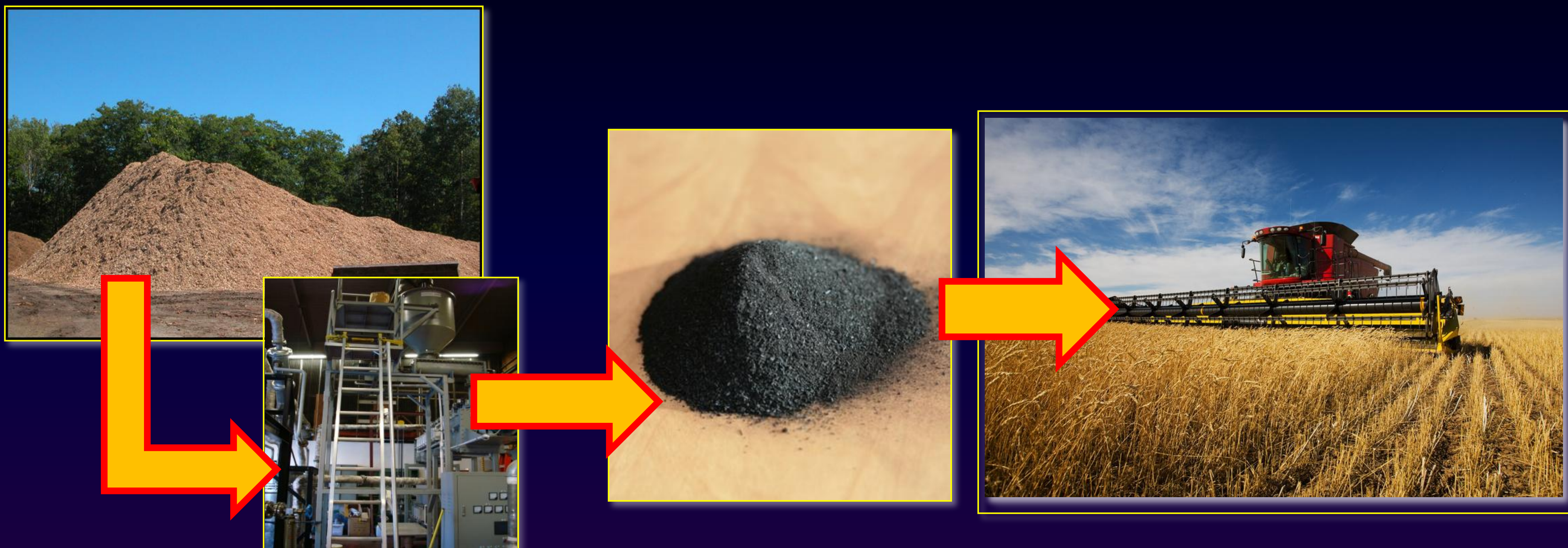
Biochar:
Impacts on Soil Microbes and the Nitrogen Cycle



Kurt Spokas

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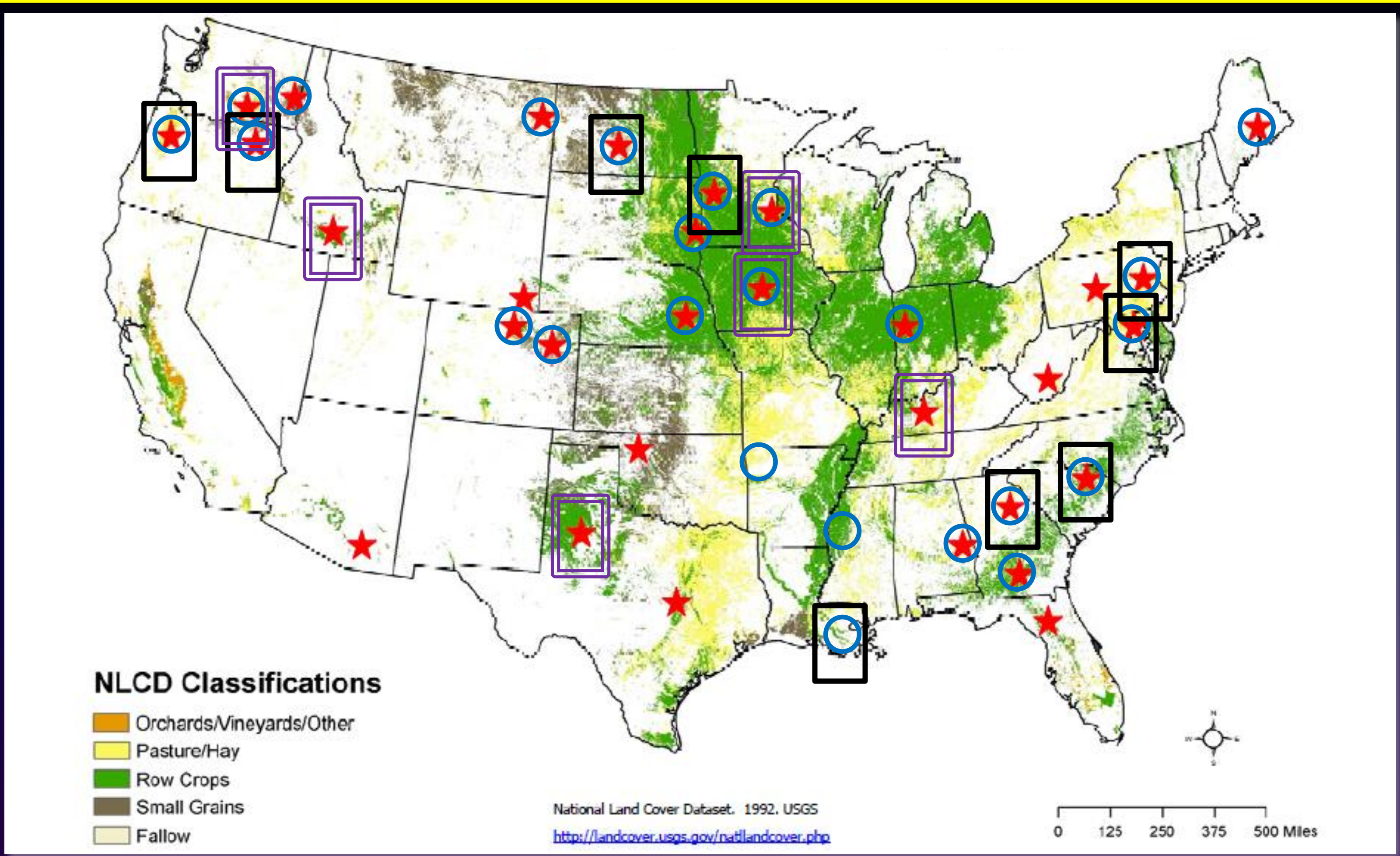
Biochar: Production, Properties, & Agricultural Use
Illinois Sustainable Technology Center – Champaign, IL
September 1, 2010

