Biochar and GHG mitigation

Which are the Trade Offs?

Kor Zwart

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KB-13-005-008
Cliff Workshop Aarhus University, December 2013

Alterra Introduction

- Wageningen UR
  - University
  - 6 Research Institutes
  - Alterra:
    - Soil, Water & Climate, Ecology, Landscape
    - Ca. 600 staff
    - Project Organisation
    - 50-60 Million €/year
- Team: Sustainable Soil Management

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Who is Kor Zwart ?

- Microbiologist,
  - Yeast Physiology, Biogas production
- Soil Scientist,
  - Microbiology, Soil organic matter dynamics, Nutrient dynamics
  - Agronomy, mostly arable production

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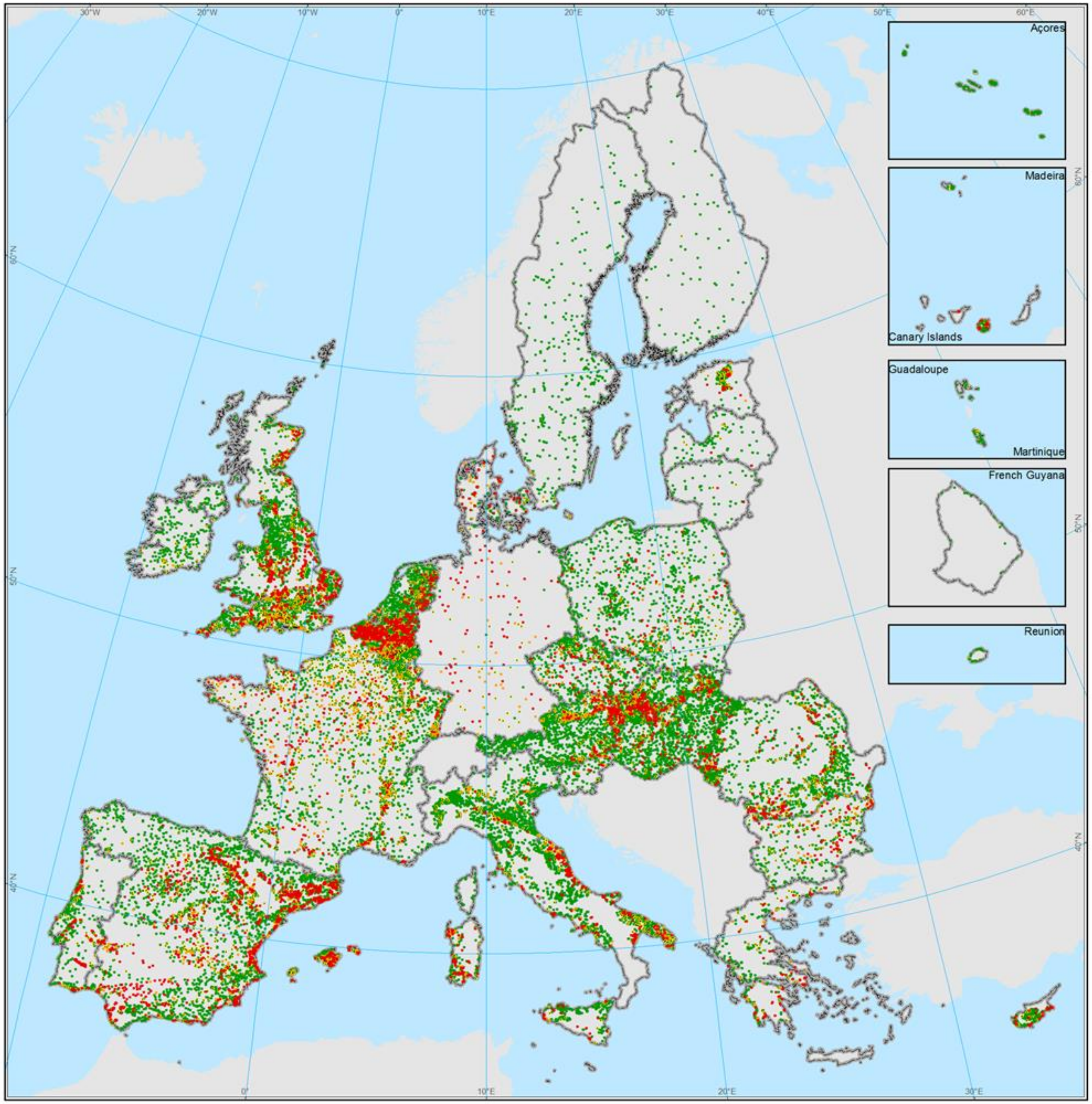
Kor Zwart Introduction

- Biobased Economy
  - Bioenergy, sustainability,
  - Biochar application
  - Biorefinery
  - 'New' Organic Fertilizers from waste
- Nitrates Directive evaluation in EU-27



NITRATES DIRECTIVE EU-27

REPORTING PERIOD 5 (2008-2011)

GROUND WATER

ANNUAL AVERAGE NITRATE CONCENTRATION

Avg NO3 mg/l

- < 25
- 25 - 40
- 40 - 50
- >= 50

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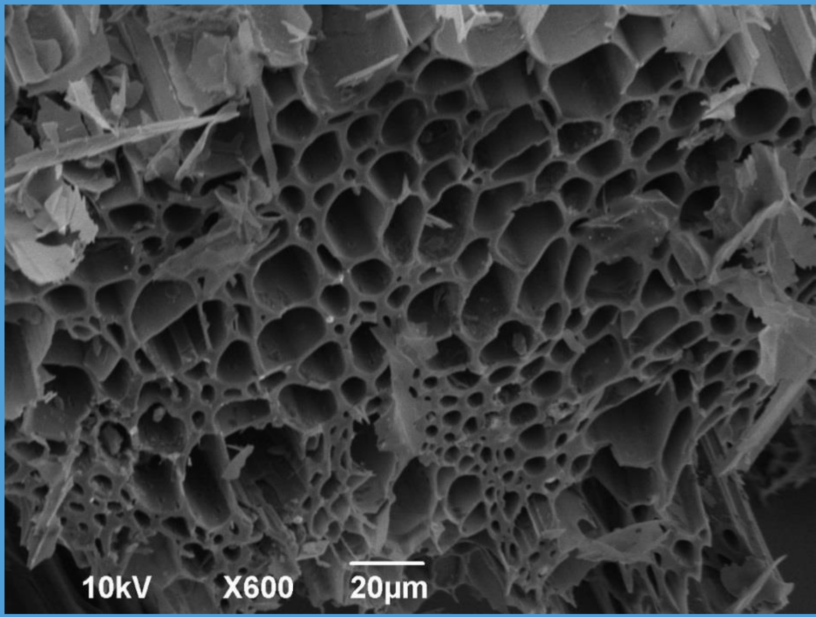
0 100 200 400 Kilometers

Sources : DG ENV, Member States reports on Nitrates Directive Implementation
Coordinate Reference System : ETRS89 Lambert Azimutal Equal Area
Cartography : JRC,05/2013
Data source: GISCO - Eurostat (European Commission)
Administrative boundaries: © EuroGeographics

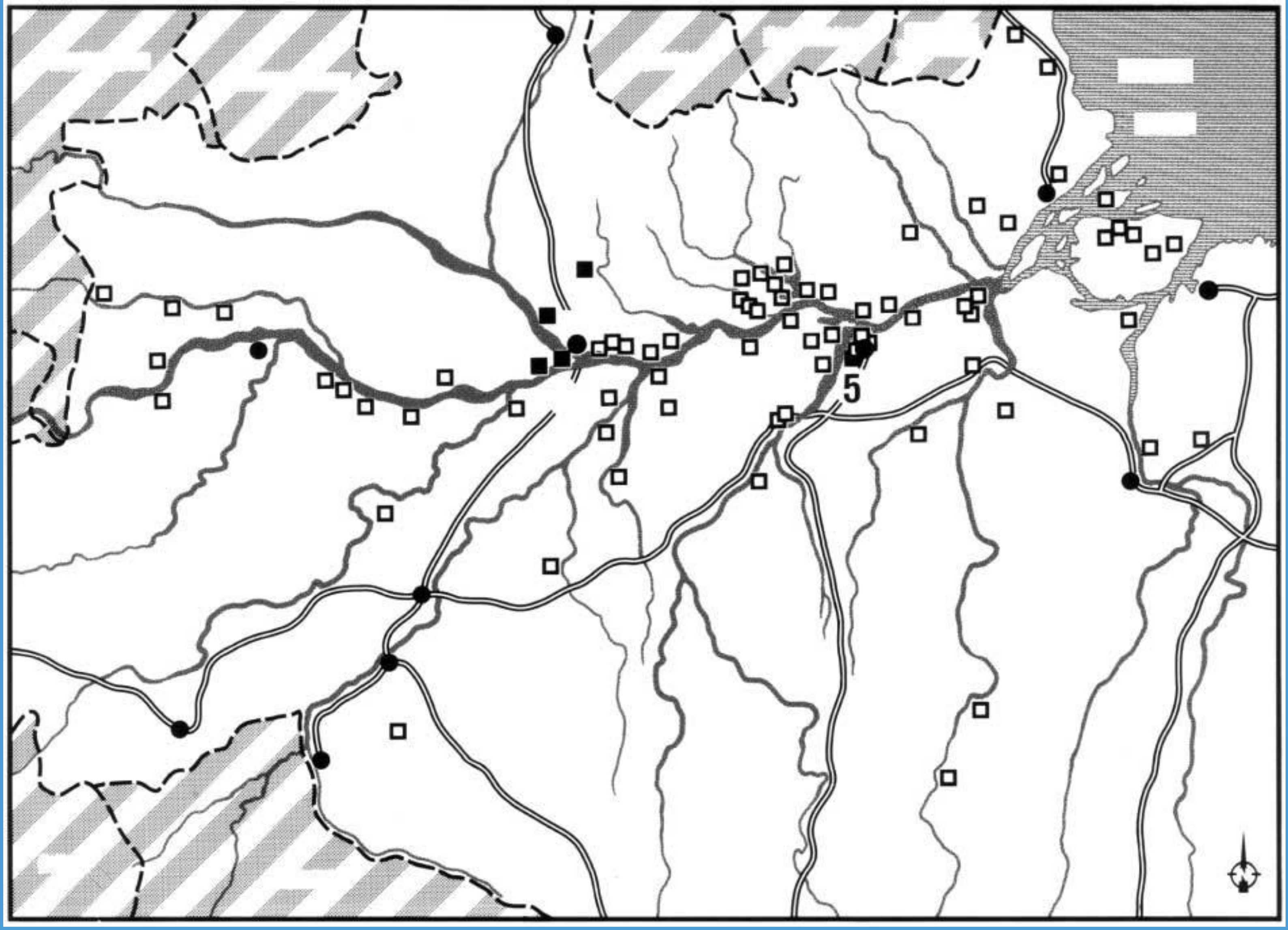
Biochar Introduction

- Char(coal),
    - Biomass based,
    - specifically produced to be applied into the soil

