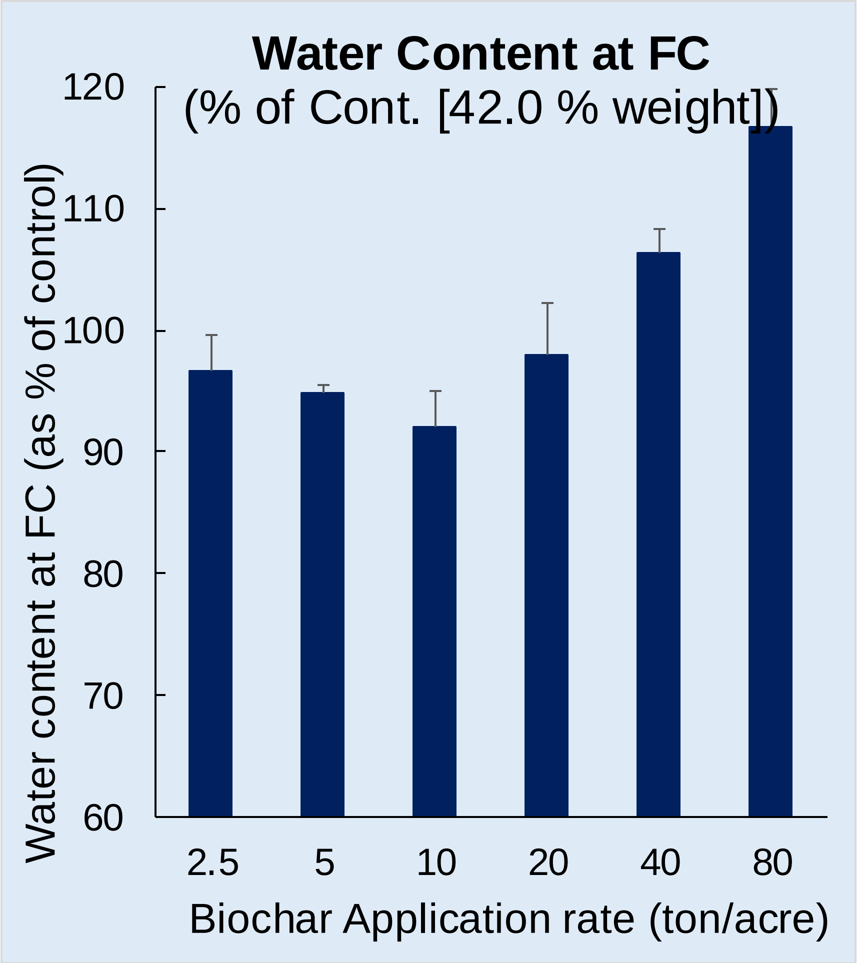


Figure 5.7 *Bulk density of wood biochar in relationship to the bulk bulk density = 0.8176 × wood bulk density. Values are for carboniz 15°C h to 900°C (Byrne and Nagle, 1997)*



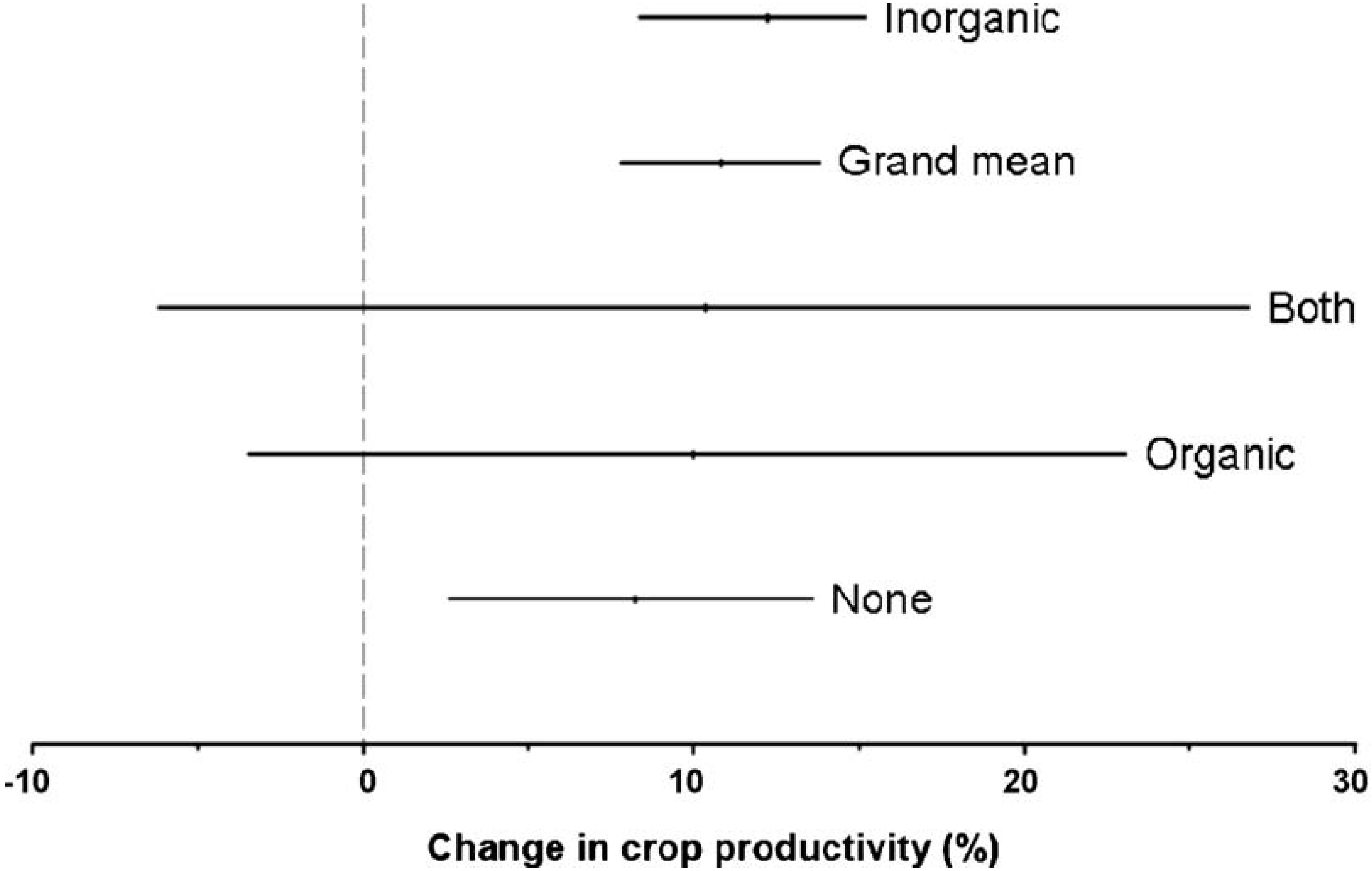
Biochar Effect on Soil Water Holding Capacity





Biochar & Soil Productivity

With Fertilizer



Jeffery et al., 2015. Biochar effect on crop yield

Biochar & Soil Productivity

N Cycling

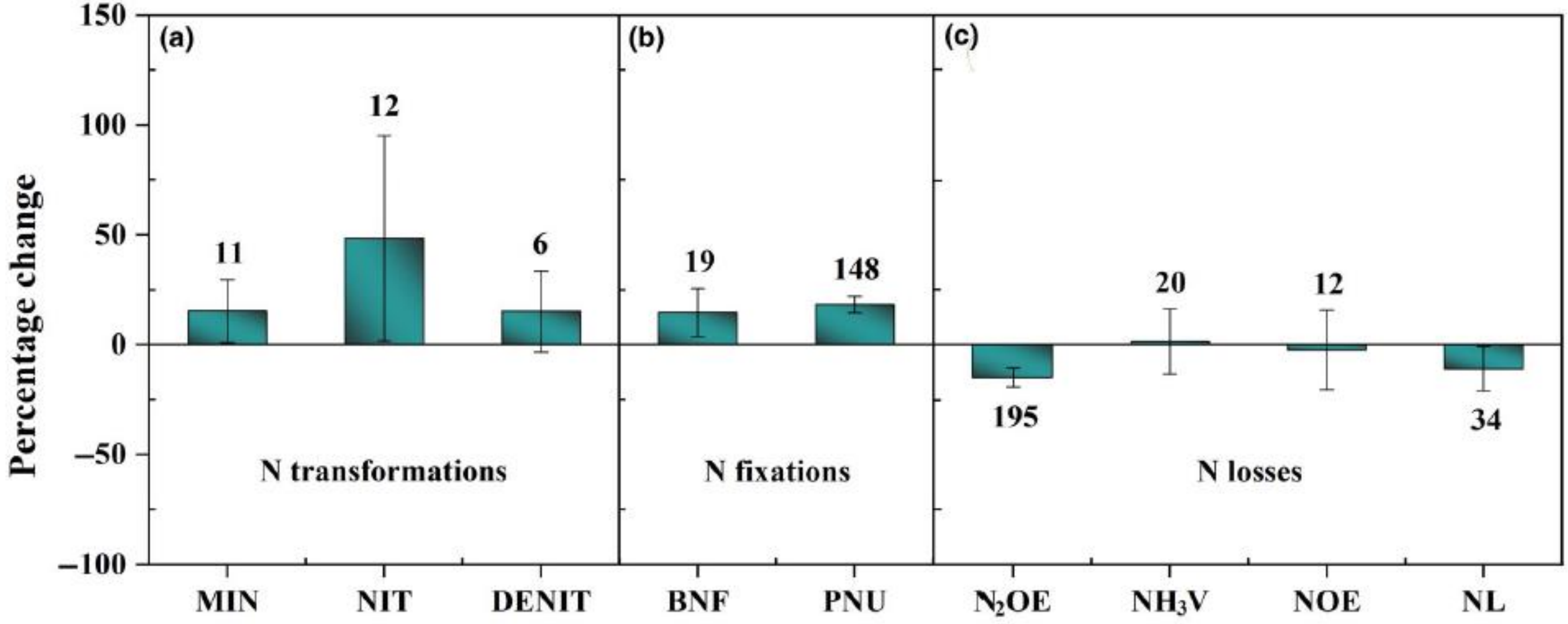


FIGURE 2 Relative changes of index for major N-cycling processes in biochar-treated soils compared with controls. Bars indicate 95% confidence intervals, and the number of observations is displayed on the upper portion of the bar. (a) N transformations include soil N mineralization ratio (MIN), nitrification ratio (NIT), and denitrification ratio (DENIT); (b) N fixations include biological N_2 fixation (BNF) and plant N uptake (PNU); (c) N losses include soil NH_3 volatilization (NH_3V), N_2O (N_2OE) and NO (NOE) emissions, and soil N leaching (NL)