USDA

Agricultural Research Service

USDA-ARS Biochar and Pyrolysis Initiative



Multi-location USDA-ARS research efforts:

- ★ **GRACEnet Project** (30 locations): Greenhouse Gas Reduction and Carbon Enhancement Network
- ○ **REAP Project** (24 locations): Renewable Energy Assessment Project
- □ **Biochar and Pyrolysis Initiative** (15 locations)
  - □ Ongoing field plot trial (6 locations)

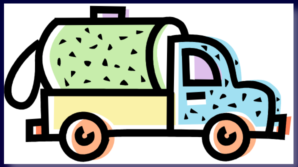
Agricultural Research Service

Biochar: New purpose not a new material

Pyrolysis, carbonization, and coalification are well establish conversion processes with long research histories

Except:

Prior emphasis:



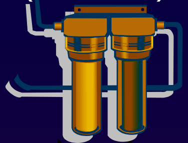
- Conversion of biomass to liquids (bio-oils) or gaseous fuels and/or fuel intermediates
- Solid byproduct (biochar) has long been considered a "*undesirable side product*"

(Titirici et al., 2007)

Cave Drawings
(>10,000 to 30,000 BC)

Used as fuel
(3000-4000 BC)

Water filtration
(2000 BC)



Charcoal production
(15th century)

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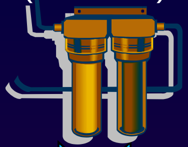

Charcoal production
(15^{th} century)


Climate Change Mitigation
(1980's)


Pyrolysis, carbonization, and coalification are well establish conversion processes with long research histories

Except:

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(Titirici et al., 2007)

- What is new

The use (or purpose) for the creation of charred biomass

- Atmospheric C sequestration

Dates to 1980's and early 2000's

(Goldberg 1985; Kuhlbusch and Crutzen, 1995; Lehmann, 2006)

Carbon Sequestration Rates

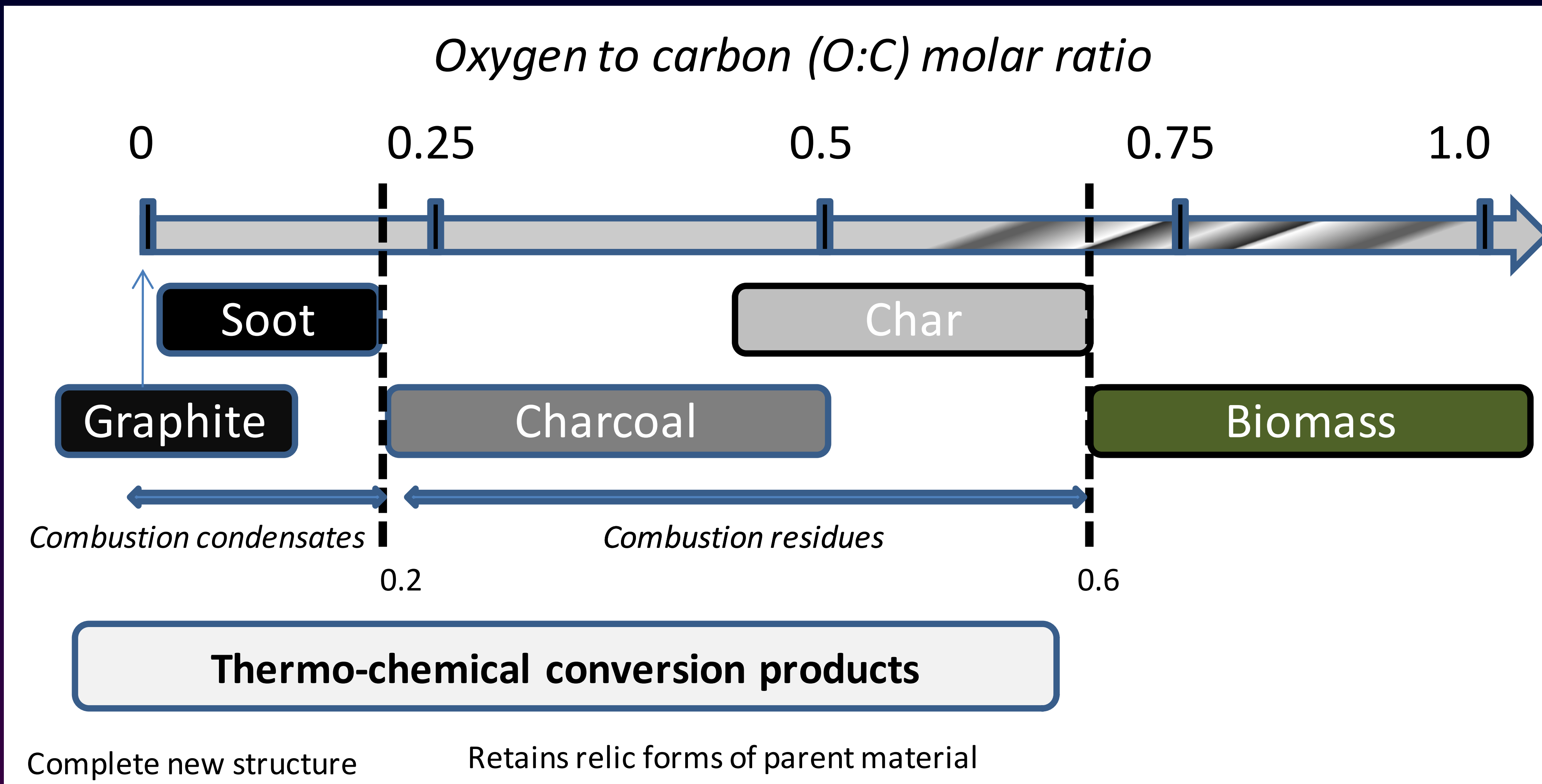
Ecosystem	Range of Natural CO_2 Sequestration Rates (tons C $acre^{-1}$ yr^{-1})
Cropland	0.2 to 1
Forest	0.1 to 4
Grassland / Prairie	0.1 to 1
Swamp / Floodplain / Wetland	2 to 4