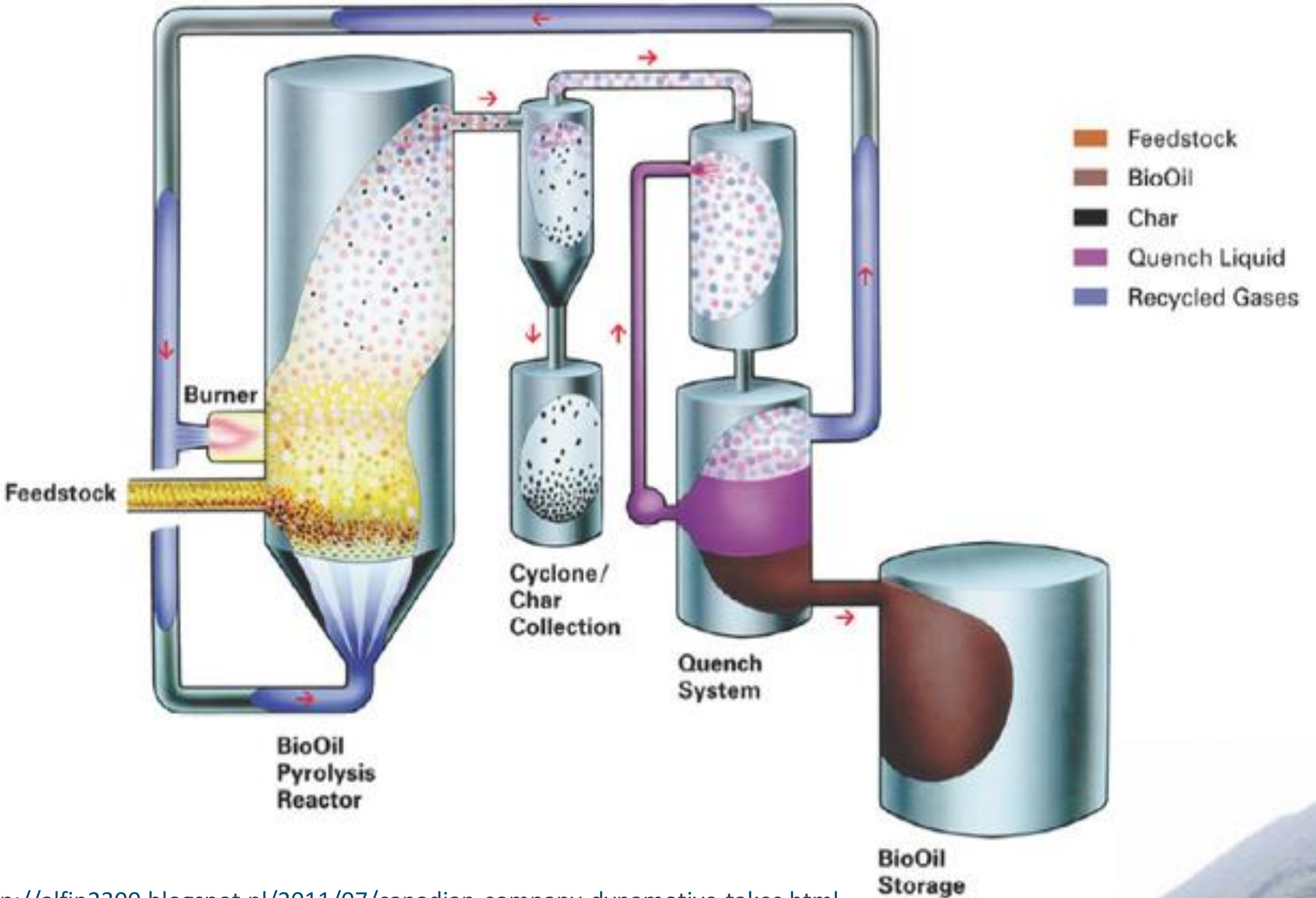


Terra preta (Black soils) Amazon Basin

Terra preta (Black soils) Amazon Basin



Pyrolysis Proces -> Biochar



http://alfin2300.blogspot.nl/2011/07/canadian-company-dynamotive-takes.html

http://www.adpholdings.com/images/tire-2.jpg

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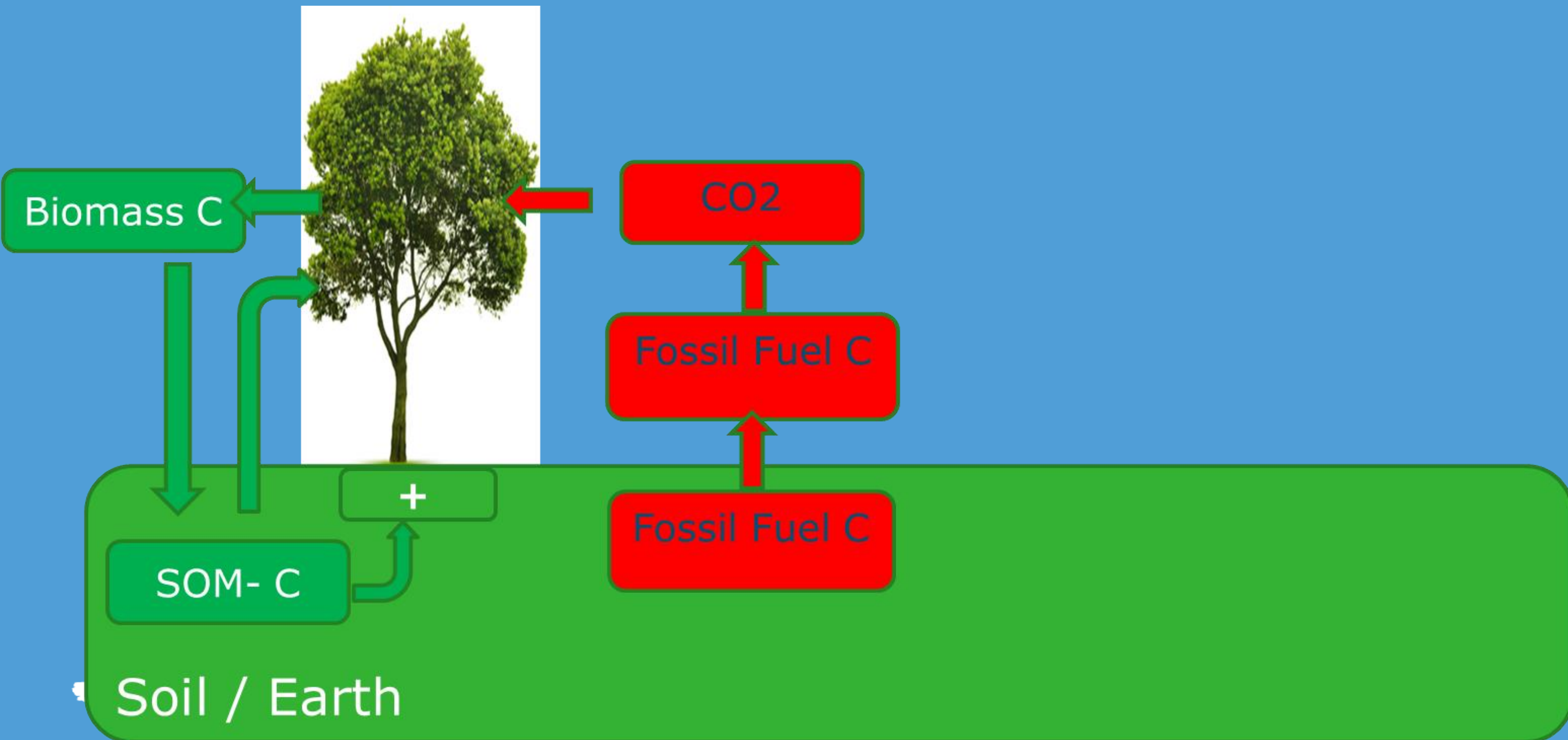
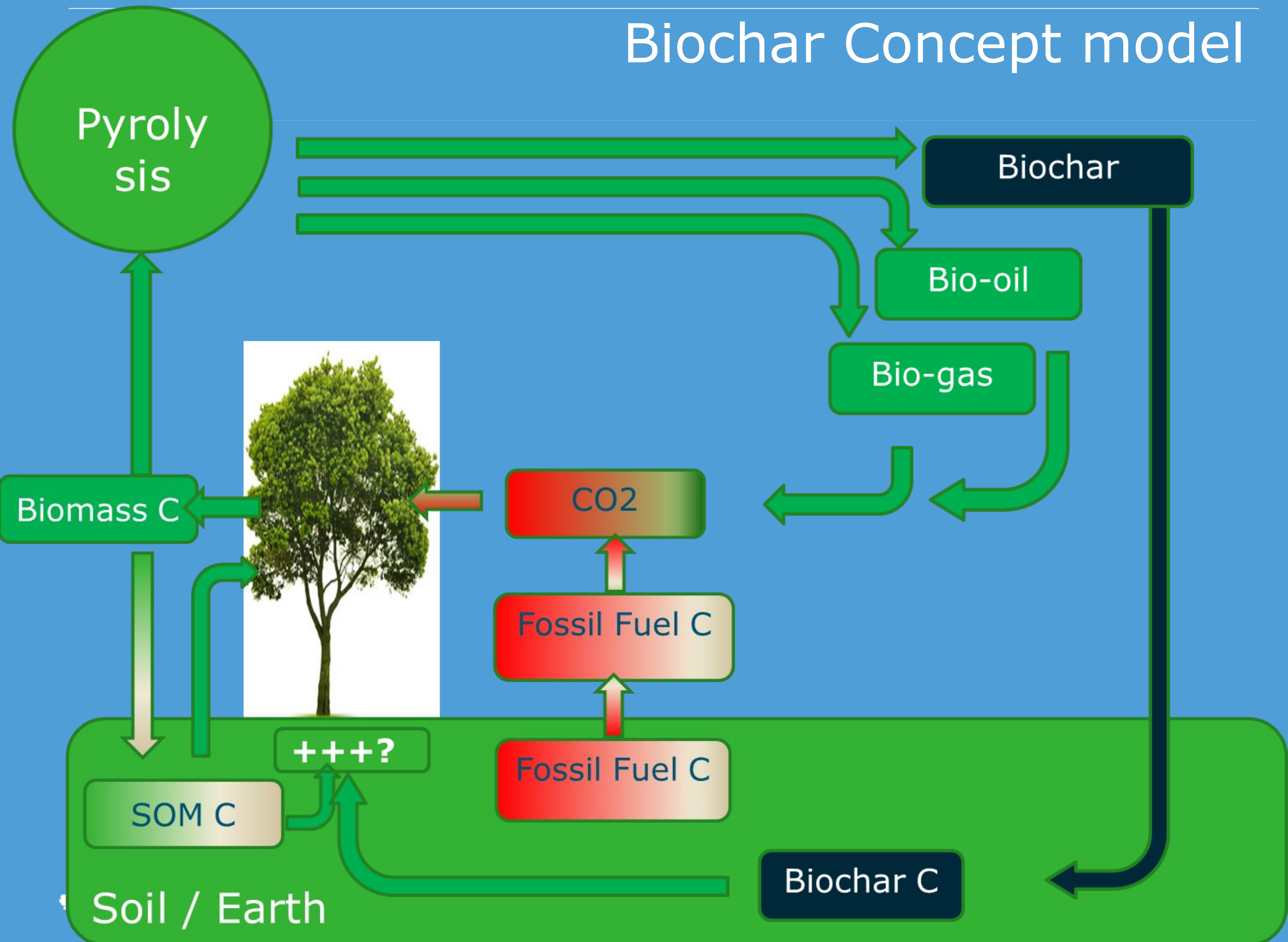
GHG mitigation concept of biochar ?

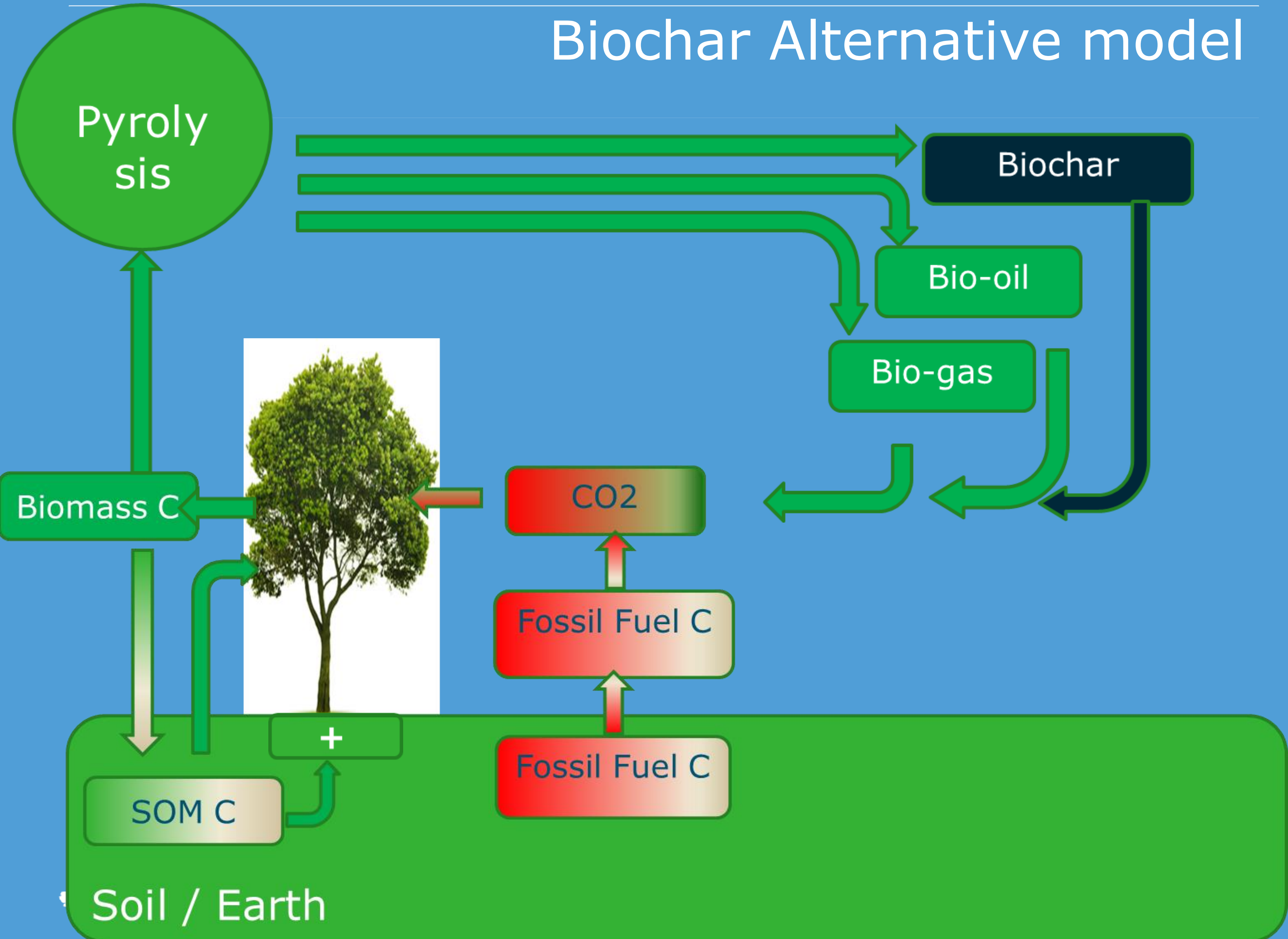
Current situation



Biochar Concept model



Biochar Alternative model



Trade offs / Considerations

Biochar for climate mitigation?

- Which are the important questions to be addressed?

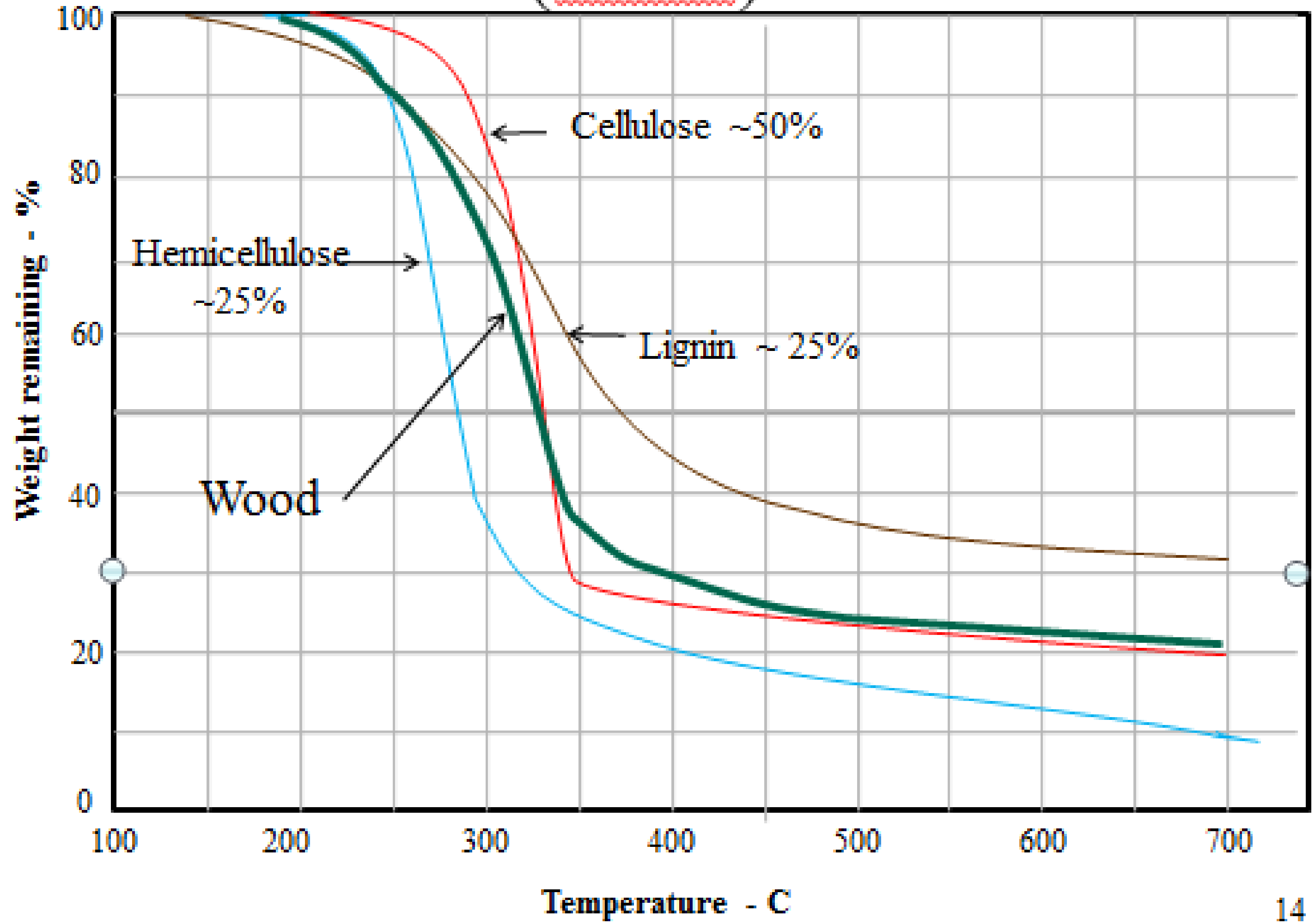
Trade offs / Considerations

- C-sequestration
  - Biochar stability > 100 years?
- Soil fertility/ Soil quality, biochar effect?
  - Claims productivity, etc.
  - Effect soil organisms
- GHG emissions: Biomass C for energy or for C-sequestration?
  - Energy / GHG balance of the system?