Zhang et al., 2021 DOI: 10.1111/gcbb.12898

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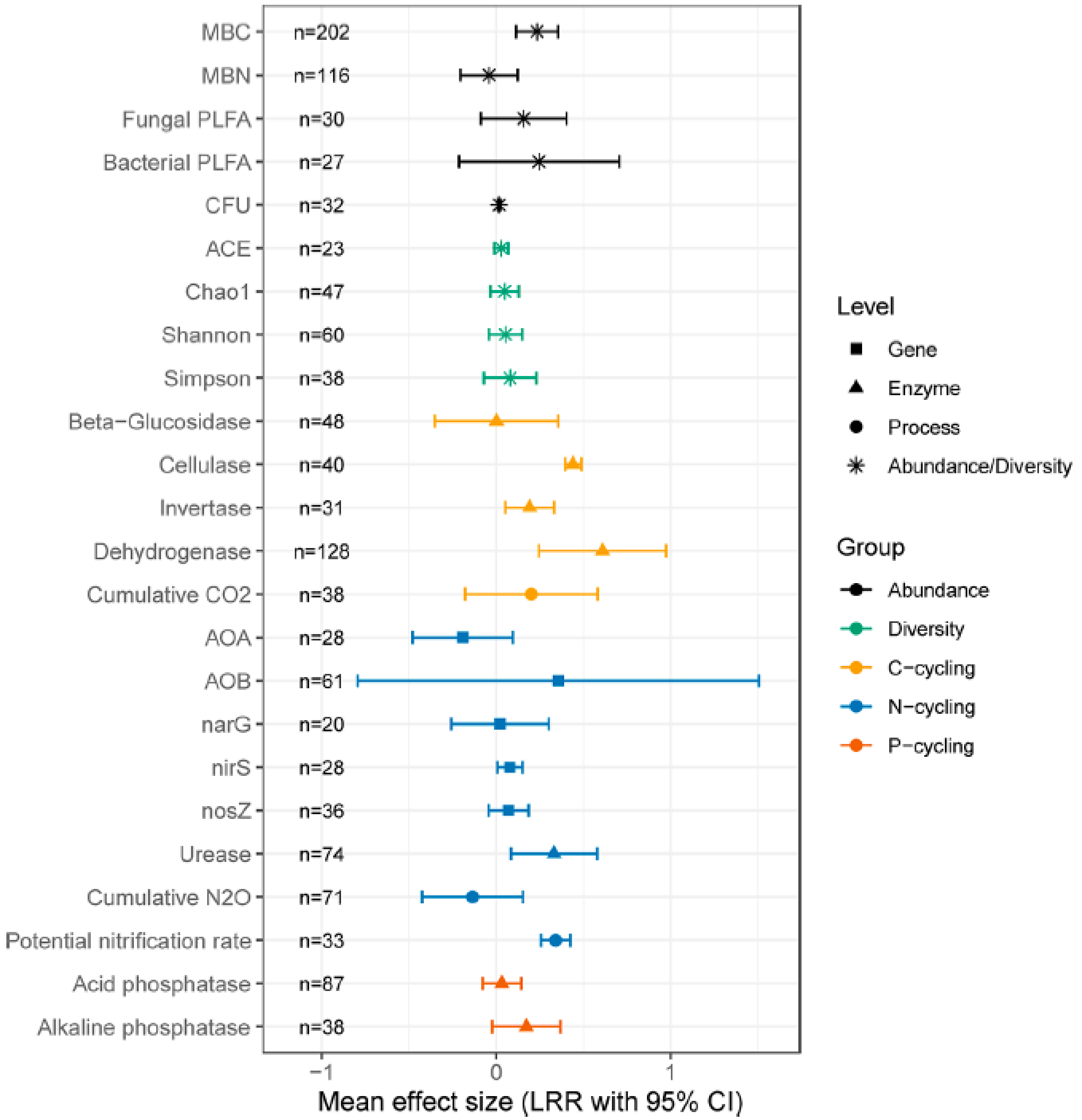
Biochar & Soil Productivity

Effects of biochar on soil microbial responses

(AOA, ammonium-oxidizing archaea; AOB, ammonium-oxidizing bacteria; CFU, colony-forming unit; MBC, microbial biomass carbon; MBN, microbial biomass nitrogen; PLFA, phospholipid fatty acid. AOB and AOA were commonly measured with quantitative PCR targeting the ammonia monooxygenase gene *amoA)*

Kerner et al., 2023; https://doi.org/10.1021/acs.est.3c04201



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Biochar & Soil Productivity

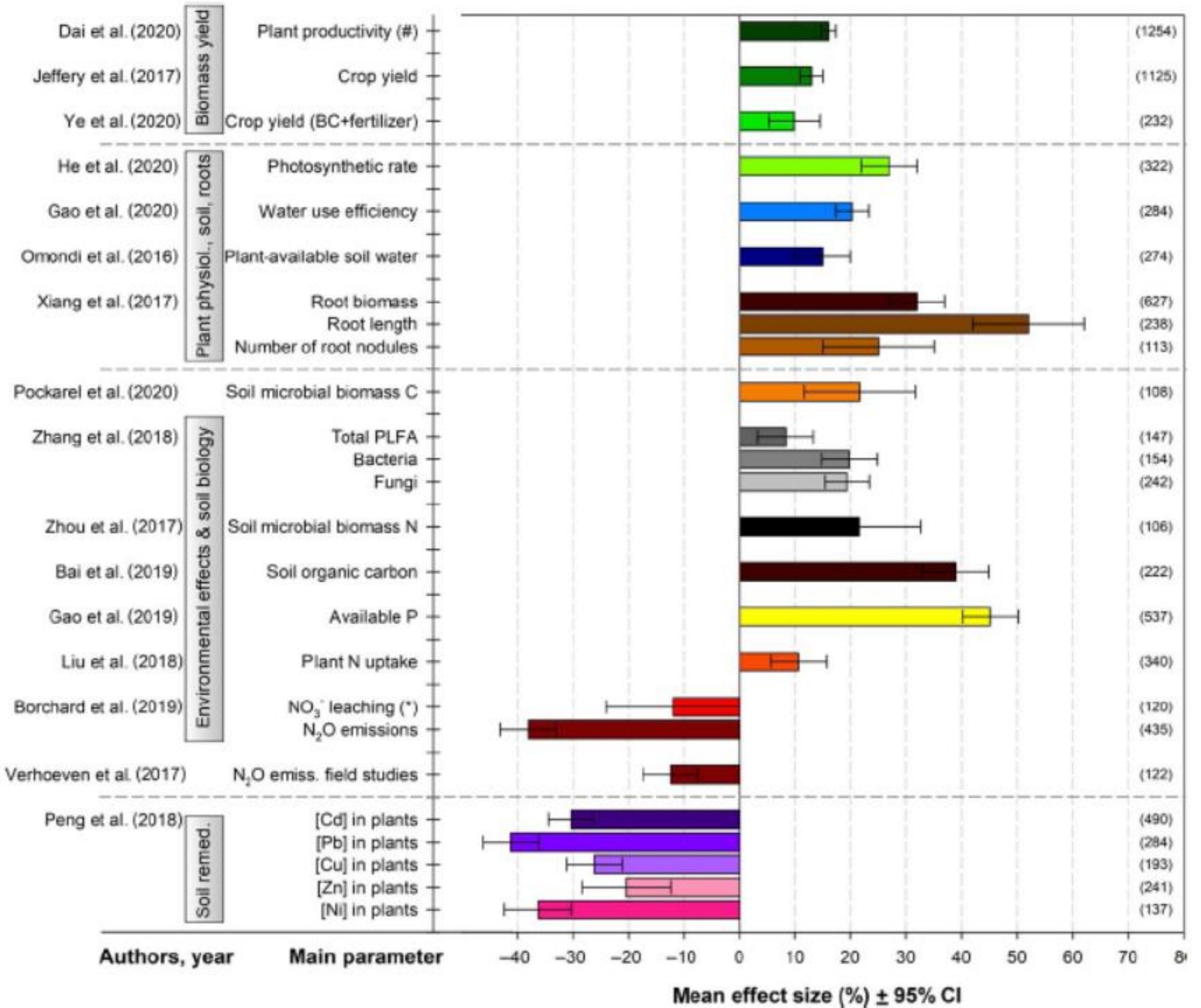
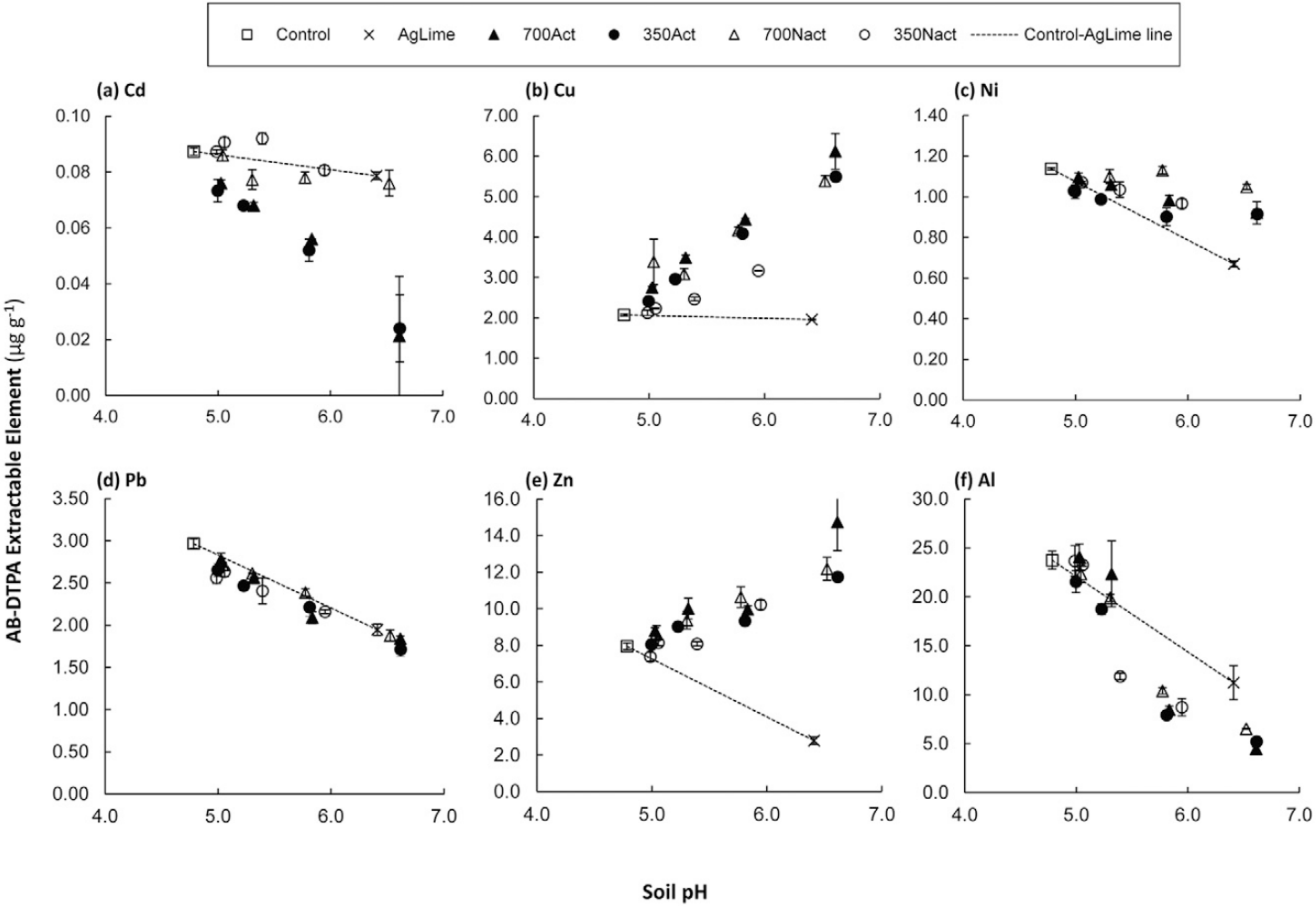