Biochar → Goal is to increase rates of C sequestration




Biochar: Black Carbon Continuum

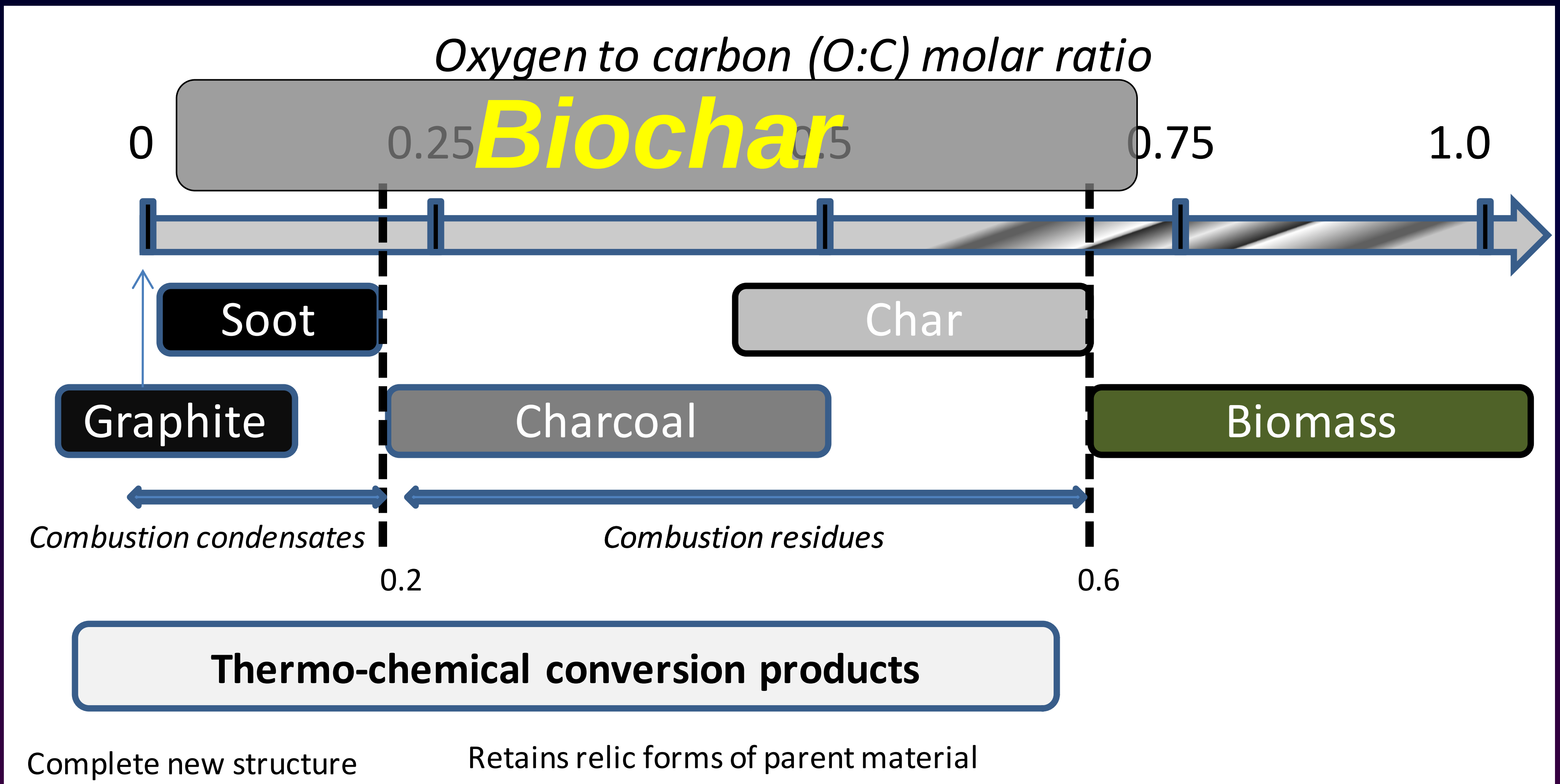
Problem → Lack of nomenclature uniformity (Jones et al., 1997)



Adapted from Hedges et al., 2000; Elmquist et al., 2006

Biochar: Black Carbon Continuum

Biochar – Spans across multiple divisions in the Black C Continuum
However, biochar is NOT a new division…



Adapted from Hedges et al., 2000; Elmquist et al., 2006

Comparisons of Natural vs. Synthetic

Natural Biochar

-Heterogeneous feedstock

- Impurities
  - Soil and oxygen
  - Minerals (metals) alter yields

    (e.g. Robertson, 1969; Bonijolya et al., 1982; Baker, 1989)
- Multiple feedstock sources
  - Species and types

-Variable temperature

- 80 to 1000 ºC

-Air cooled/Precipitation/Solar (UV)