Stability of biochar

- Biochar properties

Pyrolysis of Biomass Components (TGA)



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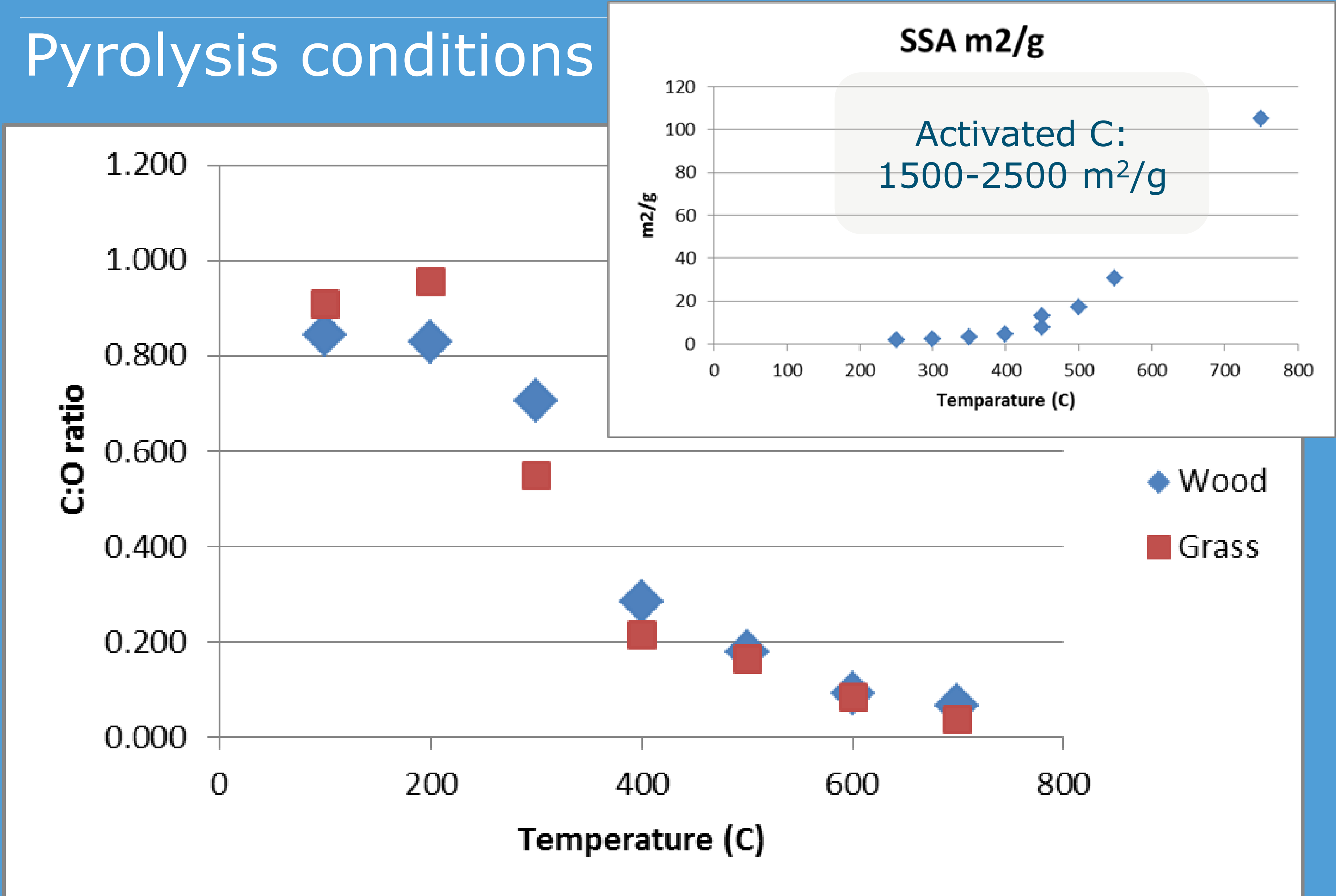
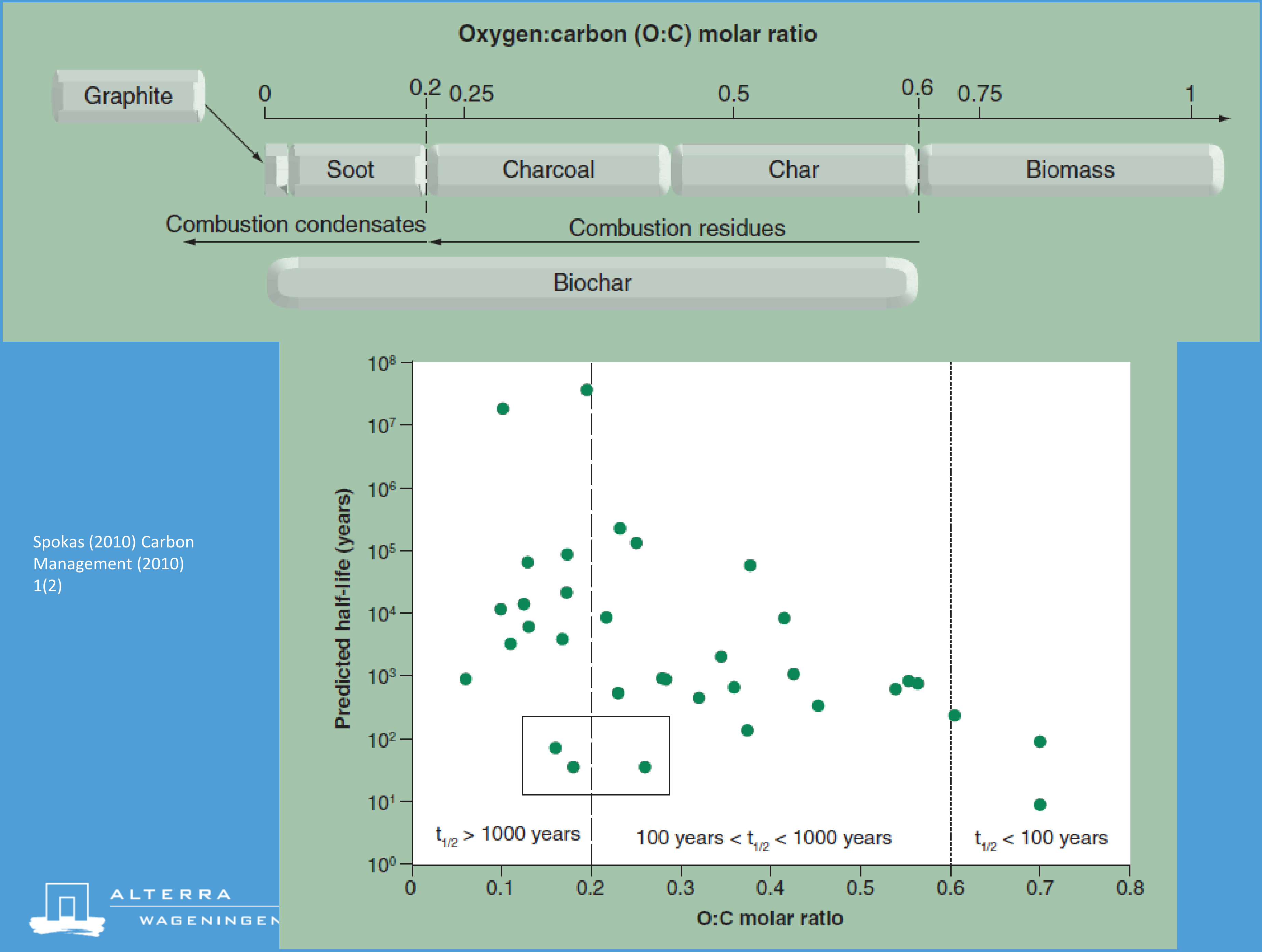
Reed and McLaughlin North American Biochar 2009

Pyrolysis conditions



Keiluweit et al, (2010) Environ. Sci. Technol.



Spokas (2010) Carbon Management (2010) 1(2)

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Conclusions stability

- Stable biochar can be produced

- Stability depends on pyrolysis conditions and
  Biochar composition

- Composition also determines other biochar properties

Role of biochar in soil properties and functions

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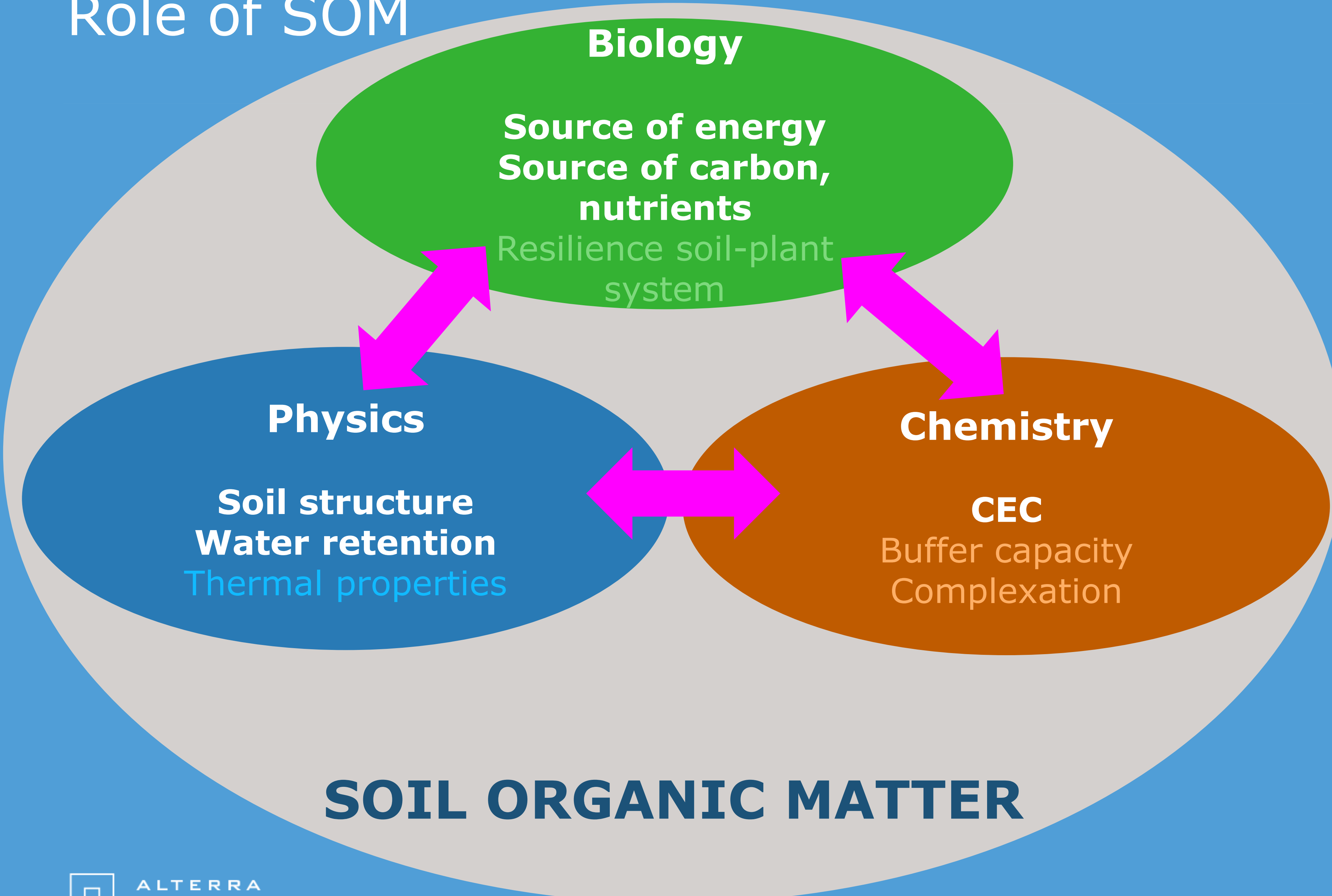
Biochar as soil improver?