FIGURE 2 Selected parameters with highest agronomic relevance that were investigated in the 26 reviewed meta-analyses. The mean overall effect size (% change) and 95% confidence intervals are given as reported in the original studies. The numbers in parentheses indicate the number of pairwise comparisons used for that specific parameter

Schmidt et al., 2021

Biochar Effect on Plant Available Metals



Oxygen and Ash content effect on Cu Sorption Capacity of Sugar Cane Bagasse Biochar

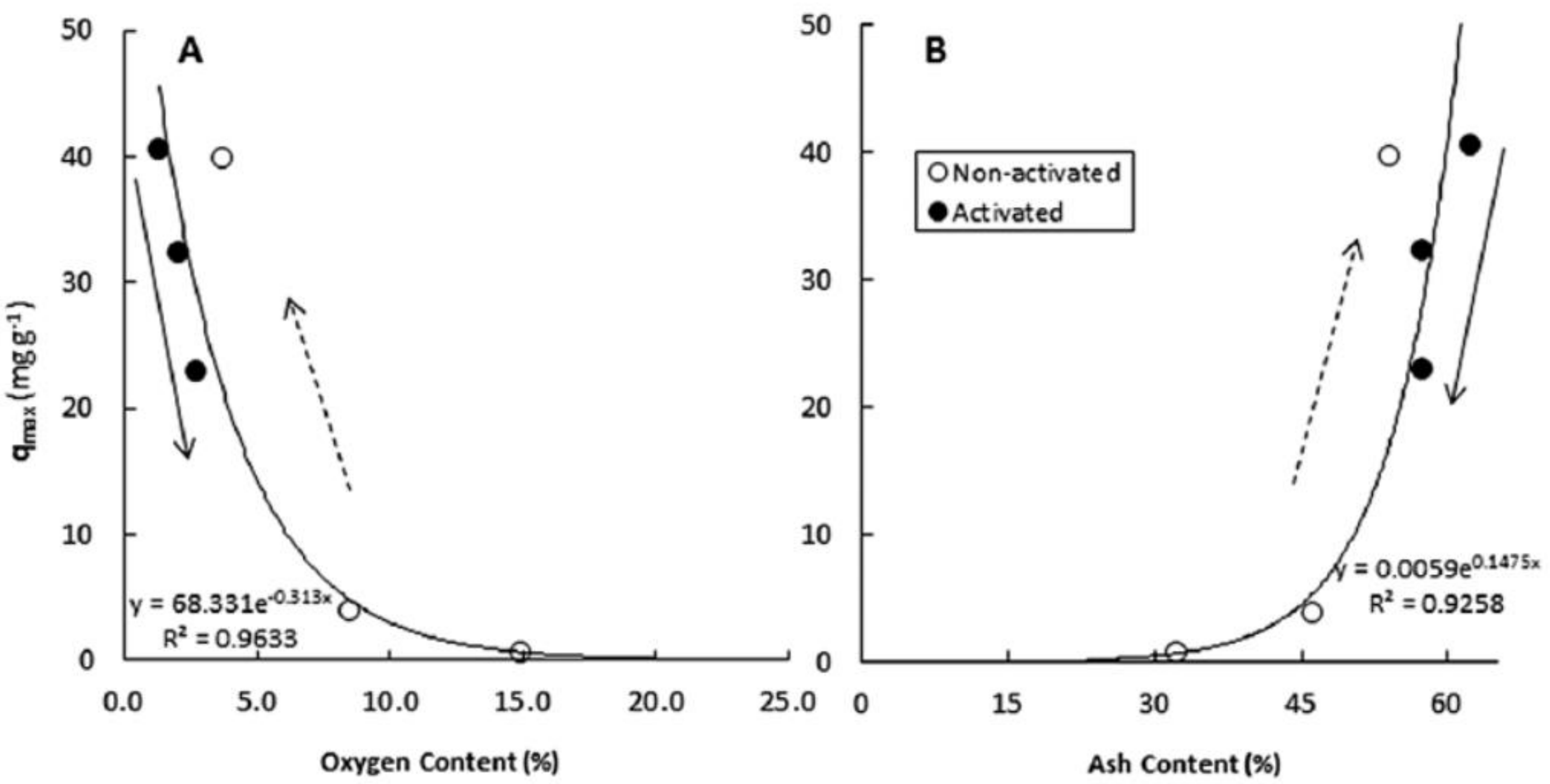
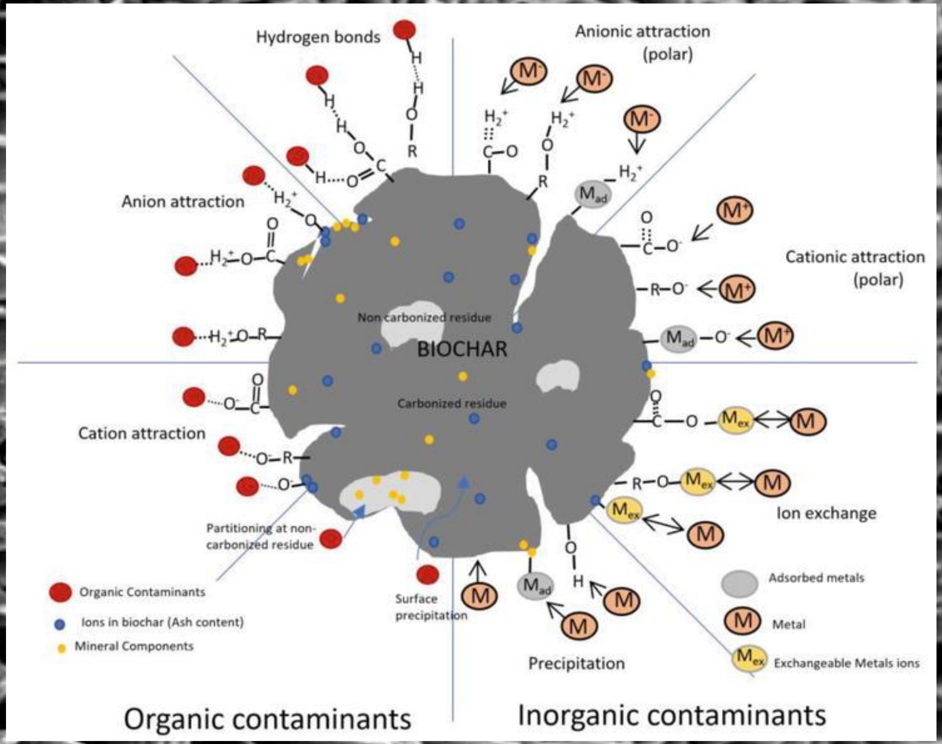


Fig. 2. Cu sorption capacity (q_{max}) and oxygen (A) and ash (B) content of old bagasse biochars (arrows point to the direction of increase in pyrolysis temperature of activated [solid line], and non-activated [dissected line] biochars; solid regression line are exponential fit for all observations).