- Exposed to environmental conditions

Synthetic (Pyrolysis) Biochar

-Pure homogeneous feedstock

-“Constant” temperature

- Industrial Process

-Typically cooled under anaerobic conditions (no water)

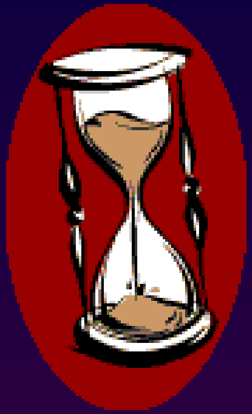
- No weather exposure

Biochar: Soil Stability

- Over a 100 year history of research

  Potter (1908) – Initial observation of fungi/microbial degradation of lignite (low grade coal/charcoal)

Biochar Degradation Study	Residence Time (yr)
Steinbeiss et al. (2009)	<30
Hamer et al. (2004)	40 to 100
Bird et al. (1999)	50-100
Lehmann et al. (2006)	100's
Baldock and Smernik (2002)	100-500
Hammes et al. (2008)	200-600
Cheng et al. (2008)	1000
Harden et al. (2000)	1000-2000
Middelburg et al. (1999)	10,000 to 20,000
Swift (2001)	1,000-10,000
Zimmerman (2010)	100's to >10,000
Forbes et al. (2006)	Millennia based on C-dating
Liang et al. (2008)	100's to millennia



Possible Stability Explanation→ O:C Ratio

Biochar Degradation Study	Residence Time (yr)
Baldock and Smernik (2002)	100-500
Bird et al. (1999)	50-100
Cheng et al. (2008)	1000
Forbes et al. (2006)	Millennia based on C-dating
Hamer et al. (2004)	40 (charred straw residue) 80 (charred wood)
Hammes et al. (2008)	200-600
Harden et al. (2000)	1000-2000
Liang et al. (2008)	several centuries to millennia
Lehmann et al. (2006)	100's
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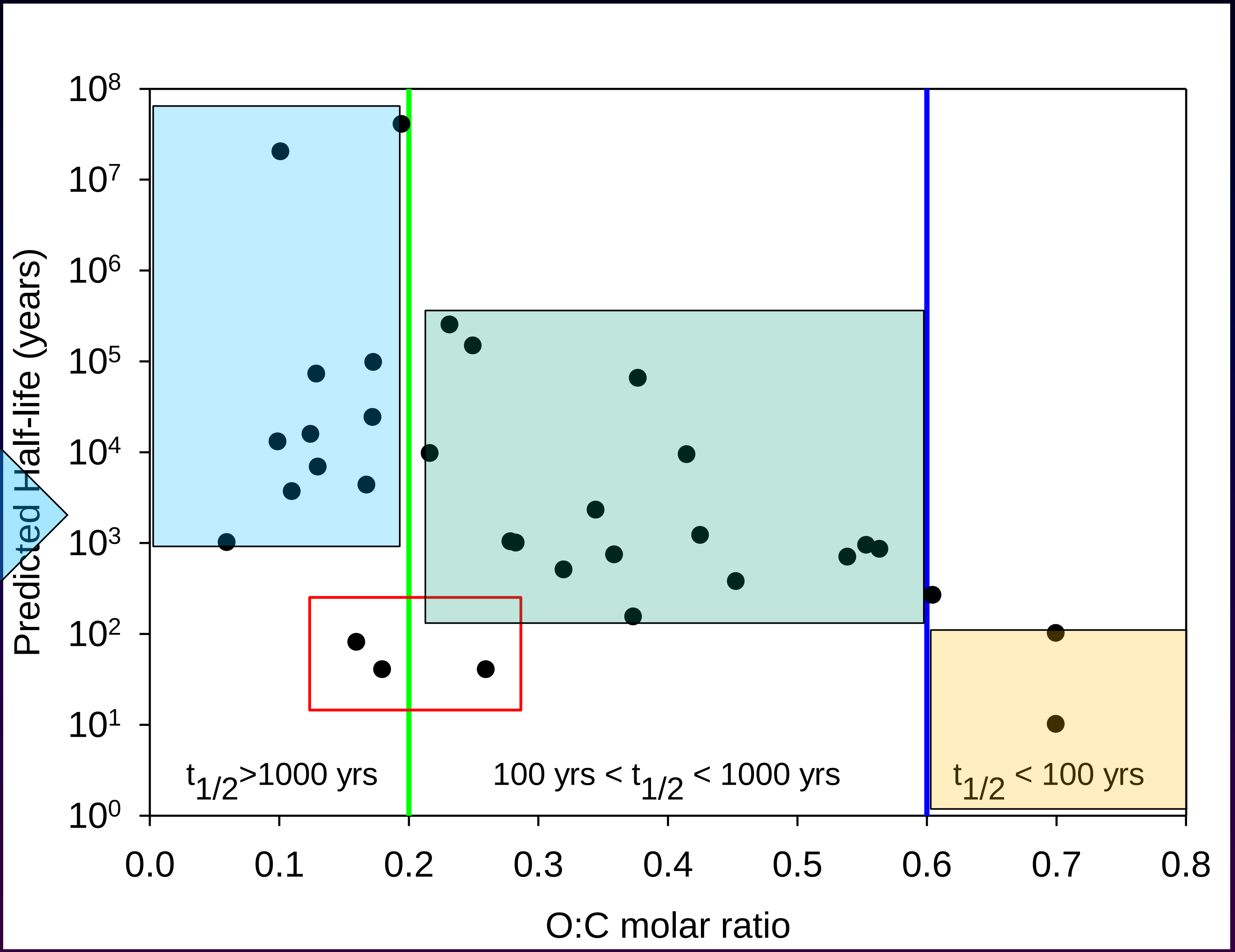
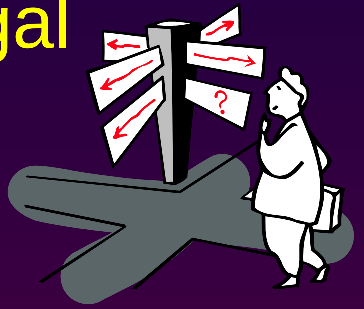


Summary of existing literature studies (n=35) on half-life estimation of biochar [Figure from Spokas (2010)]

Proposed Biochar Mechanisms

1. Alteration of soil physical-chemical properties
   - ✓ pH, CEC, decreased bulk density, increased water holding capacity
2. Biochar provides improved microbial habitat
3. Sorption/desorption of soil GHG and nutrients
4. Indirect effects on mycorrhizae fungi through effects on other soil microbes
   - ✓ Mycorrhization helper bacteria → produce *furan/flavoids* beneficial to germination of fungal spores



Warnock et al. (2007)

Soil Microbe Impacts: Laboratory Incubations

- We know when we are sick….