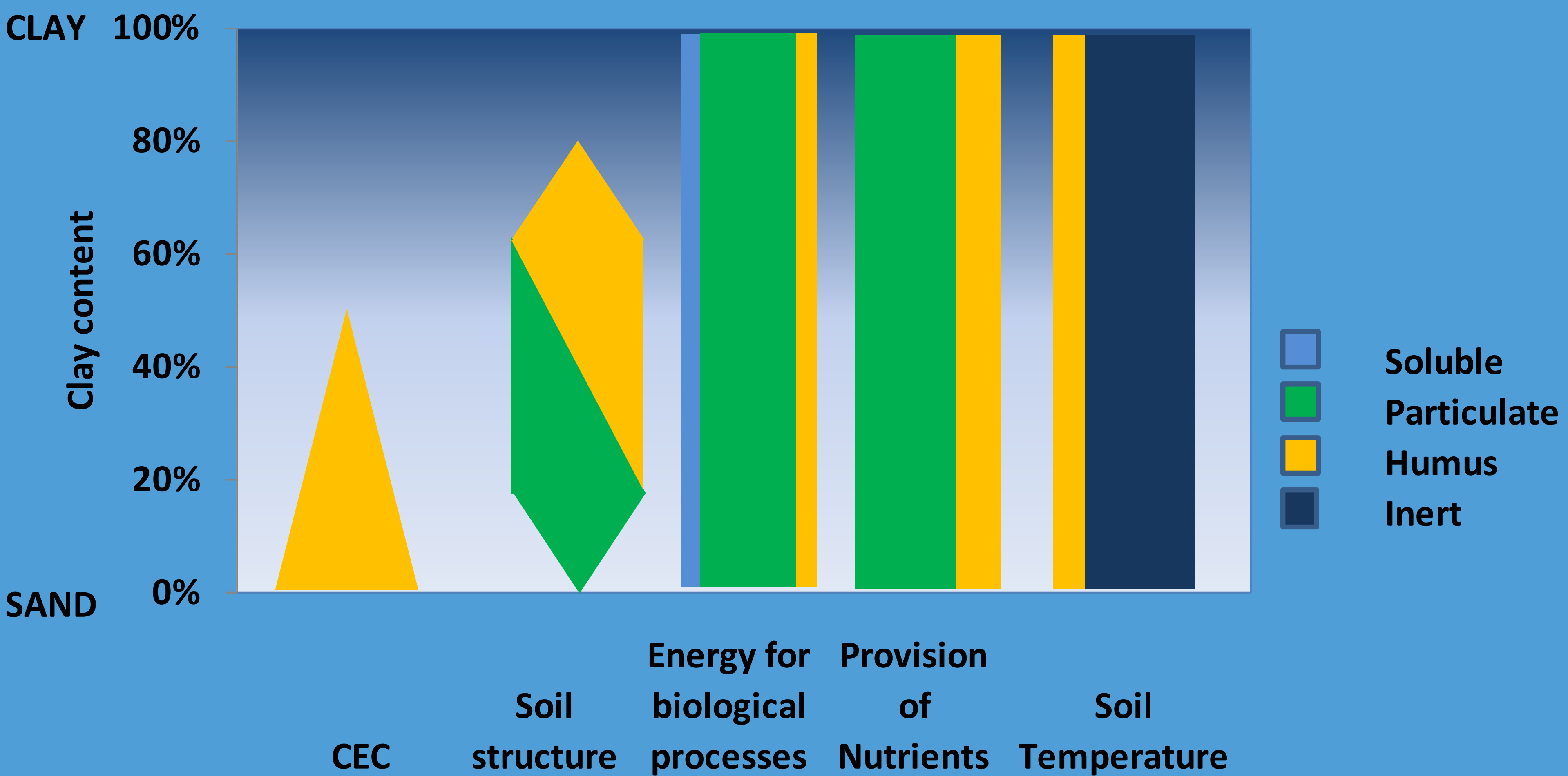
- Biochar = organic carbon
- Soil organic matter (SOM) = organic carbon
- → Biochar = SOM??

Role of SOM



After Baldock and Skjemstad, 1999

Role of SOM in SOIL types



After: http://grdc.com.au/uploads/documents/cso000291.pdf

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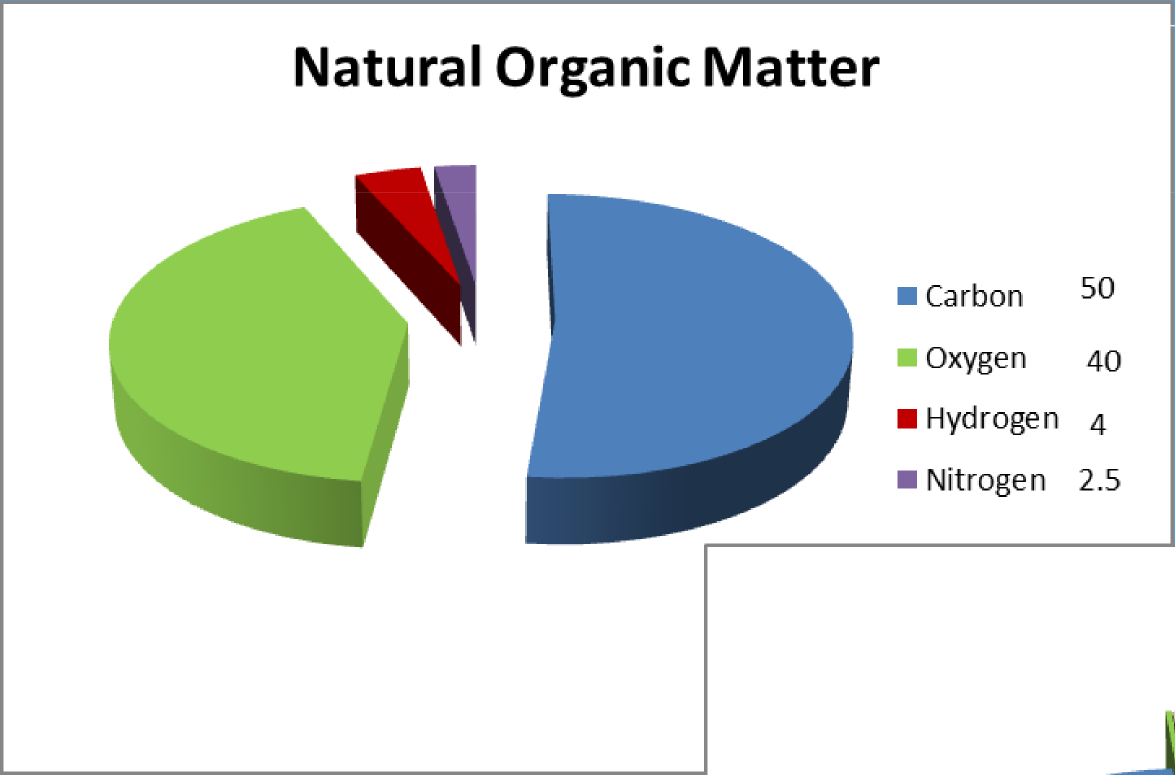

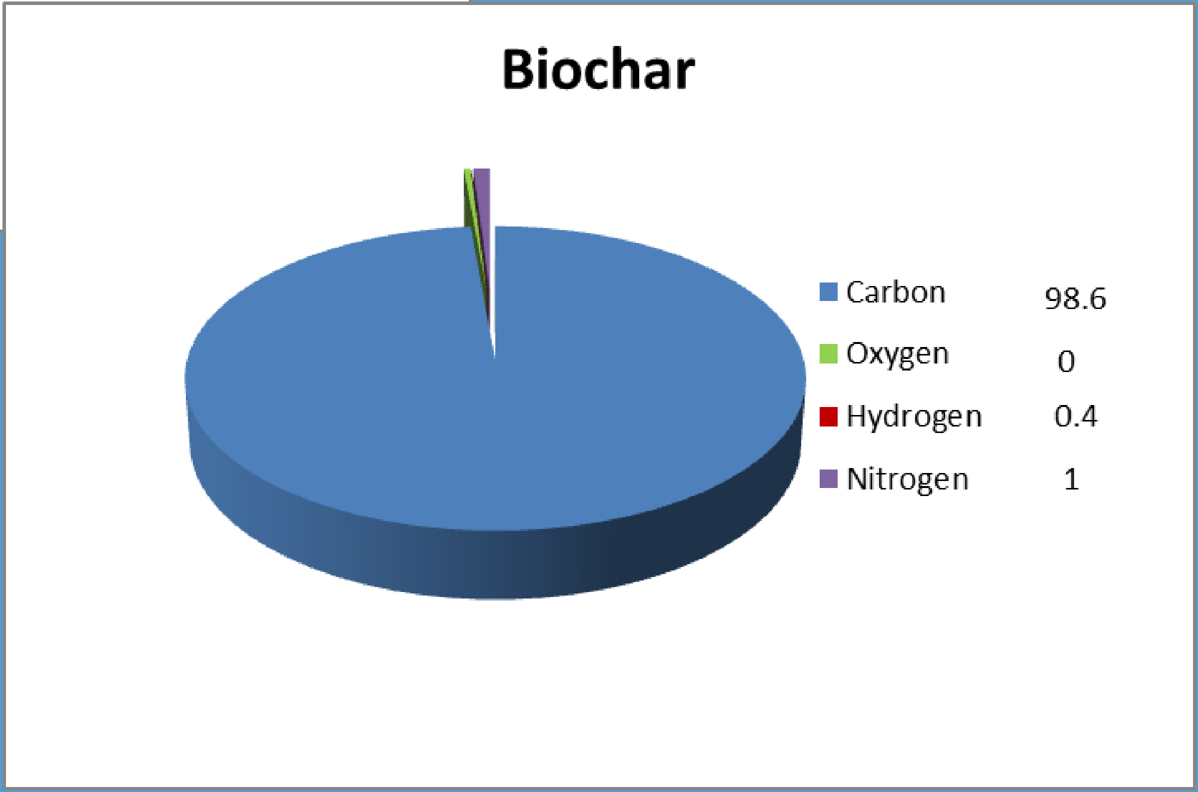

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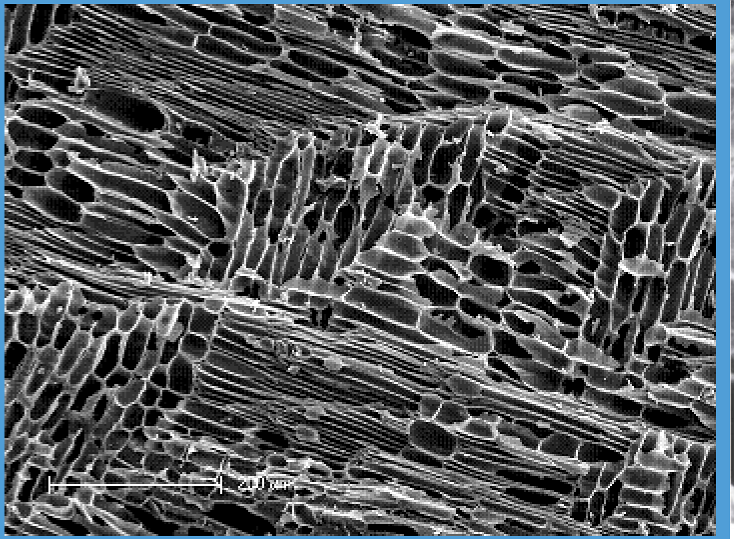
http://www.treepower.org/biochar/main.html

Biochar Carbon = Energy for micro-organisms?

- Thermodynamically: No problem, 30 GJ/kg
- Enzymatically: ??, especially at low O:C ratio’s
- CO_2 evolution: Low in soil incubations

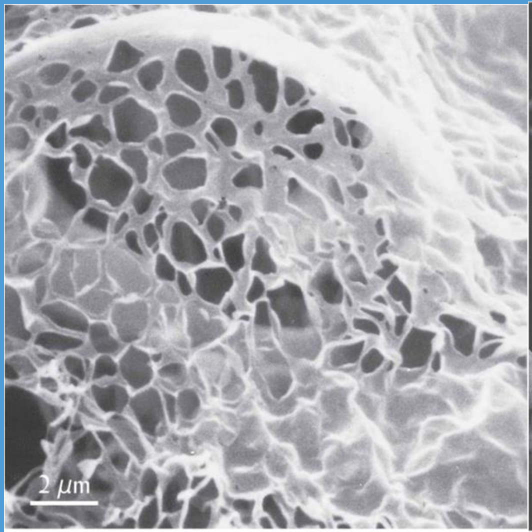
Biochar Refuge for micro-organisms ?

Biochar



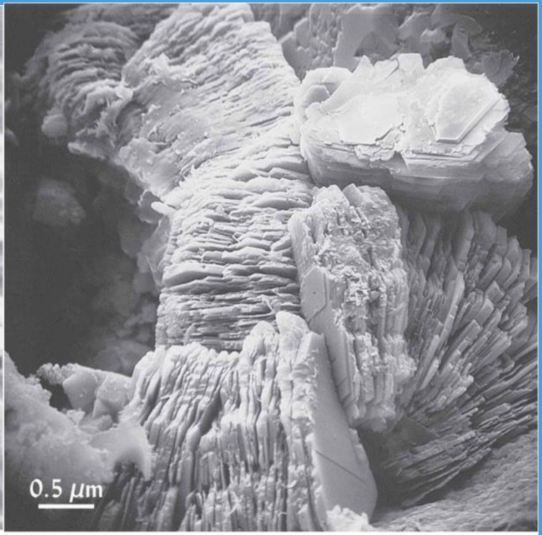
Sohi et al (2009)

Humic acid



(d)

Clay



(a)

faculty.yc.edu/ycfaculty/ags105/week08/soil_colloids/soil_colloids_print.html

Hydrophobic interaction
Fluidized bed reactor

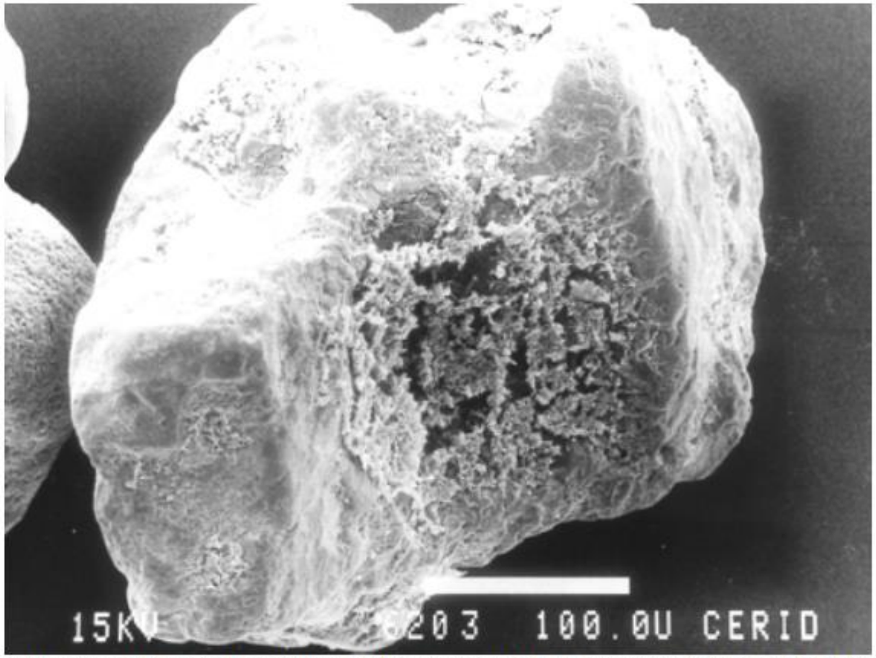


Figure 4. Representative sand particle partially covered with an anaerobic biofilm of thin thickness.