Biochar – Where Do we Go From Here



Biochar$_G$ – Biochar at The Age of Comix

Biochar Application Rate Effect

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MID-ATLANTIC SUSTAINABLE BIOMASS FOR VALUE-ADDED PRODUCTS CONSORTIUM (MASBIO). *USDA NIFA AFRI, WVA00926 acc. #1022965*

Climate Smart Technologies Evaluation And Dissemination In Disadvantage Appalachian Farming Communities. *USDA Evans Allen Capacity Grant, Wvax-MultiState acc. #7003783*

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International Biochar Initiative

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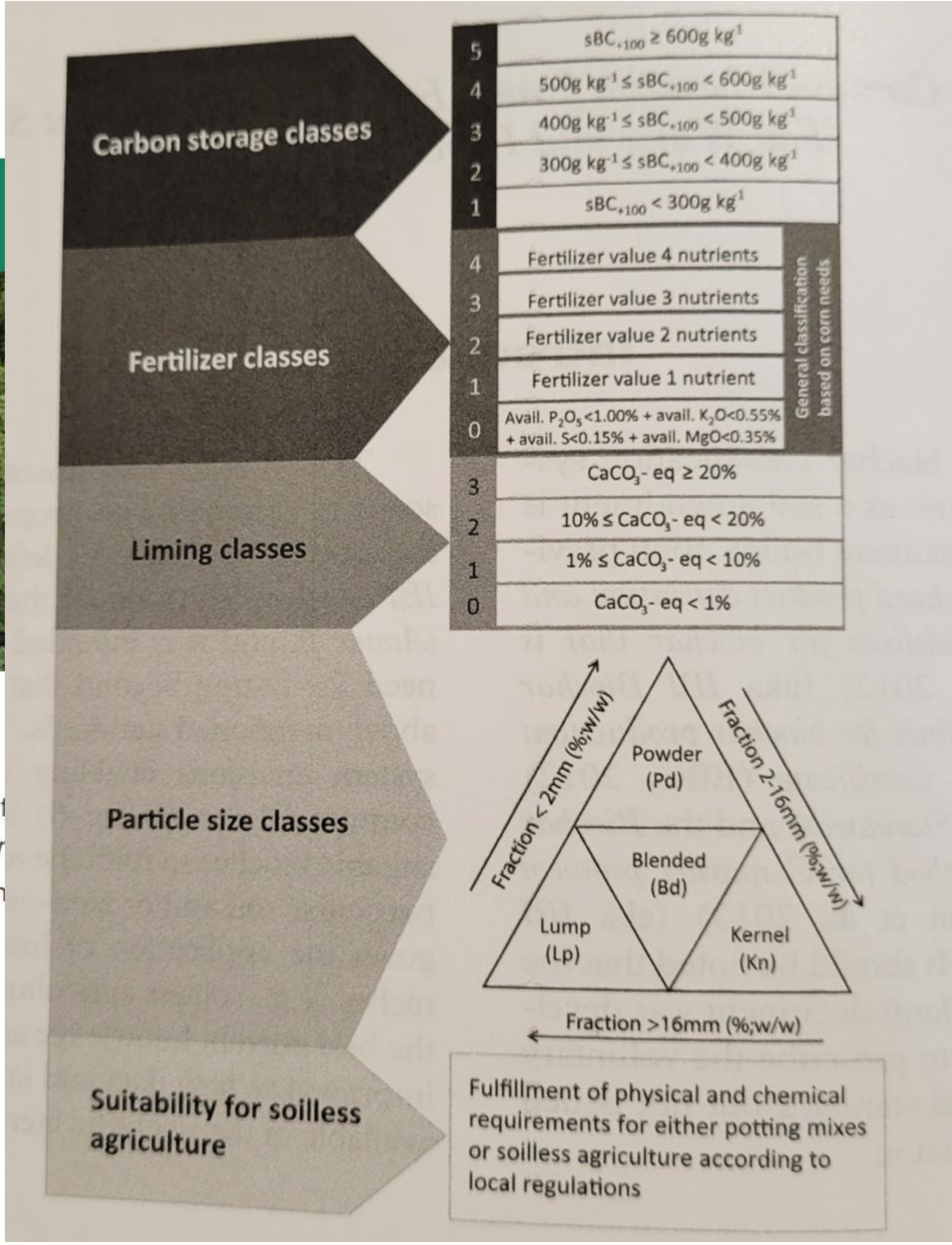
Biochar Classification Tool

Home / Resources / Biochar Classification Tool

Biochar may offer direct and indirect benefits when applied to soils. These benefits are based on diverse material properties of manifested when added to fulfil specific soil/crop needs. The *IBI Biochar Classification Tool*—derived from the paper *A biochar and associated test methods*[1]—classifies biochars based on a set of physicochemical properties (most of them tested for in th *Standards*). At present, four biochar properties are classified:

- Carbon storage value
- Fertilizer value (P, K, S, and Mg only)
- Liming value
- Particle size distribution



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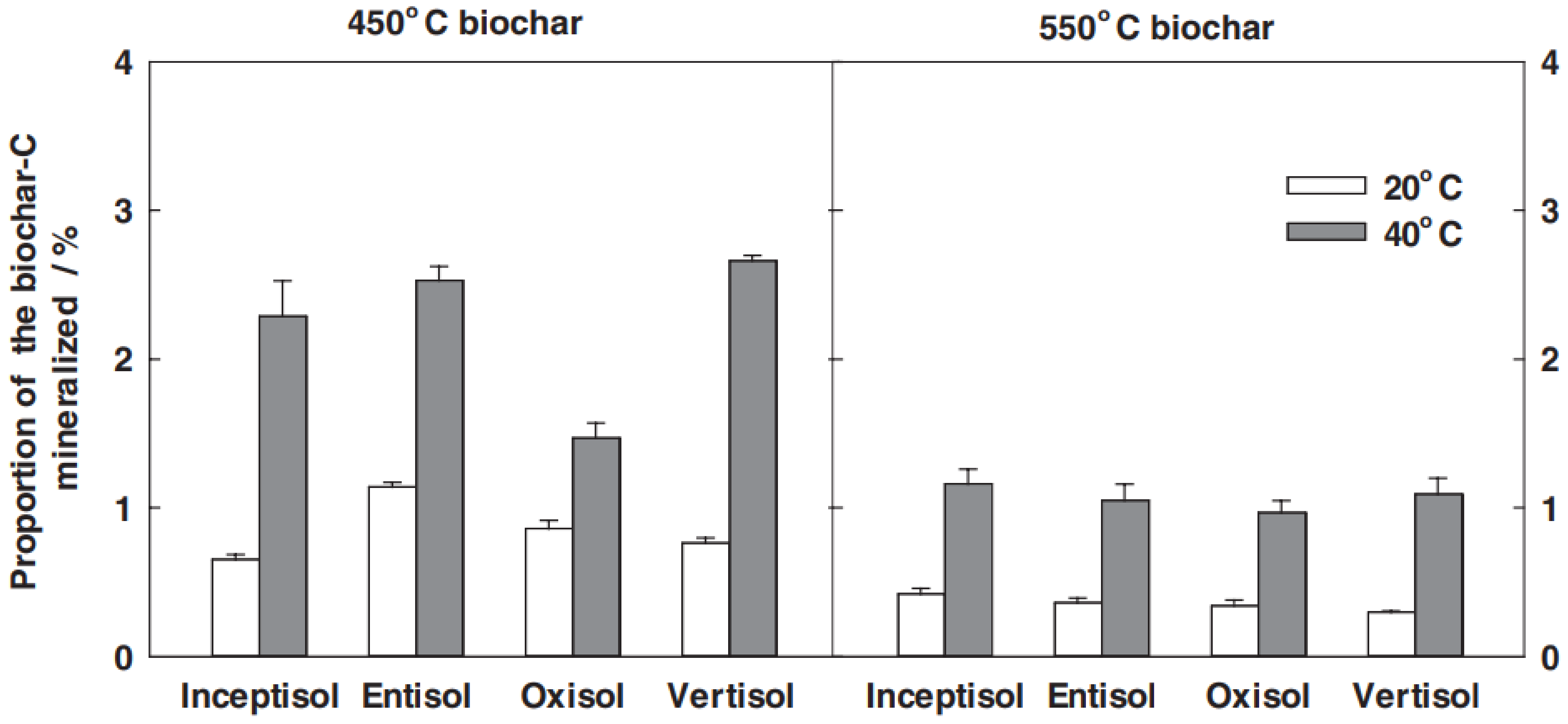
Why Biochar?
Carbon Emission & Sequestration



Fang et al., 2014. Eur. J. Soil Sci. 65:60-71

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Biochar & Soil Productivity

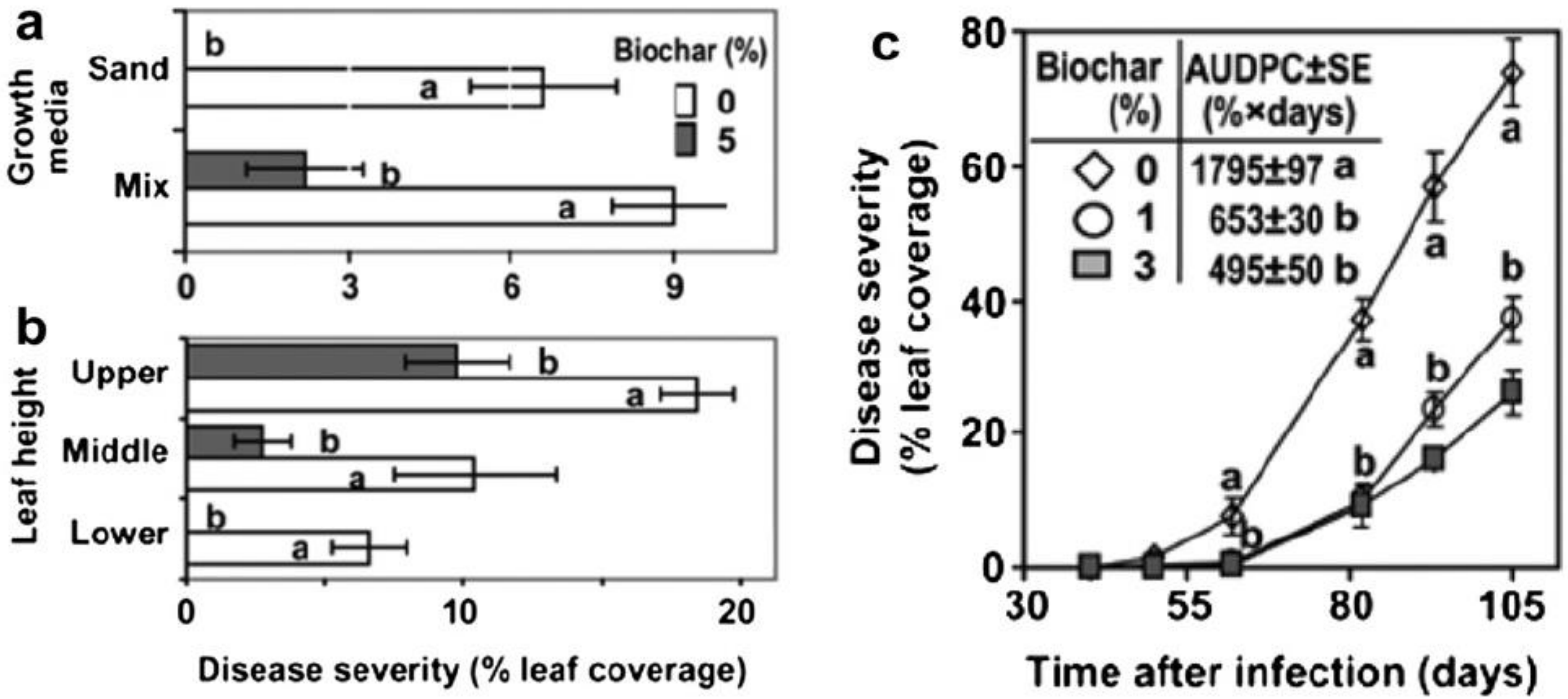

Fig. 14. Disease severity of powdery mildew (*Leveillula taurica*) on tomato as affected by biochar additions (a) in both a sand and a coconut fiber-tuff soilless potting medium (mix); (b) in sand; (c) in the potting medium over 105 days (Elad et al., 2010; with permission).