Fever, aches, pains.….

- How about for soil microbes:

- Look at their "products" – e.g. CO_2, CH_4, N_2O

- Implications on the rates of reaction and amount of gases produced

- Provide clues into the mechanisms

Biochar impacts on Soil Microbes & N Cycling

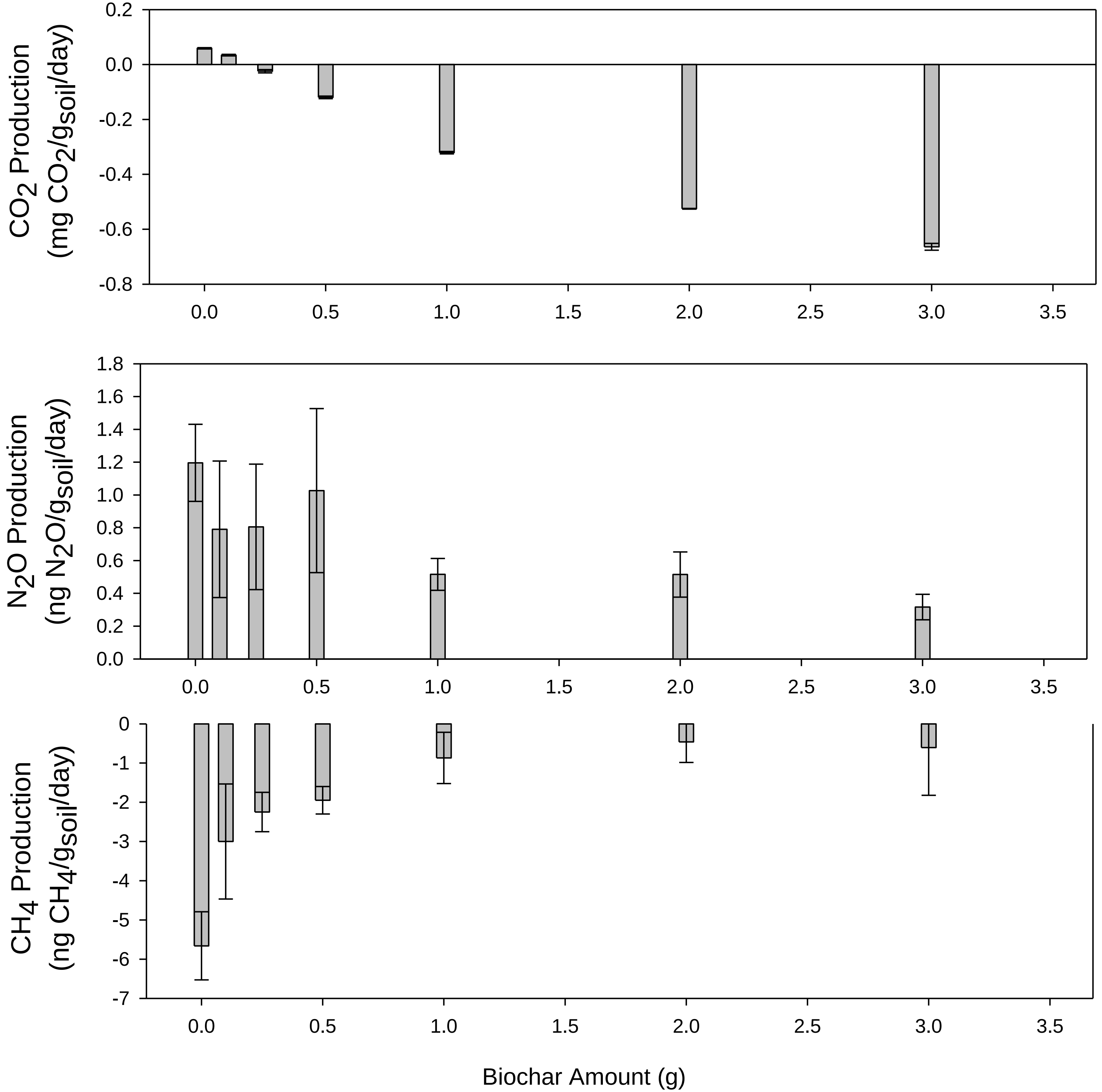
- 44 different biochars evaluated
- 11 different biomass parent materials
  - Hardwood, softwood, corn stover, corn cob, macadamia nut, peanut shell, sawdust, algae, coconut shell, turkey manure, distillers grain
- Represents a cross-sectional sampling of available “biochars”
  - C content 1 to 84 %
  - N content 0.1 to 2.7 %
  - Production Temperatures 350 to 850 ^{o}C
  - Variety of pyrolysis processes
    - Fast, slow, hydrothermal, gasification

Laboratory Biochar Incubations

- Soil incubations:
  - Serum bottle (soil + biochar)
    - 5 g soil mixed with 0.5 g biochar (10% w/w) [GHG production]
    - Field capacity and saturated