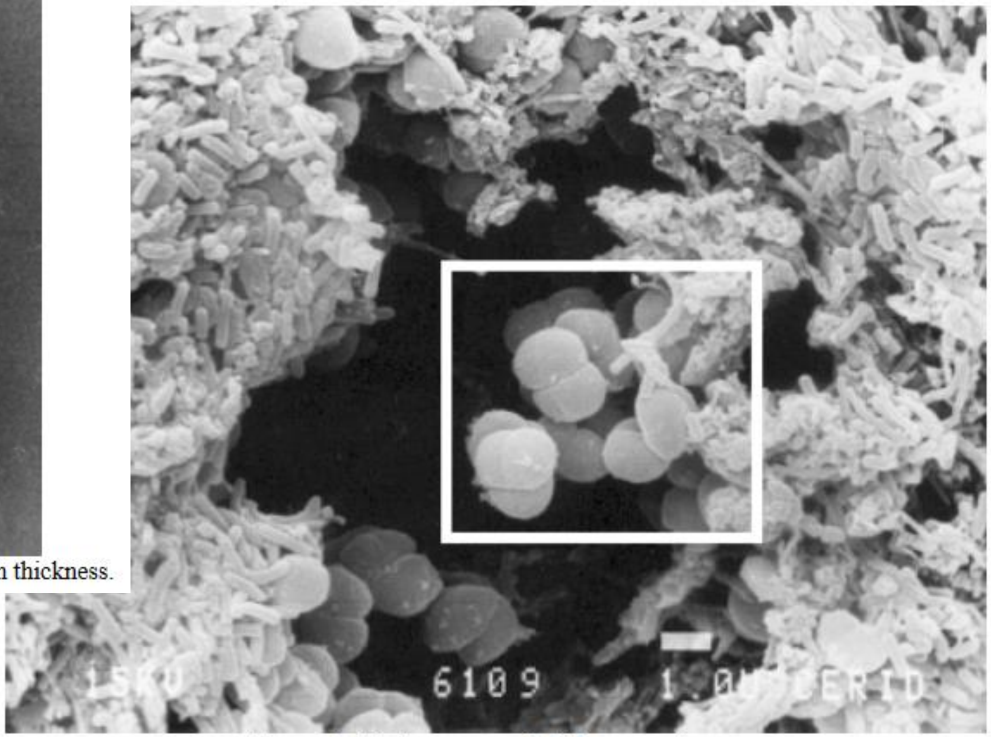


Figure 3. Methanogens: *Methanosarcina sp*

Mussati et al, 2005

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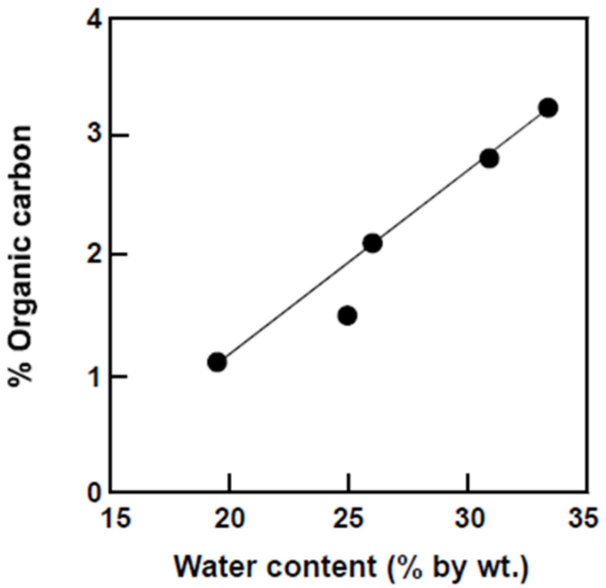
Relation SOM-plant available water (pF 2-4.2)



SOM %	Plant available water mm
2	50
4	66
5	70
6	75
8	81
10	86

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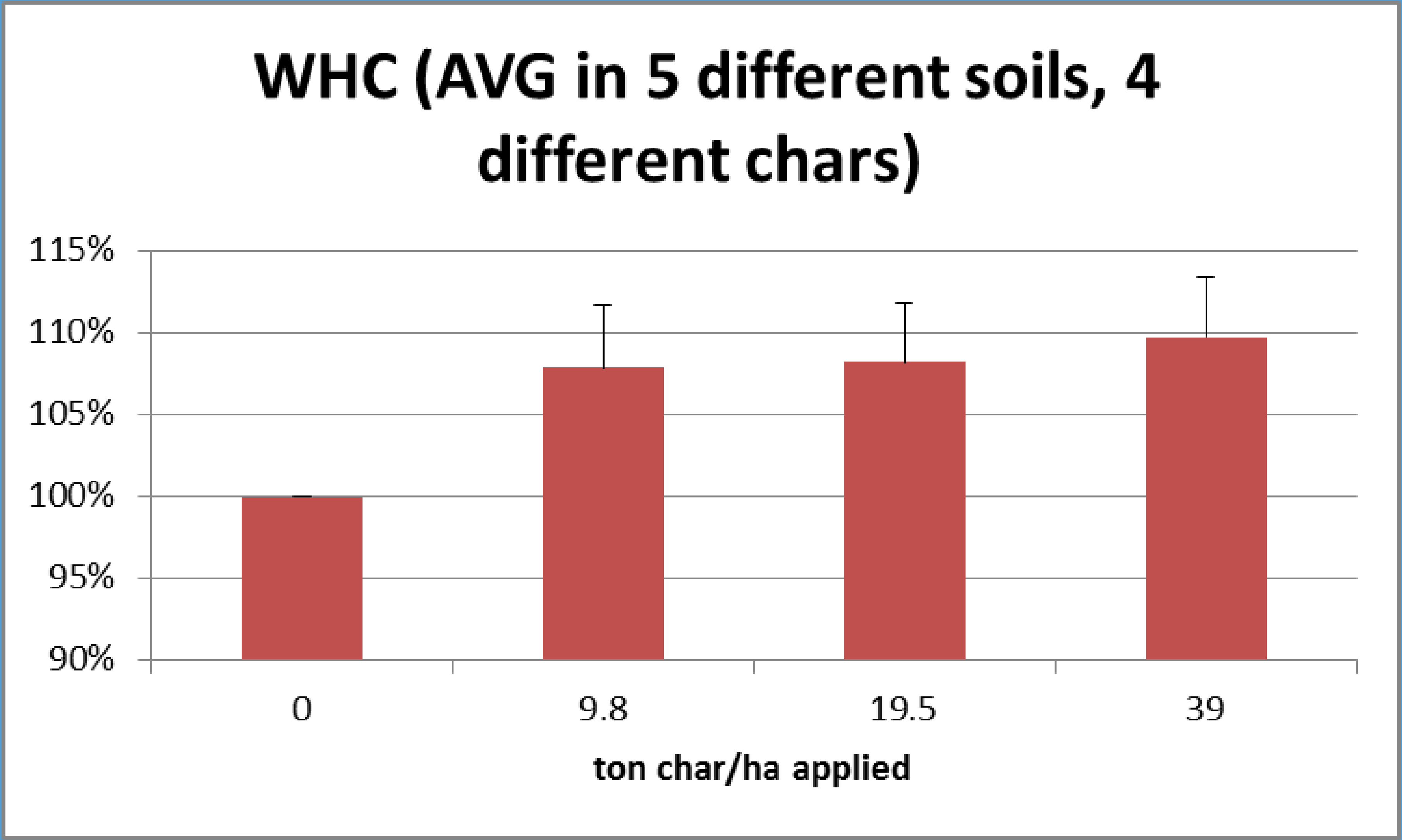
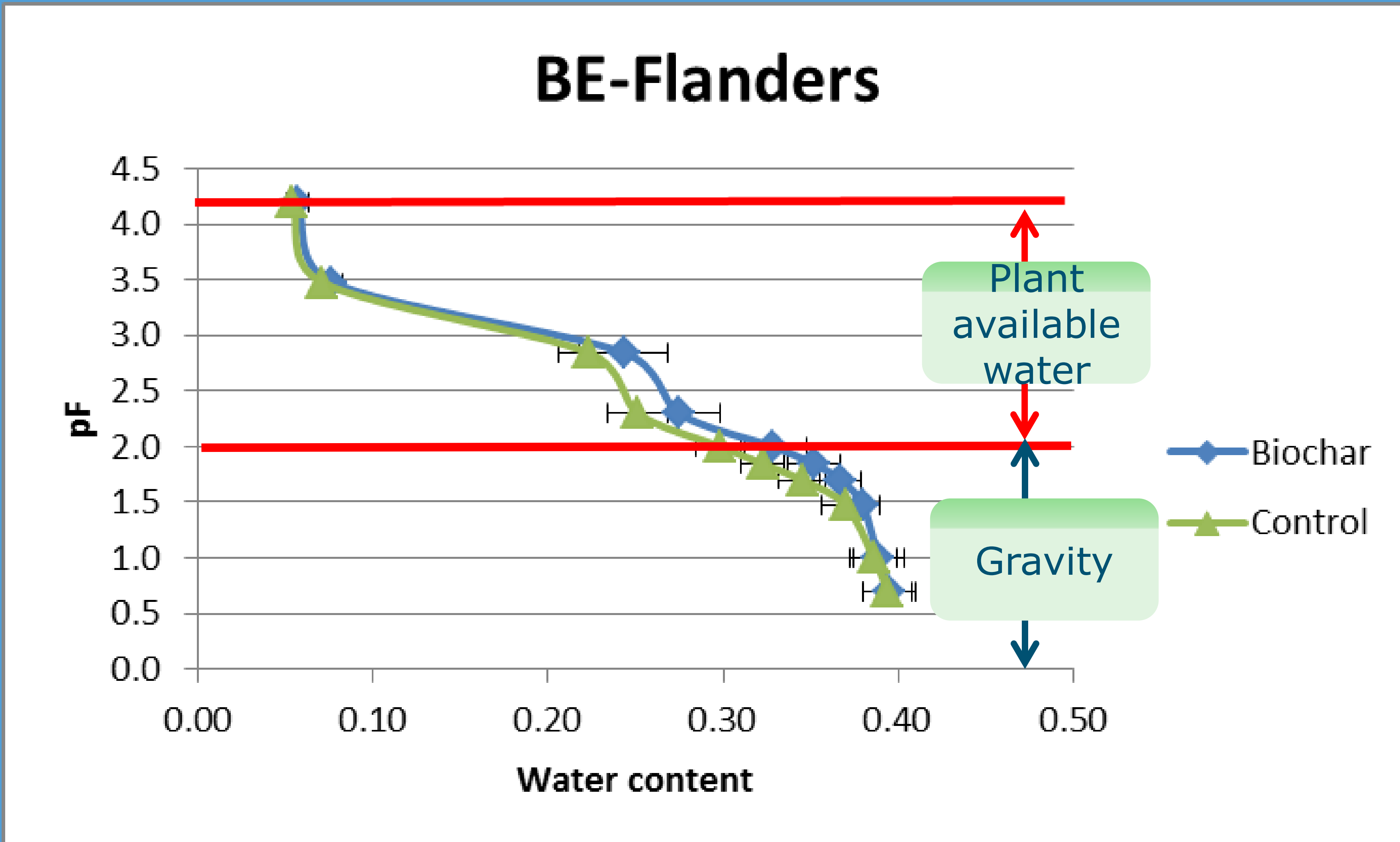
WHC effect biochar