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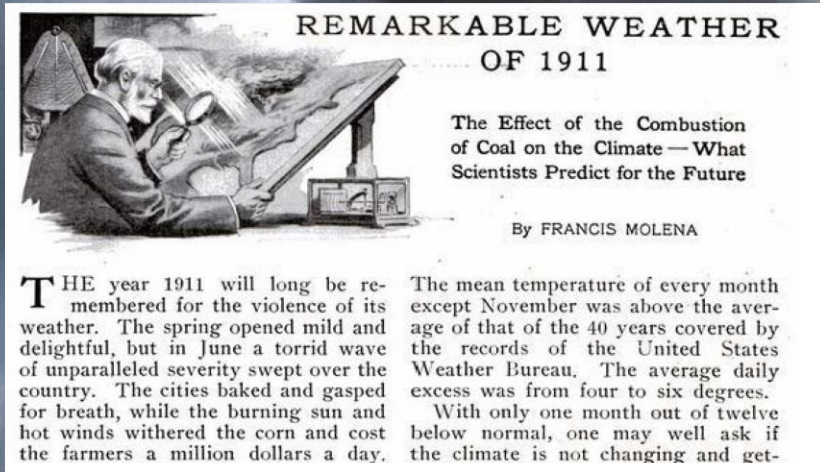
Why Now? Why Soil? Why Biochar?

Svante Arrhenius, 1896

Carl Sagan testifying before Congress in 1985 on climate change



REMARKABLE WEATHER OF 1911

The Effect of the Combustion of Coal on the Climate — What Scientists Predict for the Future

By FRANCIS MOLENA

THE year 1911 will long be remembered for the violence of its weather. The spring opened mild and delightful, but in June a torrid wave of unparalleled severity swept over the country. The cities baked and gasped for breath, while the burning sun and hot winds withered the corn and cost the farmers a million dollars a day.

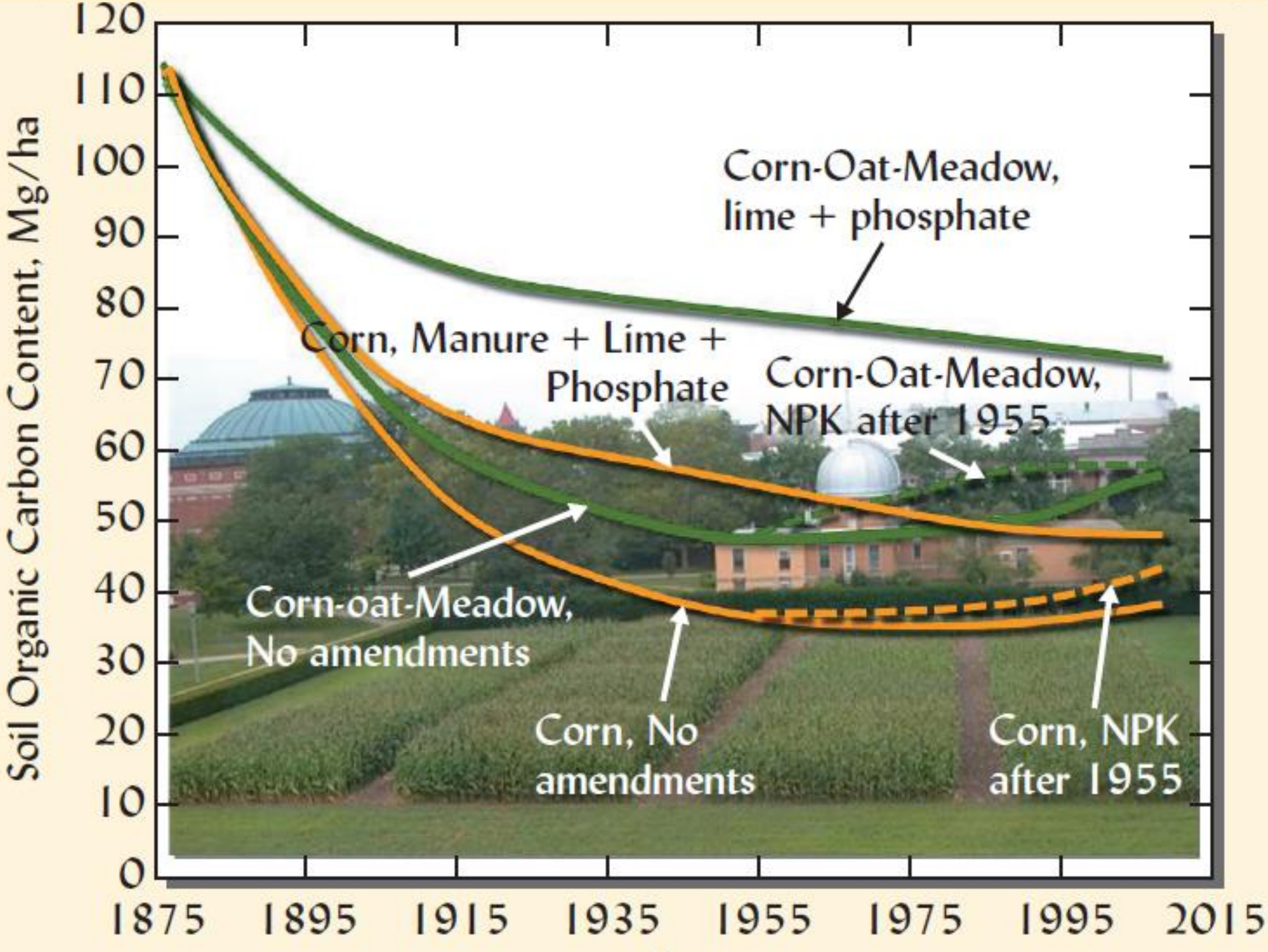
The mean temperature of every month except November was above the average of that of the 40 years covered by the records of the United States Weather Bureau. The average daily excess was from four to six degrees.

With only one month out of twelve below normal, one may well ask if the climate is not changing and get-

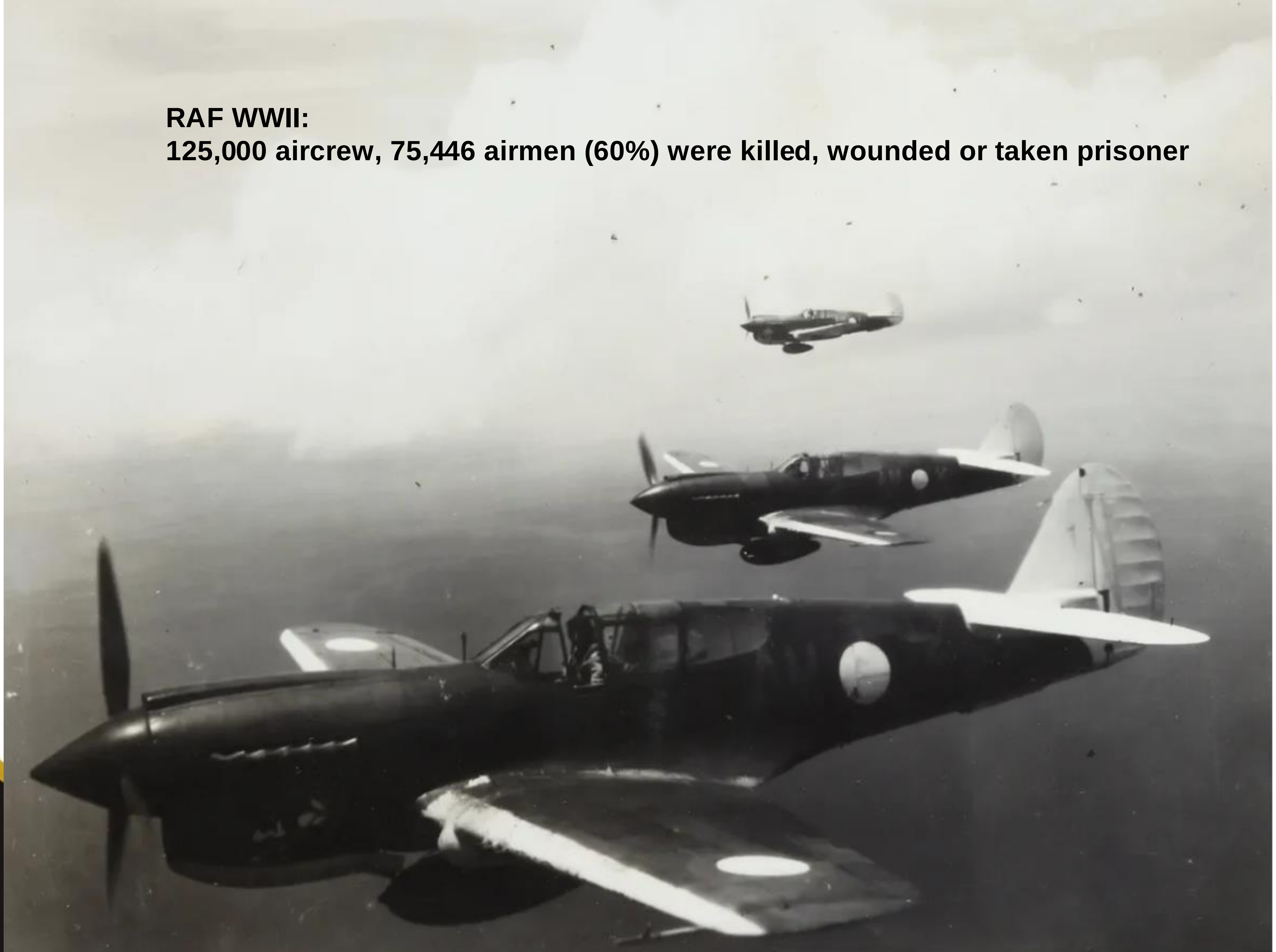
Popular Mechanics March 1, 1912 [Popular Mechanics - Google Books]