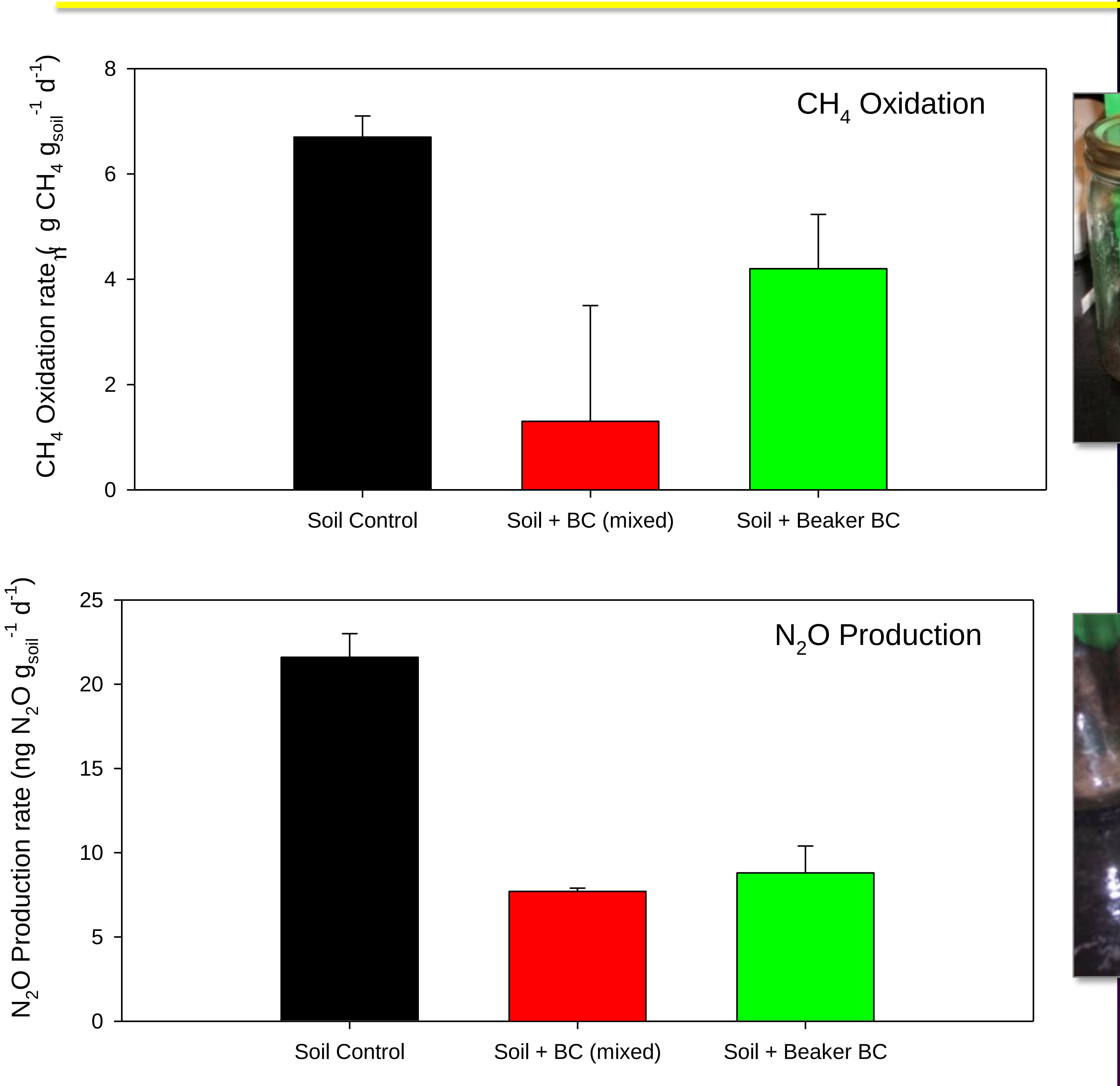
  - Mason Jar (biochar mixed & isolated)
    - Looking at impact of biochar without mixing with soil