Streubel et al, 2011, JSSSA, 75:1402-1413

Water retention



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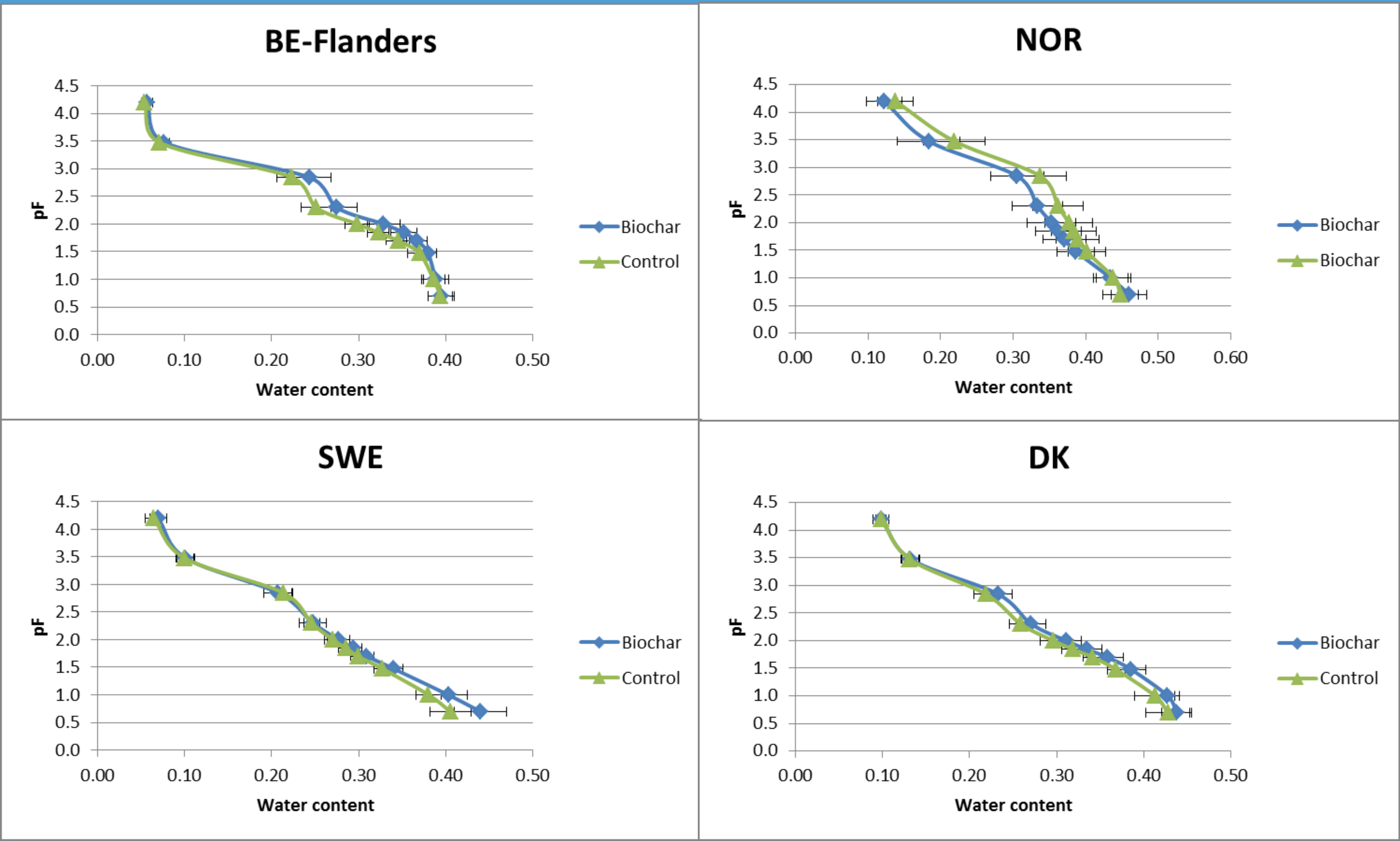
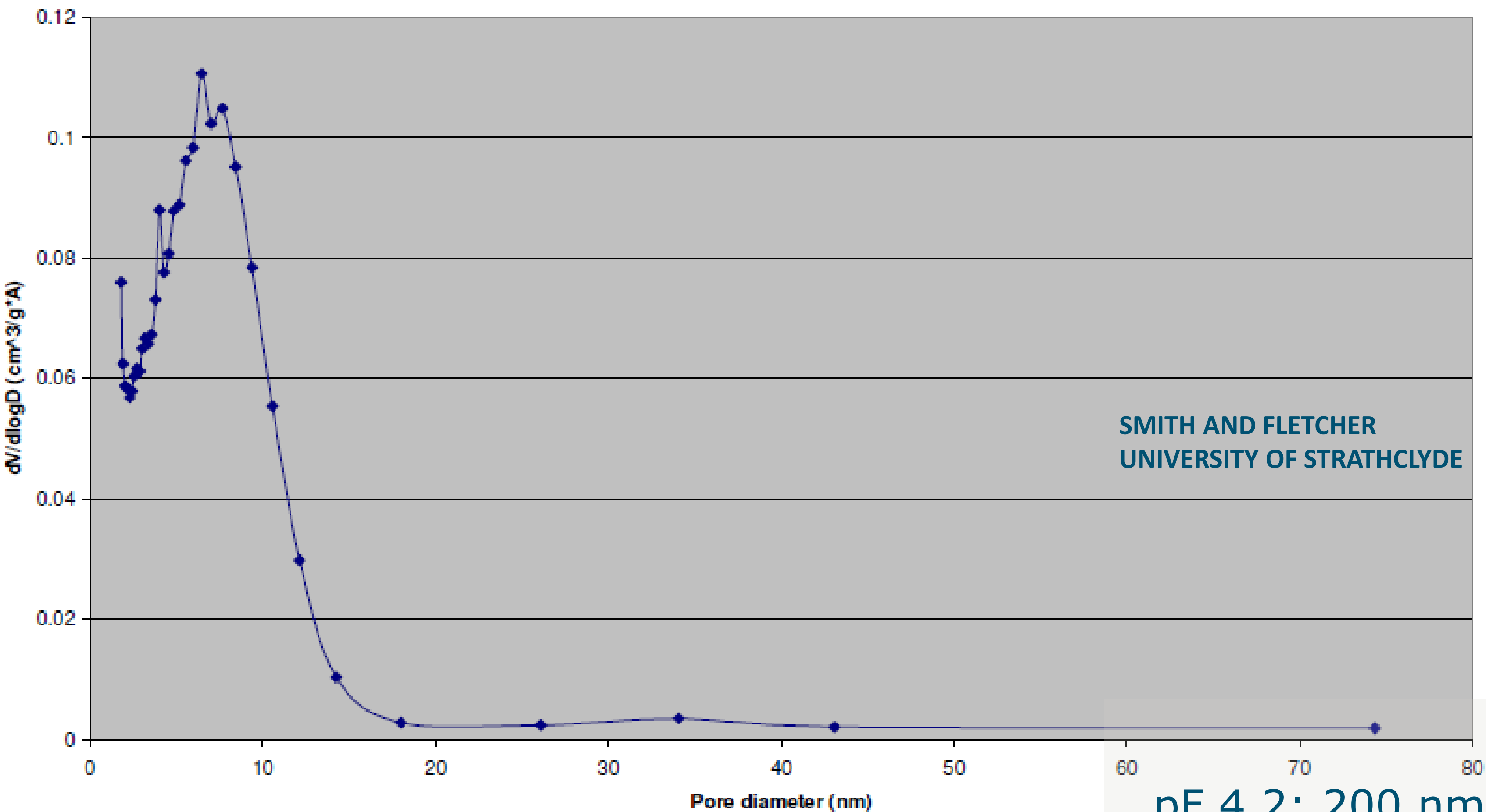
Water retention Interreg Biochar Project



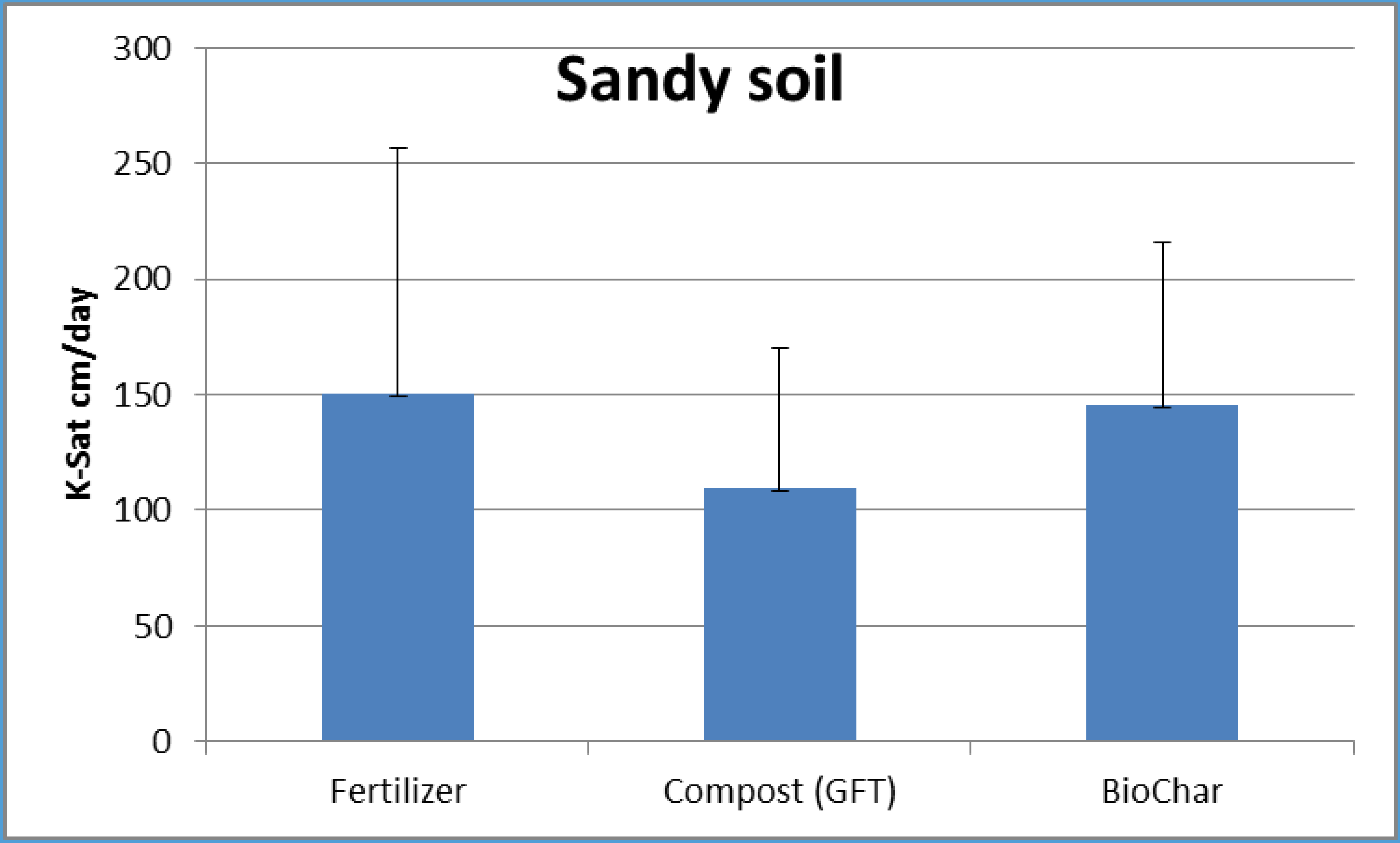
Pore size distribution



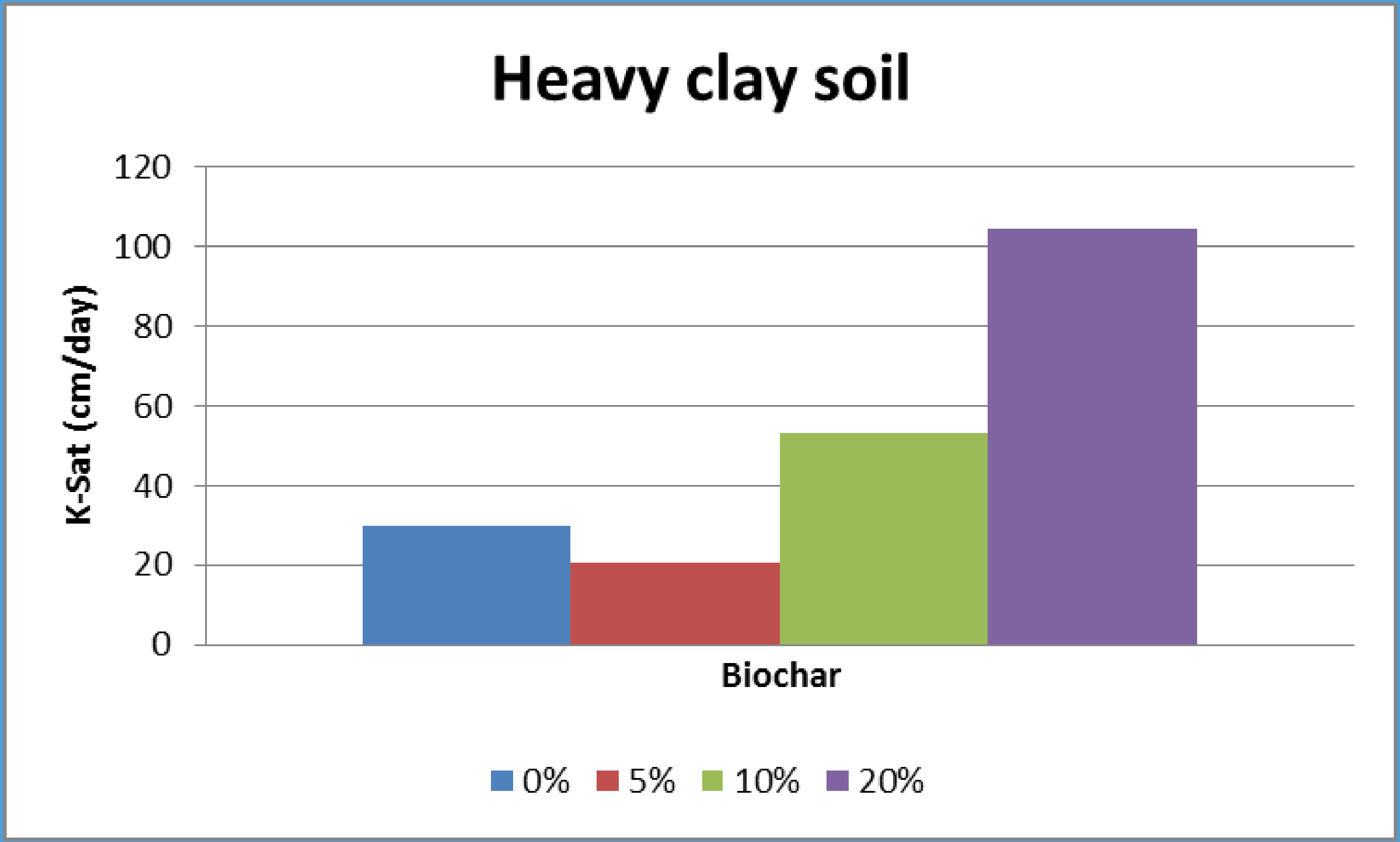
pF 4.2: 200 nm

FIGURE 2.4: PORE SIZE DISTRIBUTION FOR COARSE CHAR

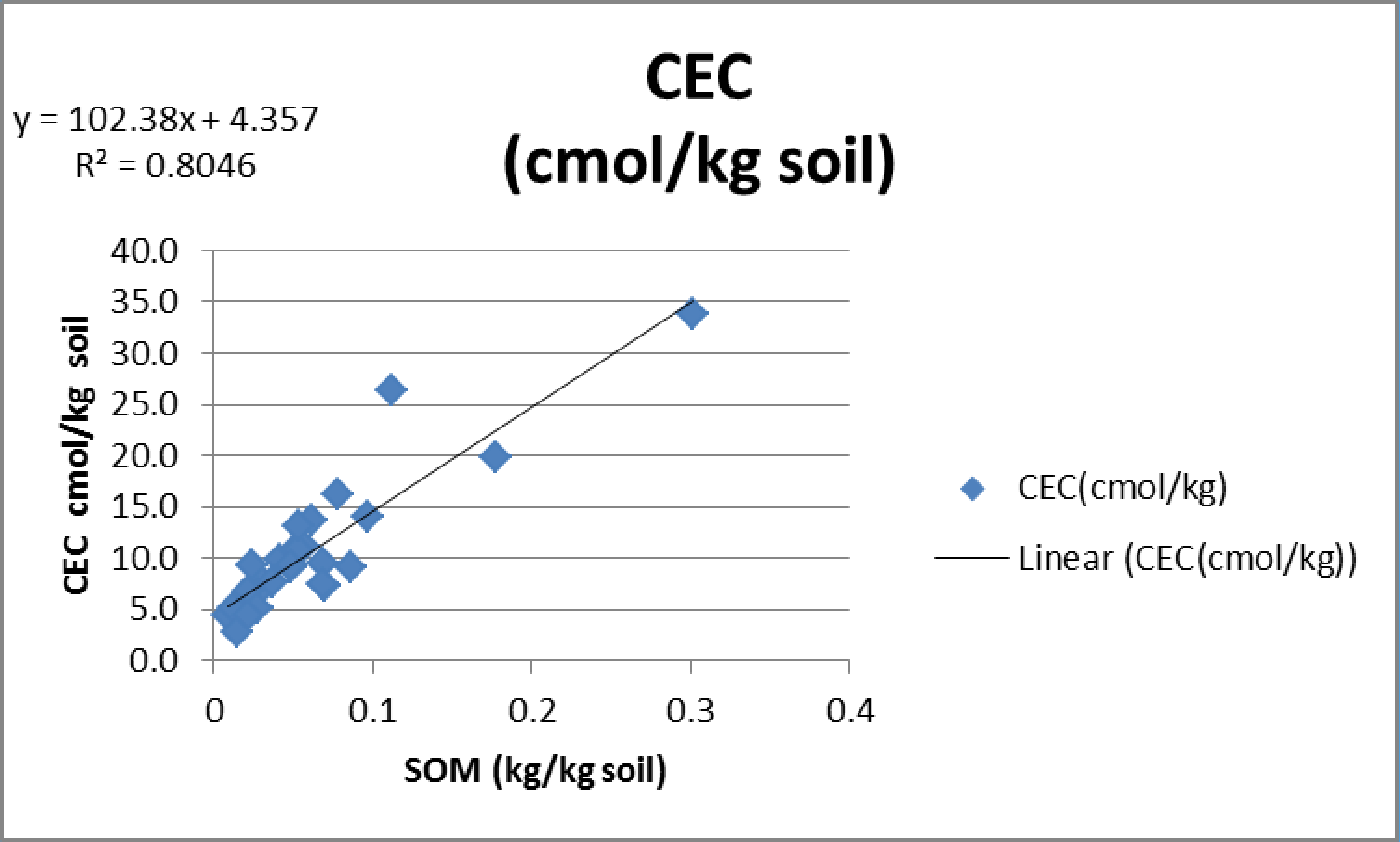
Water infiltration Interreg Biochar Project