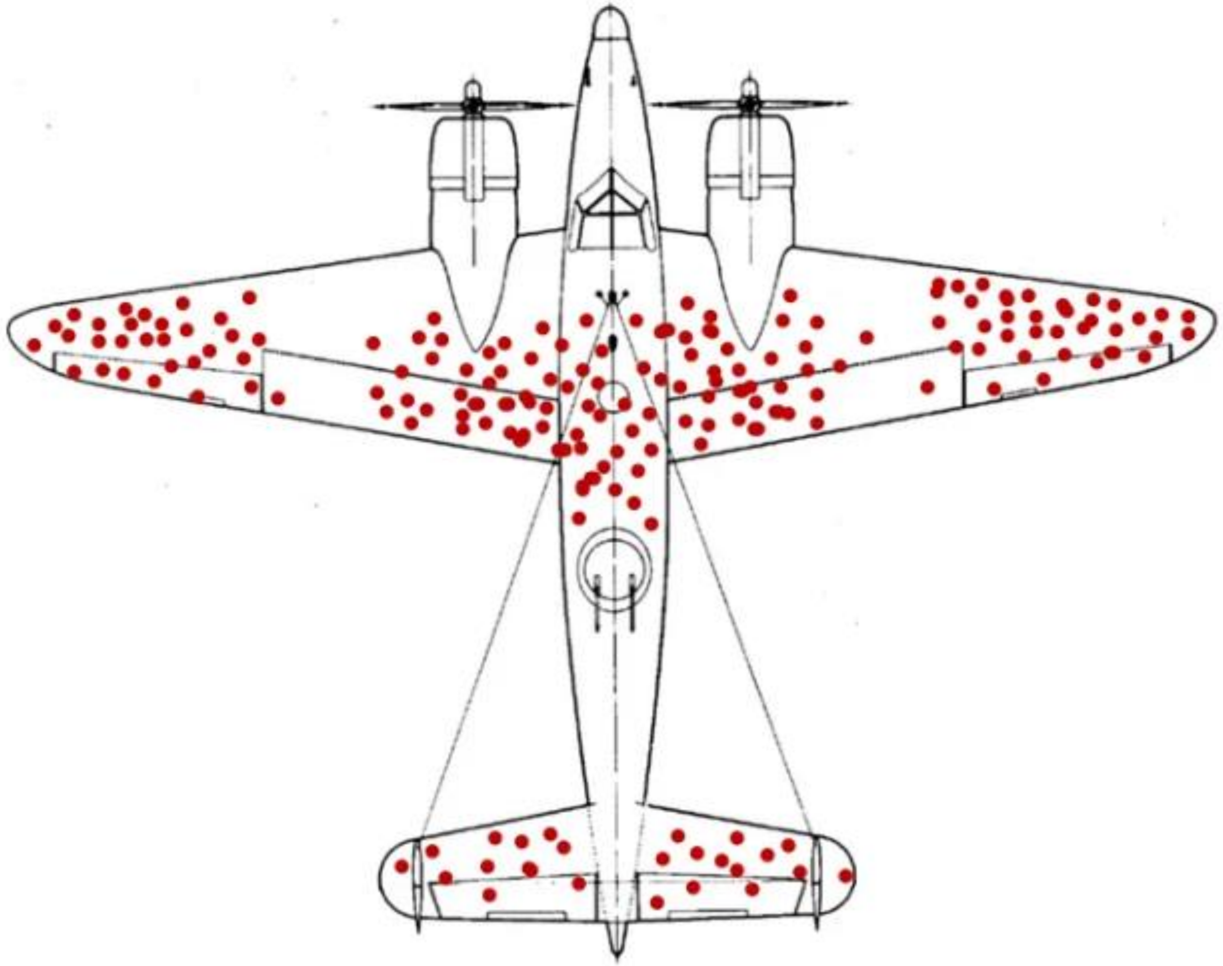
Better Than Never…

1876 – Virgin Grassland Soil (Morrow Plots, University of Illinois)



RAF WWII:
125,000 aircrew, 75,446 airmen (60%) were killed, wounded or taken prisoner





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Biochar & Carbon Credit

Method for Estimating the Change in Mineral Soil Organic Carbon Stocks from Biochar Amendments (*IPCC Guidelines for National Greenhouse Gas Inventories*)

ANNUAL CHANGE IN BIOCHAR CARBON STOCK IN MINERAL SOILS RECEIVING BIOCHAR ADDITIONS

$$\Delta BC_{Mineral} = \sum_{p=1}^{n} \left(BC_{TOT_p} \bullet F_{C_p} \bullet F_{perm_p} \right)$$

$\Delta BC_{Mineral}$ = 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 4Ap.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 4Ap.2

n = the number of different production types of biochar

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

Biochar & Carbon Credit

Method for Estimating the Change in Mineral Soil Organic Carbon Stocks from Biochar Amendments (*IPCC Guidelines for National Greenhouse Gas Inventories*)

ANNUAL CHANGE IN BIOCHAR CARBON STOCK IN MINERAL SOILS RECEIVING BIOCHAR ADDITIONS

$$\Delta BC_{Mineral} = \sum_{p=1}^{n} \left(BC_{TOT_p} \bullet F_{C_p} \bullet F_{perm_p} \right)$$

$\Delta BC_{Mineral}$ = 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 4Ap.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 4Ap.2

n = the number of different production types of biochar

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VALUES FOR ORGANIC C CONTENT FACTOR OF BIOCHAR BY PRODUCTION TYPE (F_{C_p}).

Feedstock	Pyrolysis Production Process	Values for F_{C_p} [2]
Animal manure	Pyrolysis [1]	0.38 ± 49%
	Gasification [1]	0.09 ± 53%
Wood	Pyrolysis	0.77 ± 42%
	Gasification	0.52 ± 52%
Herbaceous (grasses, forbs, leaves; excluding rice husks and rice straw)	Pyrolysis	0.65 ± 45%
	Gasification	0.28 ± 50%
Rice husks and rice straw	Pyrolysis	0.49 ± 41%
	Gasification	0.13 ± 50%
Nut shells, pits and stones	Pyrolysis	0.74 ± 39%
	Gasification	0.40 ± 52%
Biosolids (paper sludge, sewage sludge)	Pyrolysis	0.35 ± 40%
	Gasification	0.07 ± 50%

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VALUES FOR F_{perm_p} (FRACTION OF BIOCHAR C REMAINING AFTER 100 YEARS)

Production	Value for F_{perm_p} [1, 2]
High temperature pyrolysis and gasification (> 600 °C)	0.89 ± 13%
Medium temperature pyrolysis (450-600 °C)	0.80 ± 11%
Low (350-450 °C)	0.65 ± 15%

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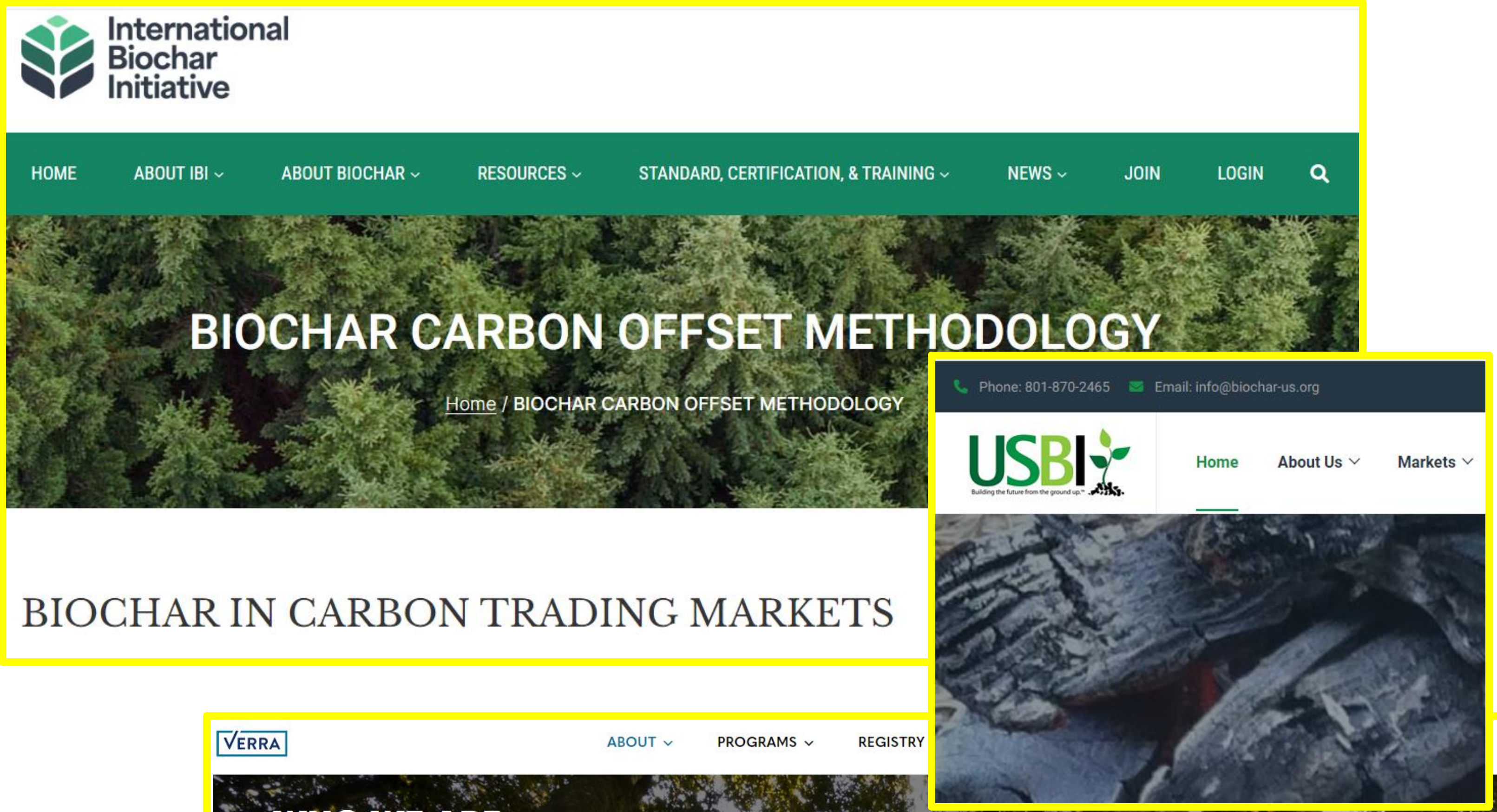