Influence of biochar addition on GHG Production

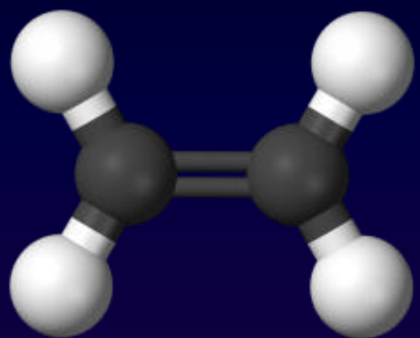


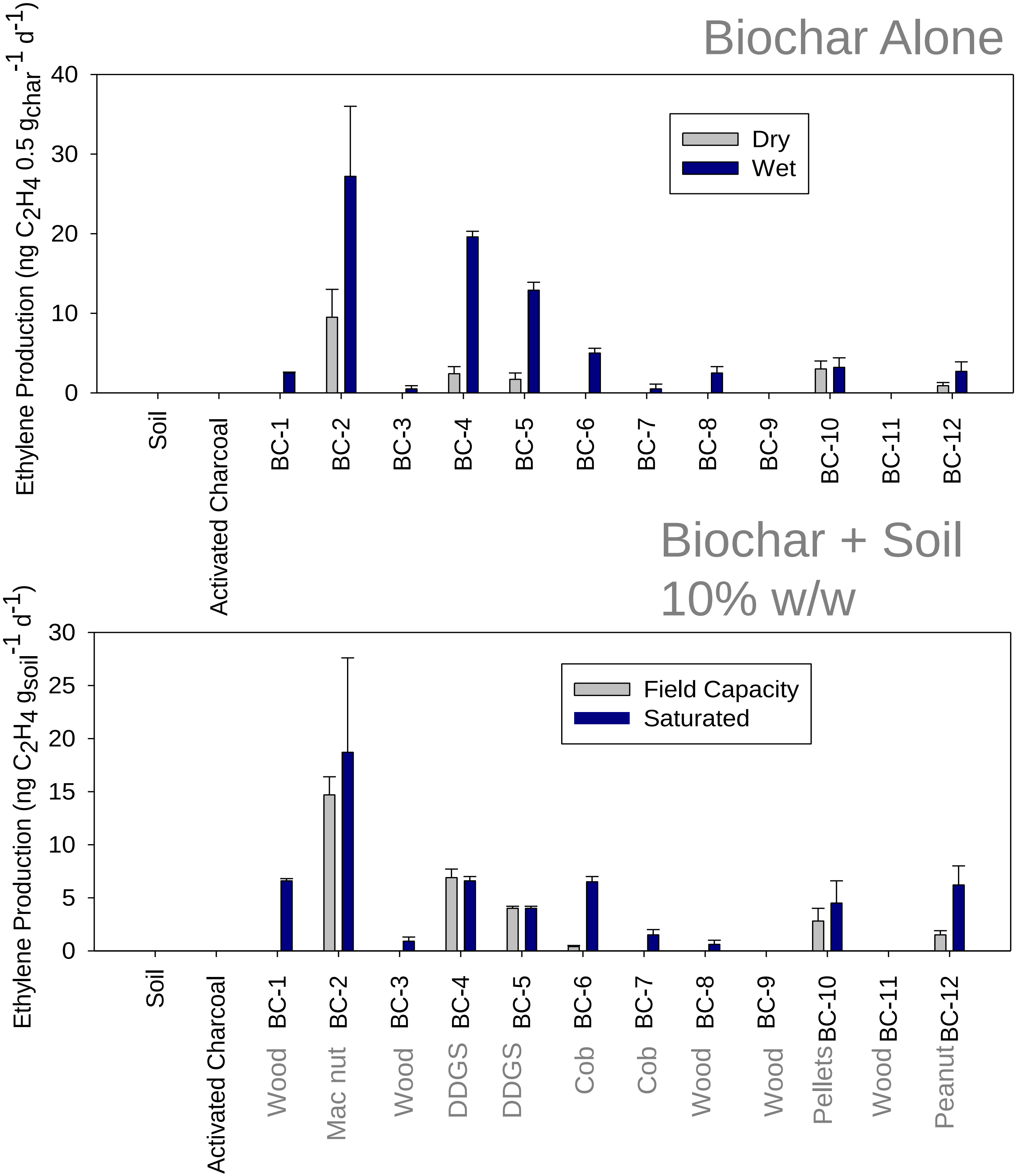
Spokas et al., 2009

Biochar isolated or mixed with soil

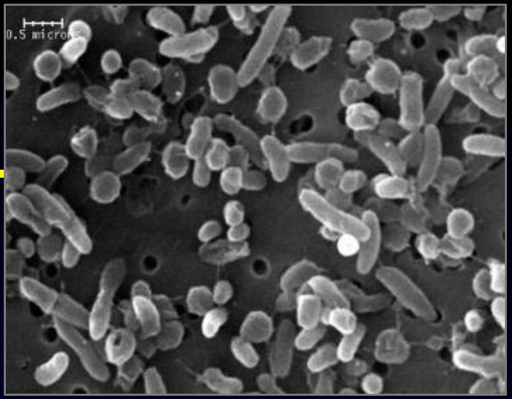


Ethylene Production Rates





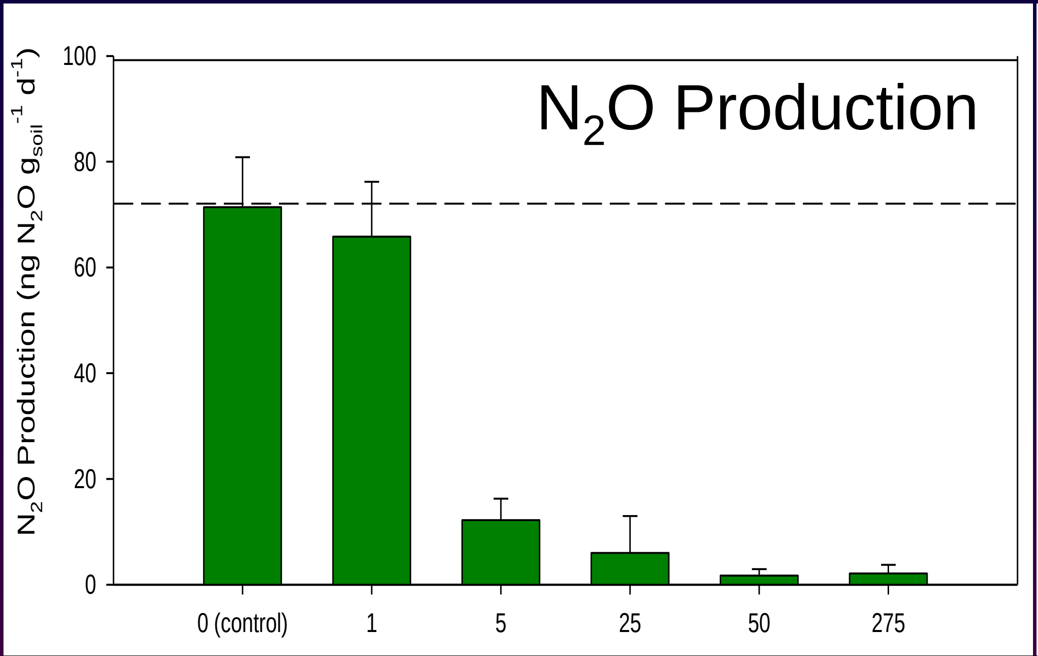
Ethylene Impacts



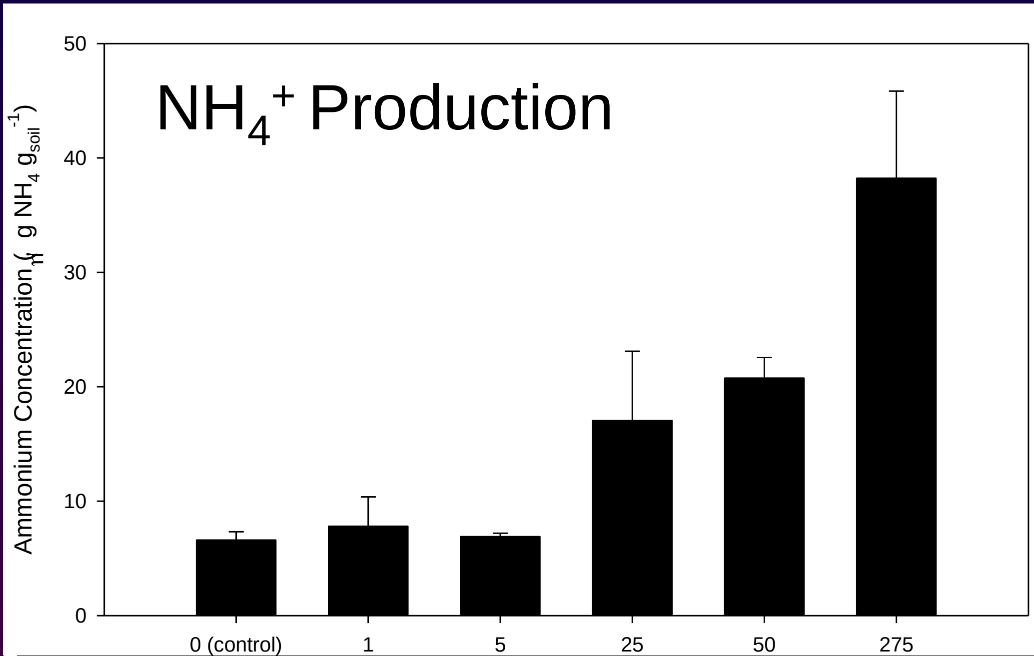