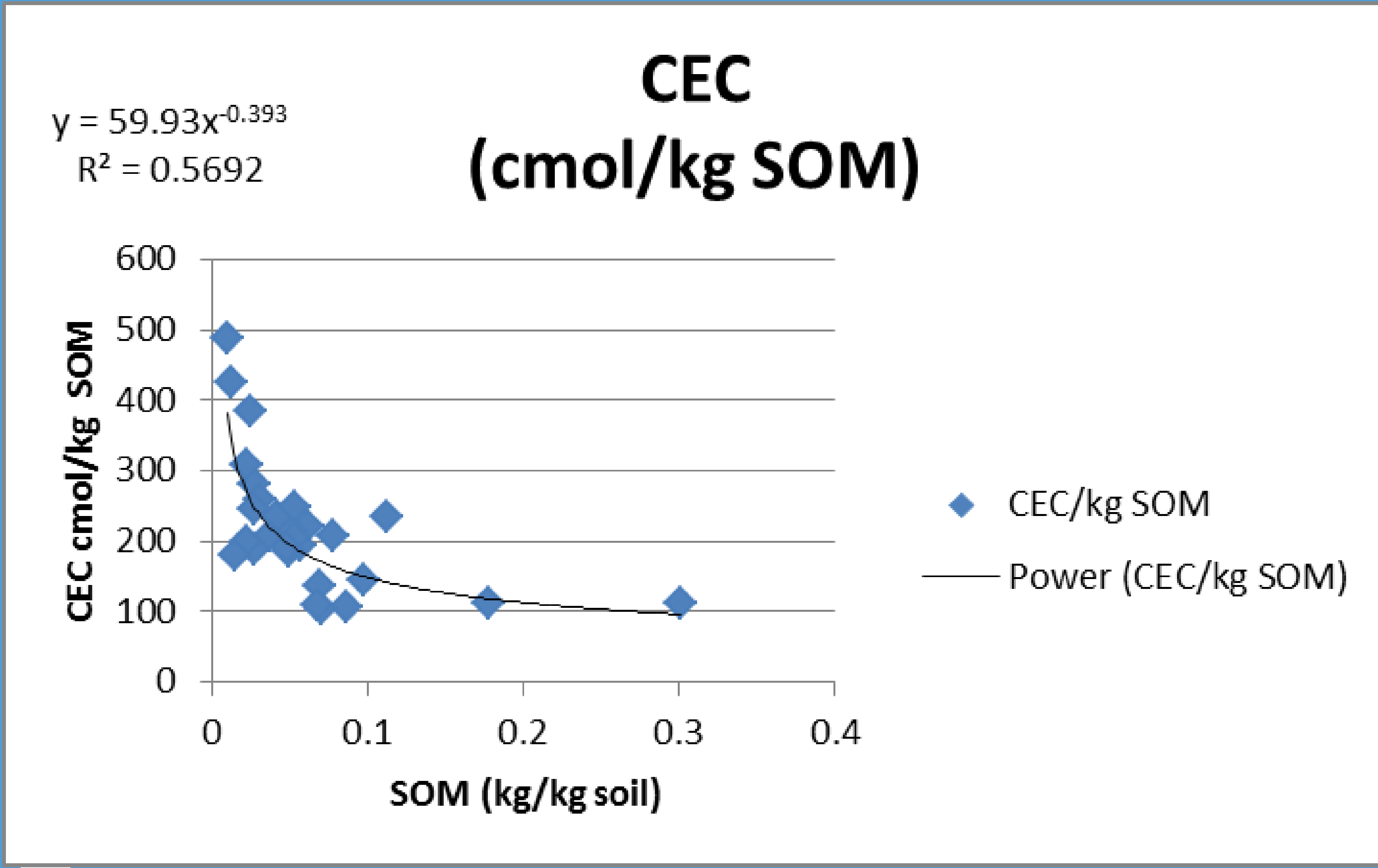
Water infiltration Interreg Biochar Project

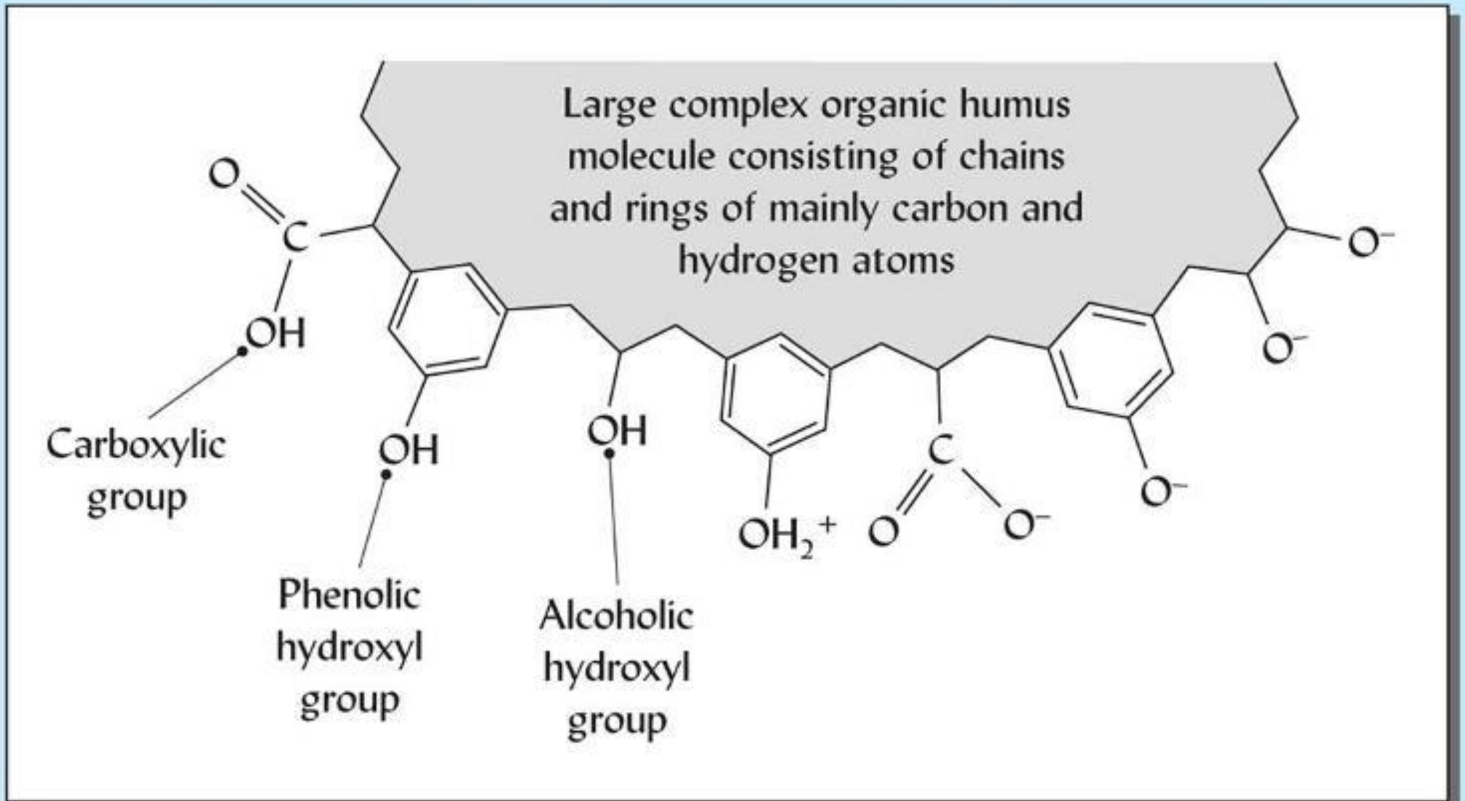


CEC reclaimed peat soils

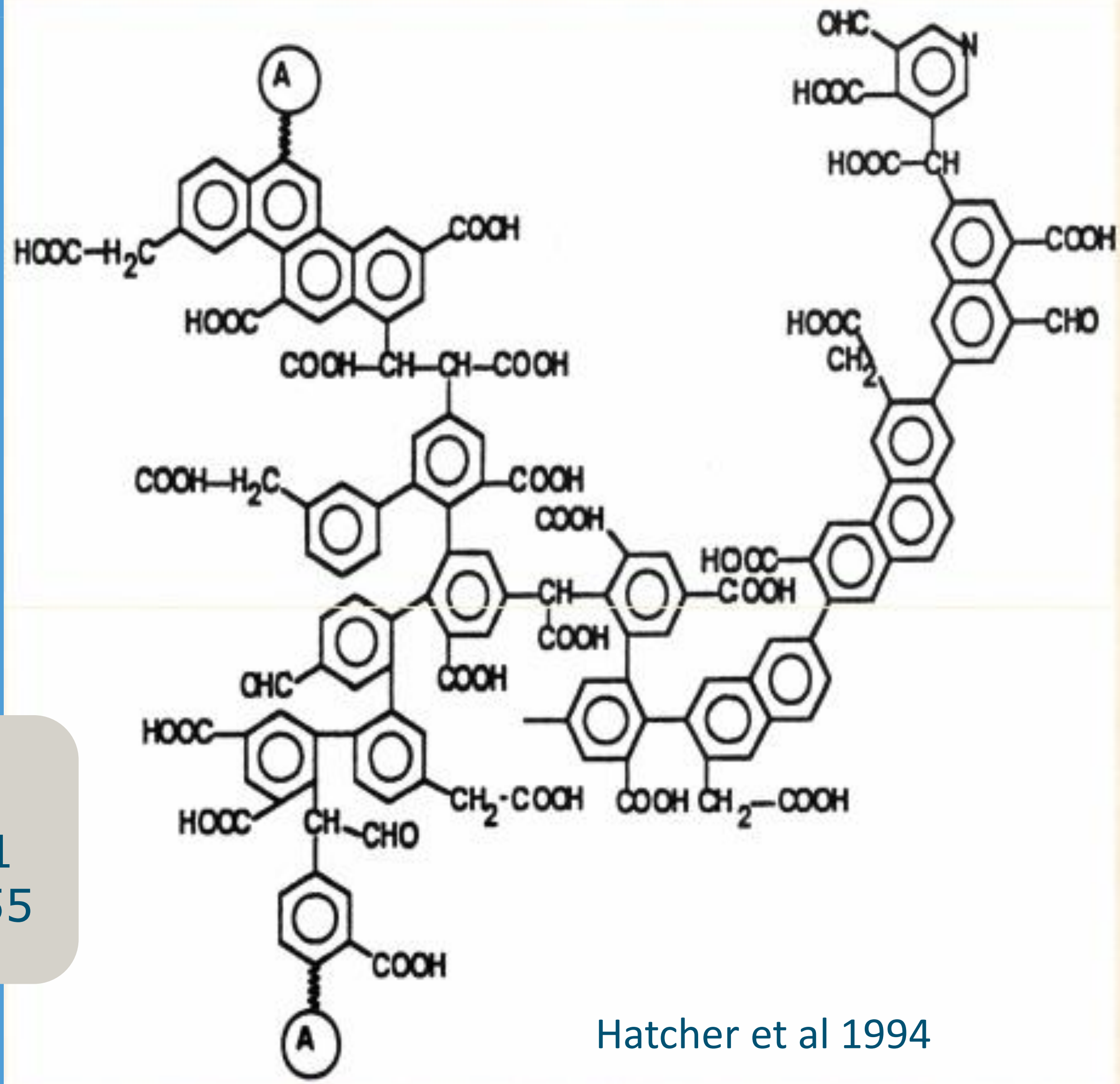


CEC reclaimed peat soils




Large complex organic humus molecule consisting of chains and rings of mainly carbon and hydrogen atoms
O
C
OH
Carboxylic group
OH
Phenolic hydroxyl group
OH
Alcoholic hydroxyl group
OH2+
O
C
O-
O-
O-
O-