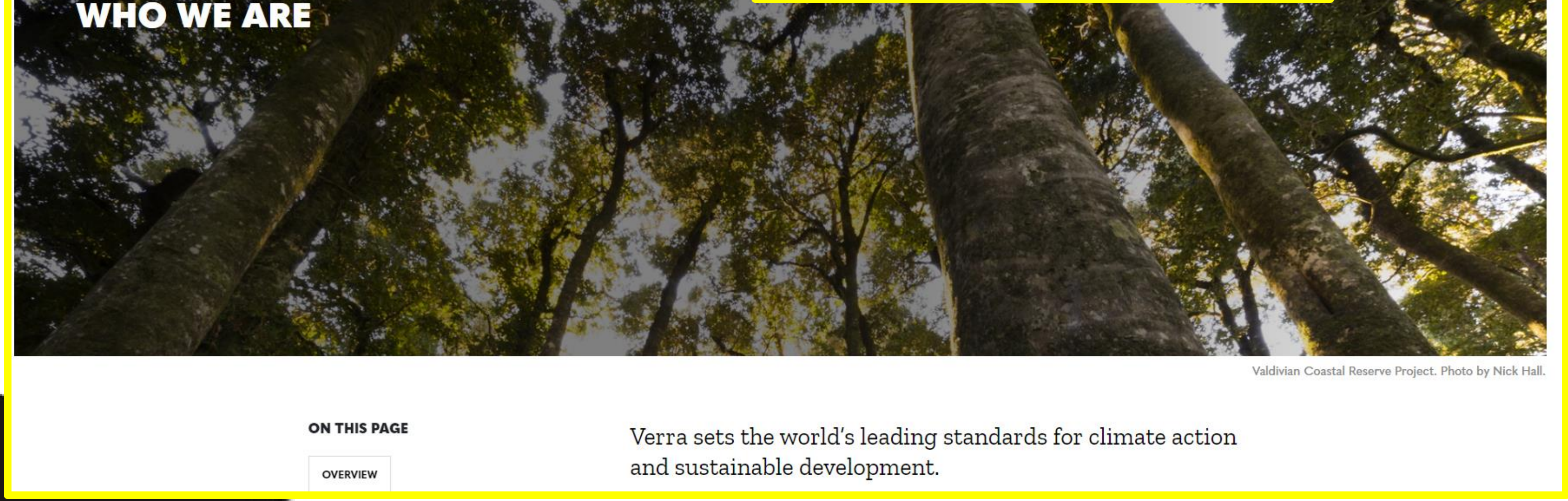

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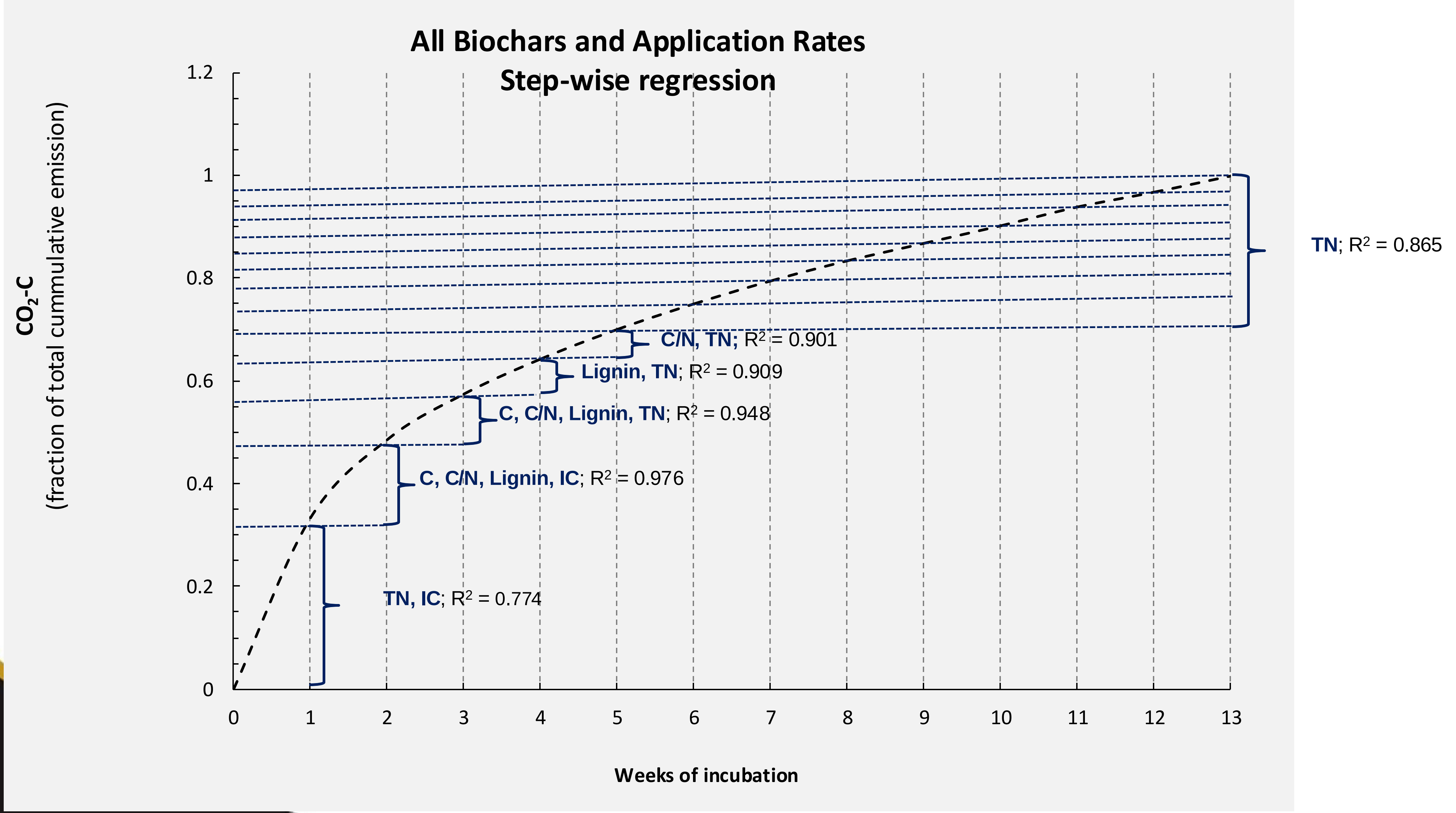
CO_2 Emission from Biochar Amended Soil

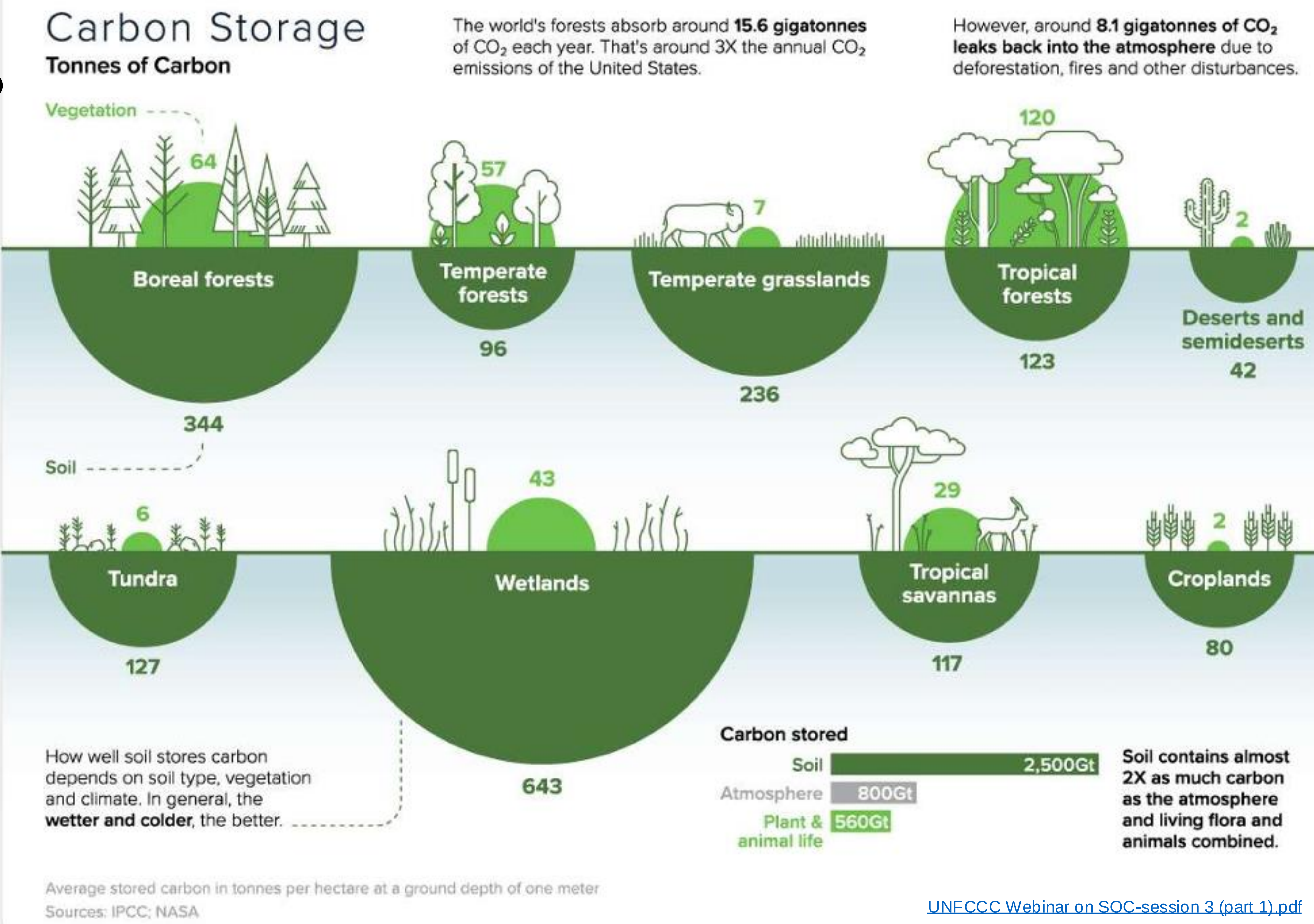


Thermal Decomposition

Thermochemical	Temp. (°C)	Other defining parameters	Gas	Liquid	Solid	Major intended product
Carbonization	300–1200	Air tightness, residence time, materials	60–75	3–5	10–35	Charcoal; solid fuel and industrial input
Pyrolysis (for bio-oil)	400–600	Heating rates, residence time, particle size, gas flow rates	20–40	40–70	10–25	Bio-oil; chemical products and fuels
Pyrolysis (for biochar)	300–700	Residence time, heating rates	40–75	0–15	20–50	Biochar; soil amendment, carbon sequestration and bioremediation
Gasification	500–1500	Oxidizing media, equivalence ratio	85–95	0–5	5–15	Syngas; gaseous fuel for heat and power, and gas to liquid
Hydrothermal processing	200–400	Elevated pressures, solvent type and ratio (e.g. water)	0–90	0–80	0–60	Various chemical products
Combustion	1000–1500	Excess air for complete combustion	95	0	5	Energy converted to heat and power

Biochar for environmental management, Routledge, 2015

Why Soil?



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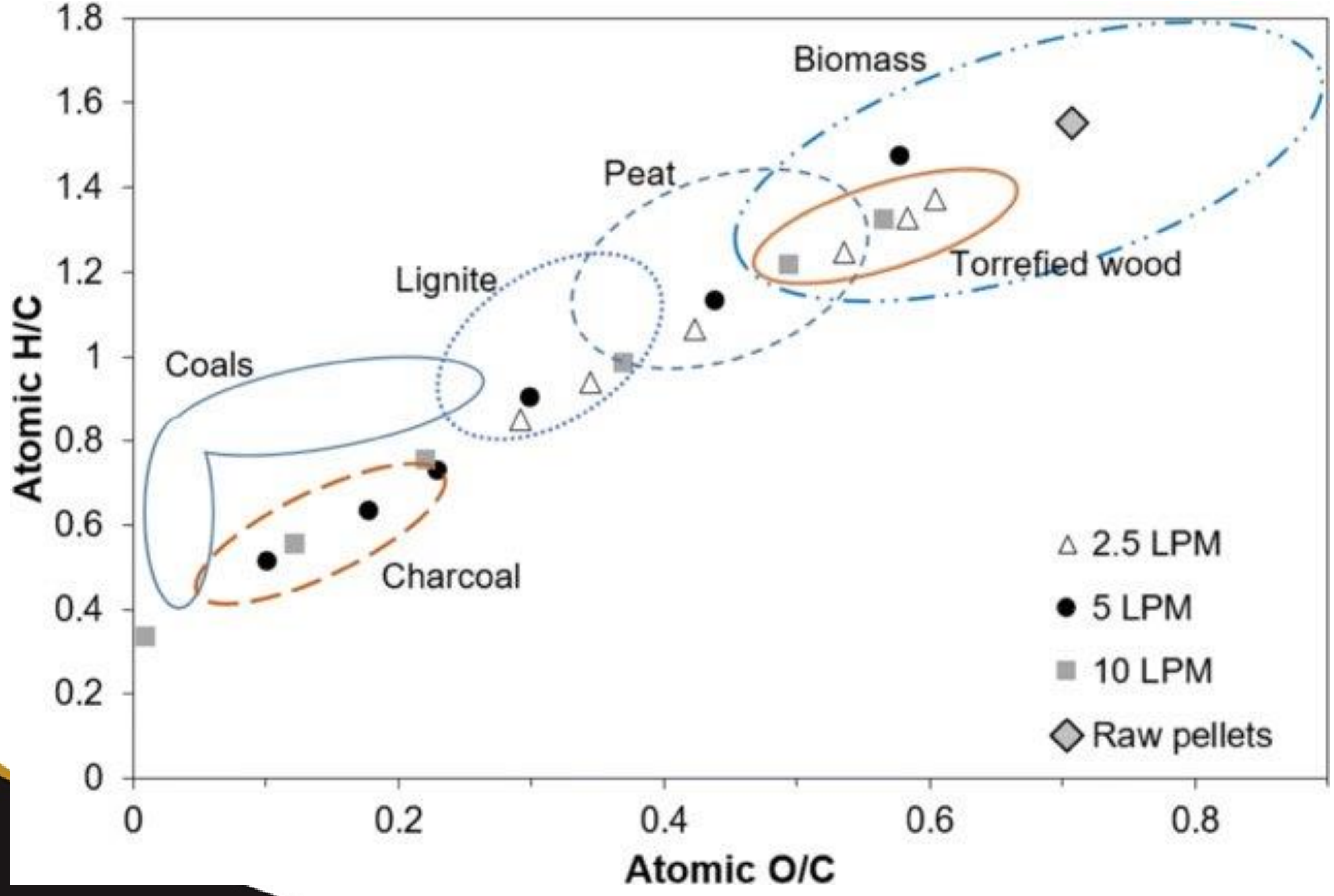
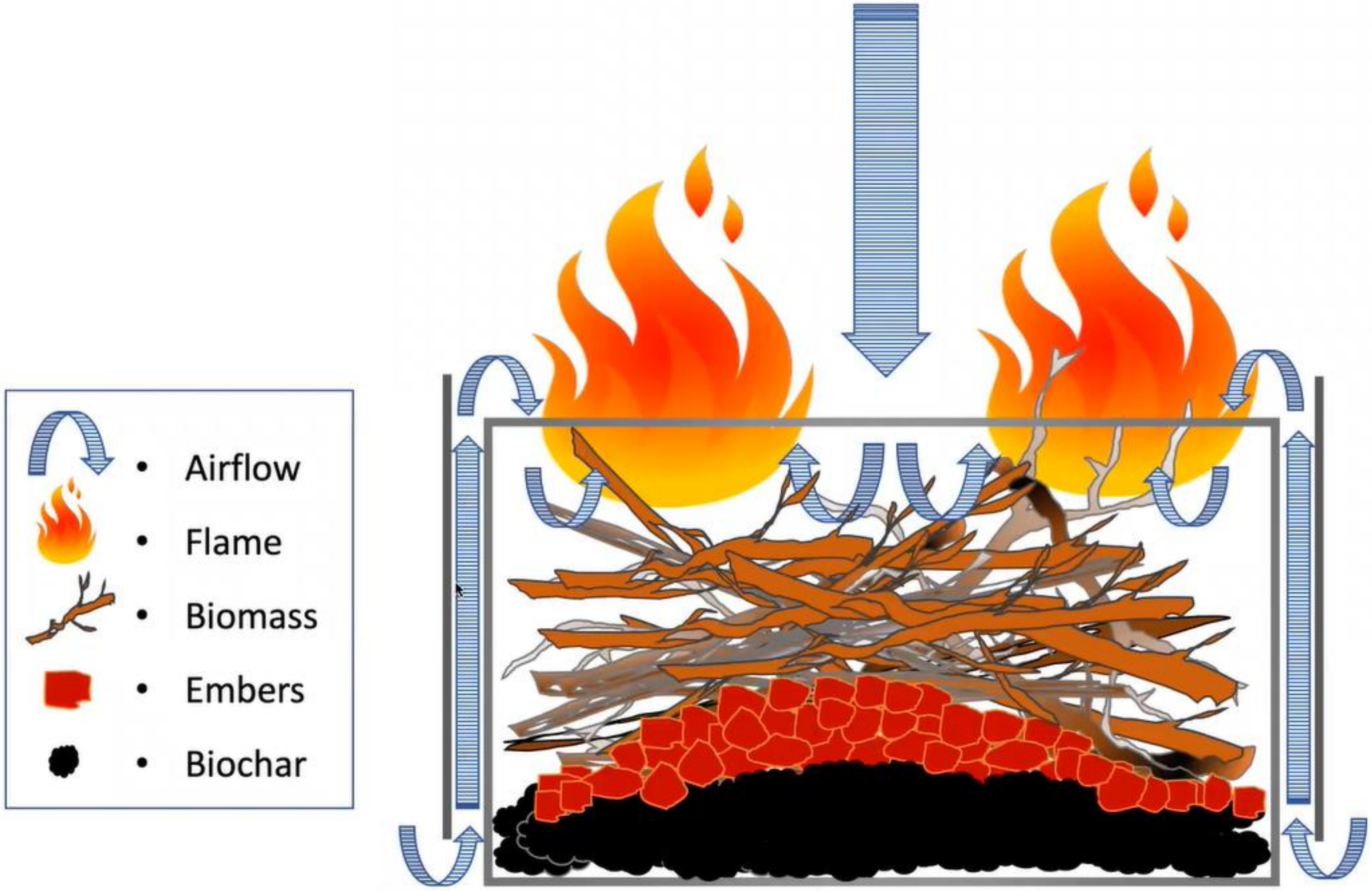
(Condensed) Aromatic Structure
Van Krevelen Diagram



[A Novel Approach to the Production of Biochar with Improved Fuel Characteristics from Biomass Waste]

The Ring-of-Fire



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