Humic Acid structure



Hatcher et al 1994

C:O
Fulvic acids: 1
Humic acids : 0.55

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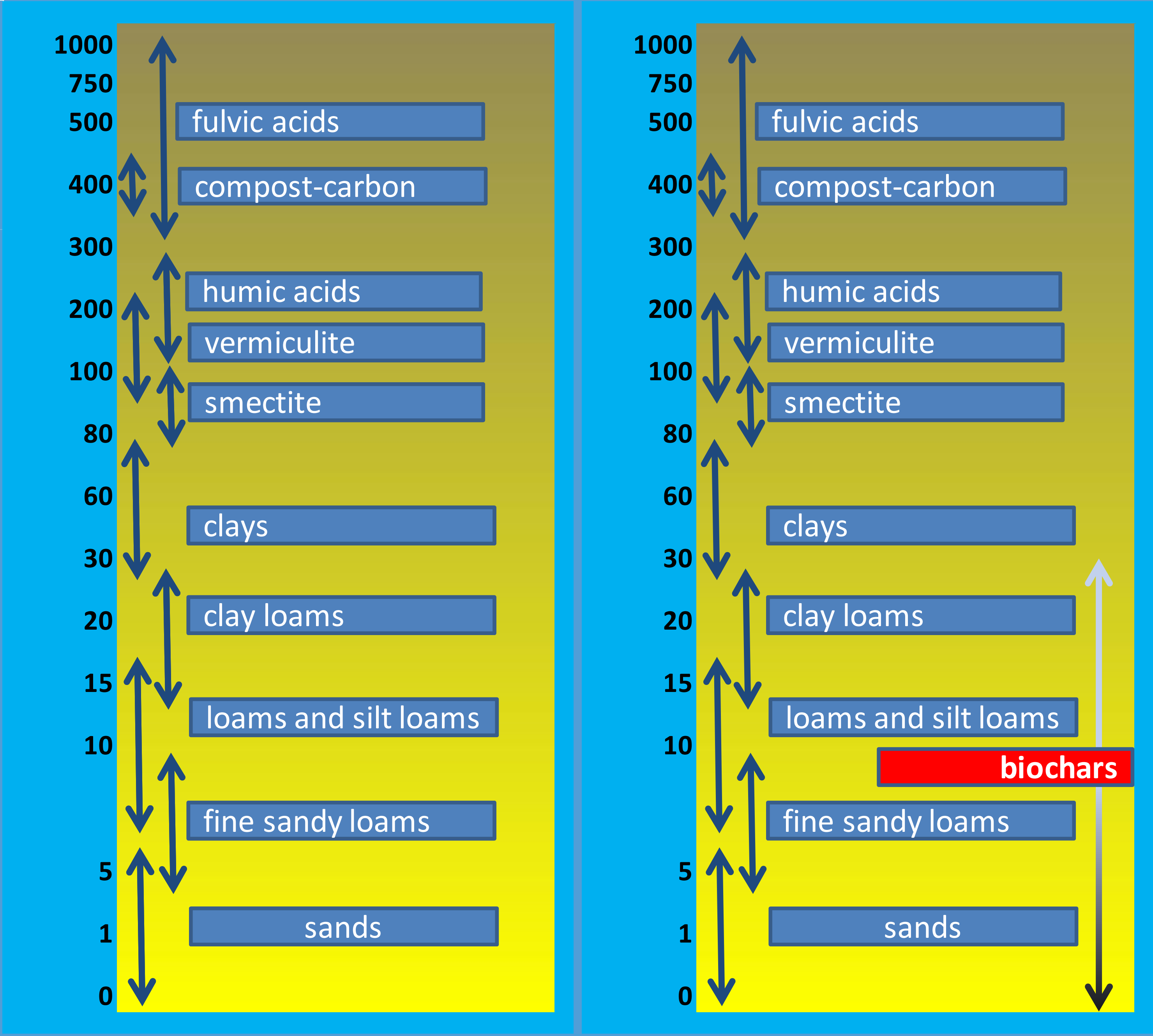
CEC (cmol/kg)

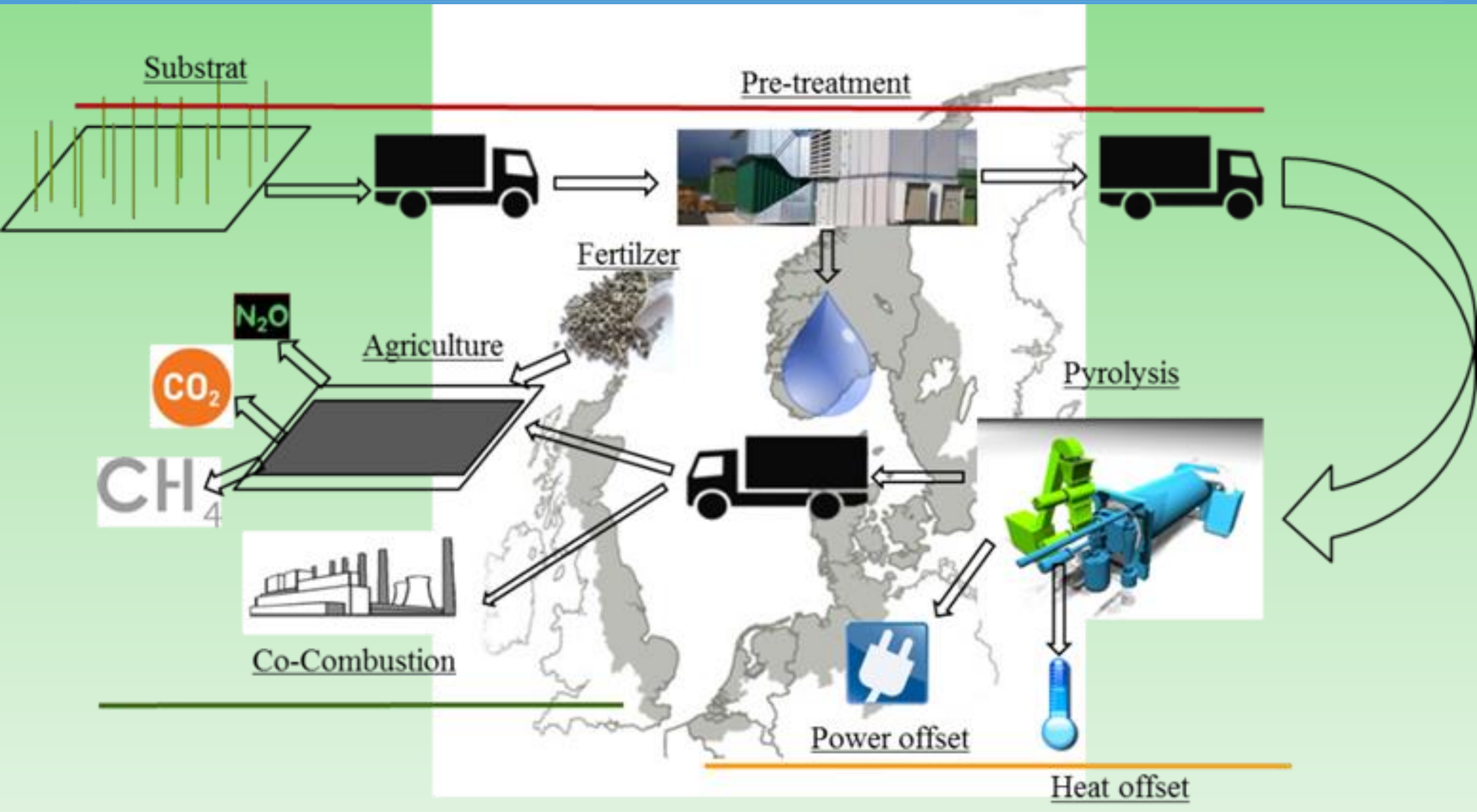

1000
750
500
400
300
200
100
80
60
30
20
15
10
5
1
0
fulvic acids
compost-carbon
humic acids
vermiculite
smectite
clays
clay loams
loams and silt loams
fine sandy loams
sands
1000
750
500
400
300
200
100
80
60
30
20
15
10
5
1
0
fulvic acids
compost-carbon
humic acids
vermiculite
smectite
clays
clay loams
loams and silt loams
biochars
fine sandy loams
sands

Modification of Biochar

- Activation (?)
- Adsorption of SOM
- Biological modification (?)
- Chemical modification
  - Functional groups CEC
  - Functional groups AEC (NR_4^+)

Energy or C-sequestration?

LCA



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Biochar Yields % kg DM^{-1}

Pyrolysis	Commercial Softwood Pellets	Anaerobic Digestate	Mixed Wood Chip	Green Waste
Char Yield	23.9	44	25.2	60.6
Carbon	0.89	0.52	0.87	0.18
Liquid Yield	37	24.3	33.9	12.9
Syngas Yield	39.1	31.7	40.8	26.5

Markus Roedger, Biochar Climate Saving Soils

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Biochar energy content MJ/kg^{-1}

	Pyrolysis	Commercial Softwood Pellets	Anaerobic Digestate	Mixed Wood Chip	Green Waste
Biochar	HHV	33.6	16.9	32.2	8
Liquid	HHV	12.8	10.9	13	13.8
Syngas	HHV	15.3	11.3	13.3	11.5

Markus Roedger, Biochar Climate Saving Soils

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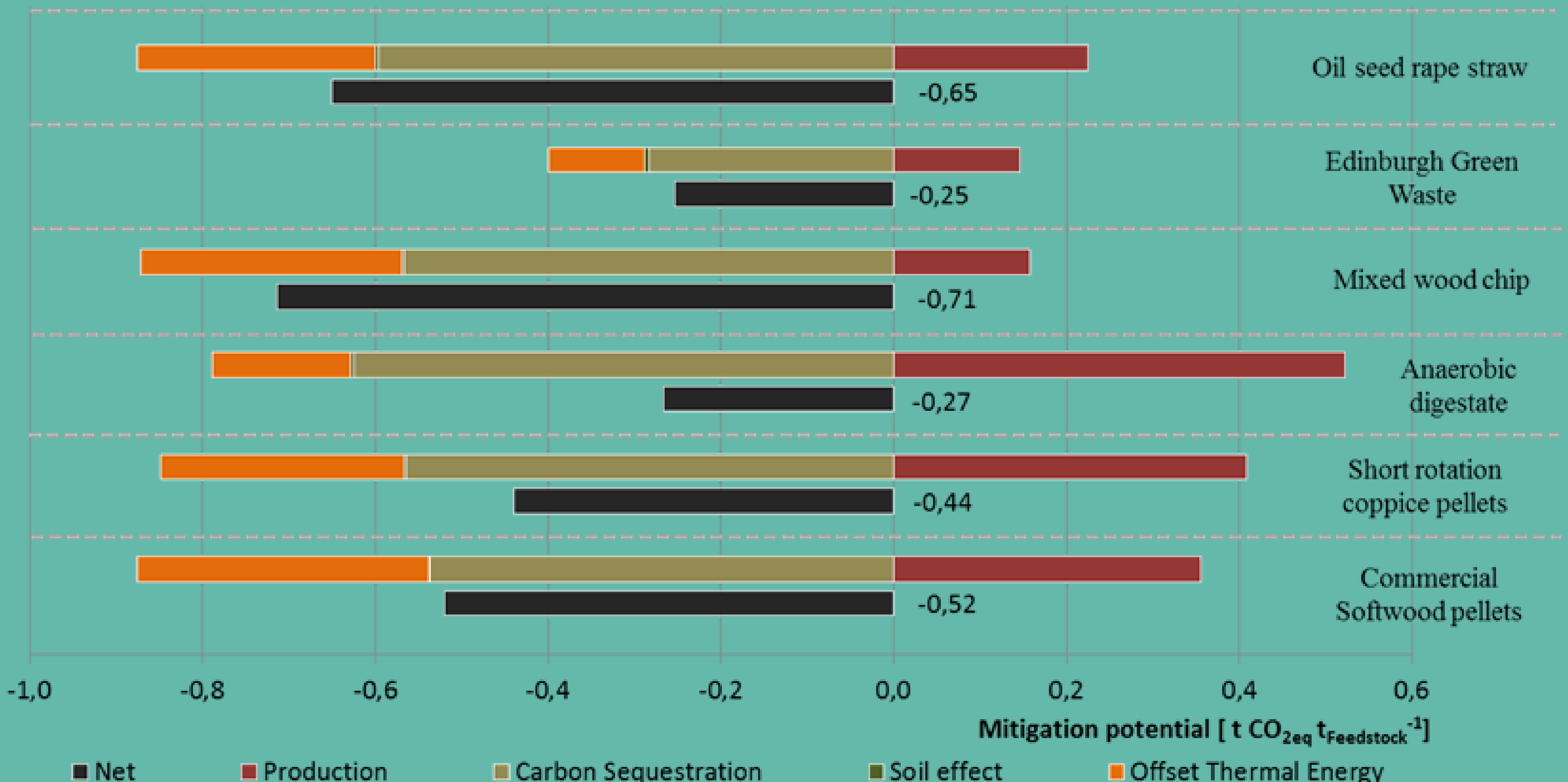
LCA results



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Conclusions

- Biochar can be used to sequester short cyclic C in the soil
- Biochar is rather different from SOM
- It seems unlikely that biochar can completely replace SOM
- Modification of biochar to improve its functionality is needed and is possible
- Application of biochar in agriculture? Mechanisms of effect!!!

- Energy or C-sequestration?

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Biochar Process Yield

Typical product yields (dry basis) for different modes of pyrolysis

Mode	Conditions	Liquid	Char	Gas
Fast	Moderate temperature ~ 500°C short vapor residence time ~ 1 s	75%	12%	13%
Moderate	moderate temperature ~ 500°C moderate vapor residence time ~ 10-20 s	50%	20%	30%
Slow	moderate temperature ~ 500°C very long vapor residence time ~ 5-30 min	30%	35%	35%
Gasification	high temperature > 750°C moderate vapor residence time ~ 10-20 s	5%	10%	85%

Effect of Feedstock and Thermal Process on Char Properties

Feedstock	Process	Higher Heating Value (kJ/kg)	BET Surface Area (m^2/g)
Corn Stover	Slow Pyrolysis	21,596	4.1
Switchgrass	Slow Pyrolysis	12,799	22.8
Corn Stover	Fast Pyrolysis	13,833	4.5
Switchgrass	Fast Pyrolysis	16,337	17.7
Corn Stover	Gasification	15,290	43.6
Switchgrass	Gasification	15,864	39.2

Cation Exchange Capacity (CEC) of Chars

Feedstock	Process	Reactor type	CEC (cmol/kg)
Corn stover	Fast pyrolysis	PDU fluidized bed	29.89
Switchgrass	Fast pyrolysis	PDU fluidized bed	16.3
Loblolly pine	Fast pyrolysis	Lab scale fluidized bed	14.21
Corn stover	Fast pyrolysis	Lab scale free fall reactor	12.23
Switchgrass	Gasification	PDU fluidized bed	11.34
Corn stover	Gasification (cyclone 1)	PDU fluidized bed	31.4
Corn stover	Gasification (cyclone 2)	PDU fluidized bed	17.21
Hardwood	Slow pyrolysis	Lab scale fixed bed	19.04
Switchgrass	Slow pyrolysis	Lab scale fixed bed	12.35
Woodwaste	Gasification	Large pilot-scale	12.11

Used modified Compulsive Exchange Method (Gilman & Sumpter 1986, Laird & Fleming 2008)