Soil Microbial Impacts

- ✓Induces fungal spore germination
- ✓Inhibits/reduces rates of nitrification/denitrification
- ✓Inhibits CH_4 oxidation (methanotrophs)
- ✓Involved in the flooded soil feedback

Both microbial and plant (adventitious root growth)



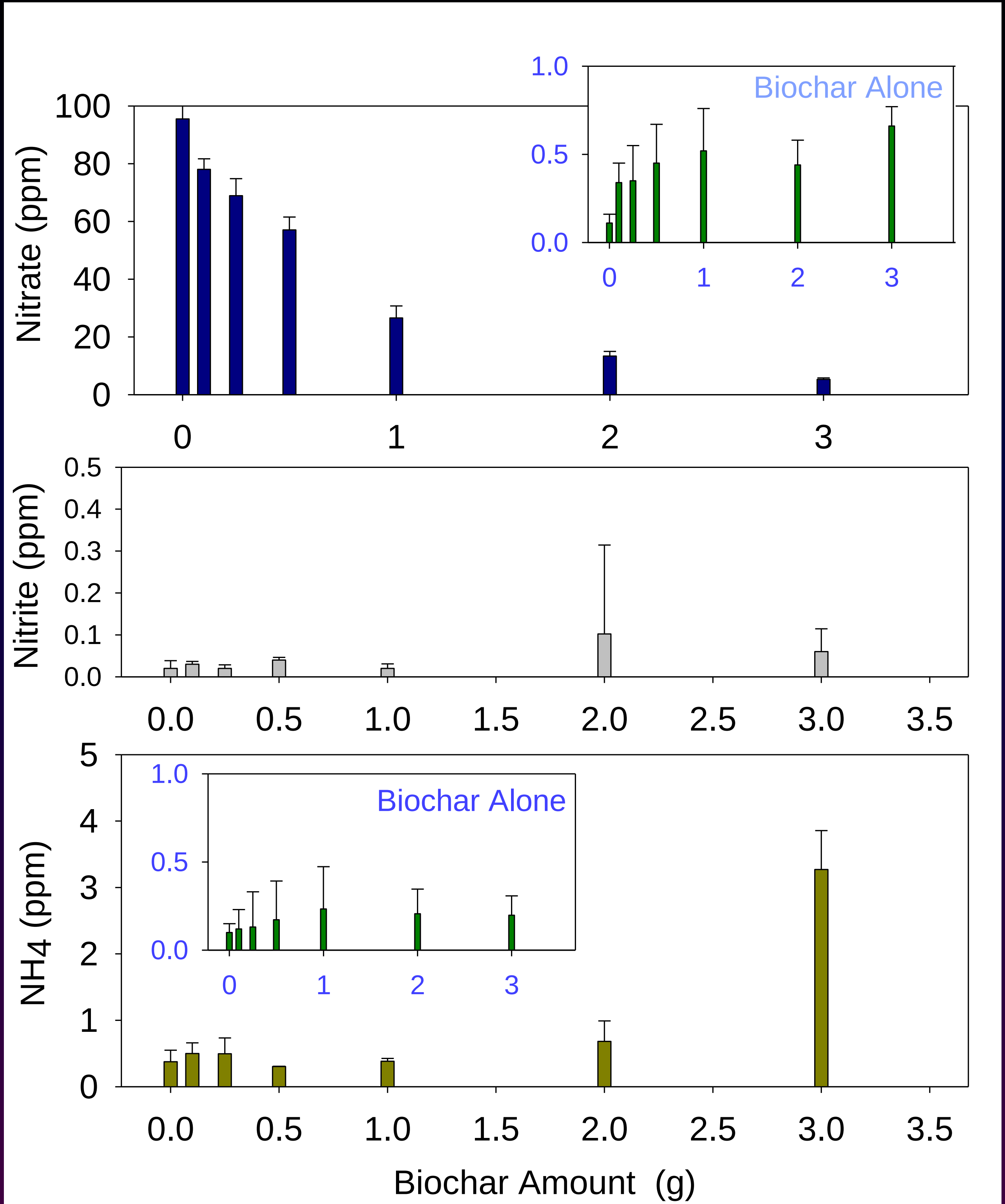
Ethylene Headspace Concentration (0 to 275 ppmv)



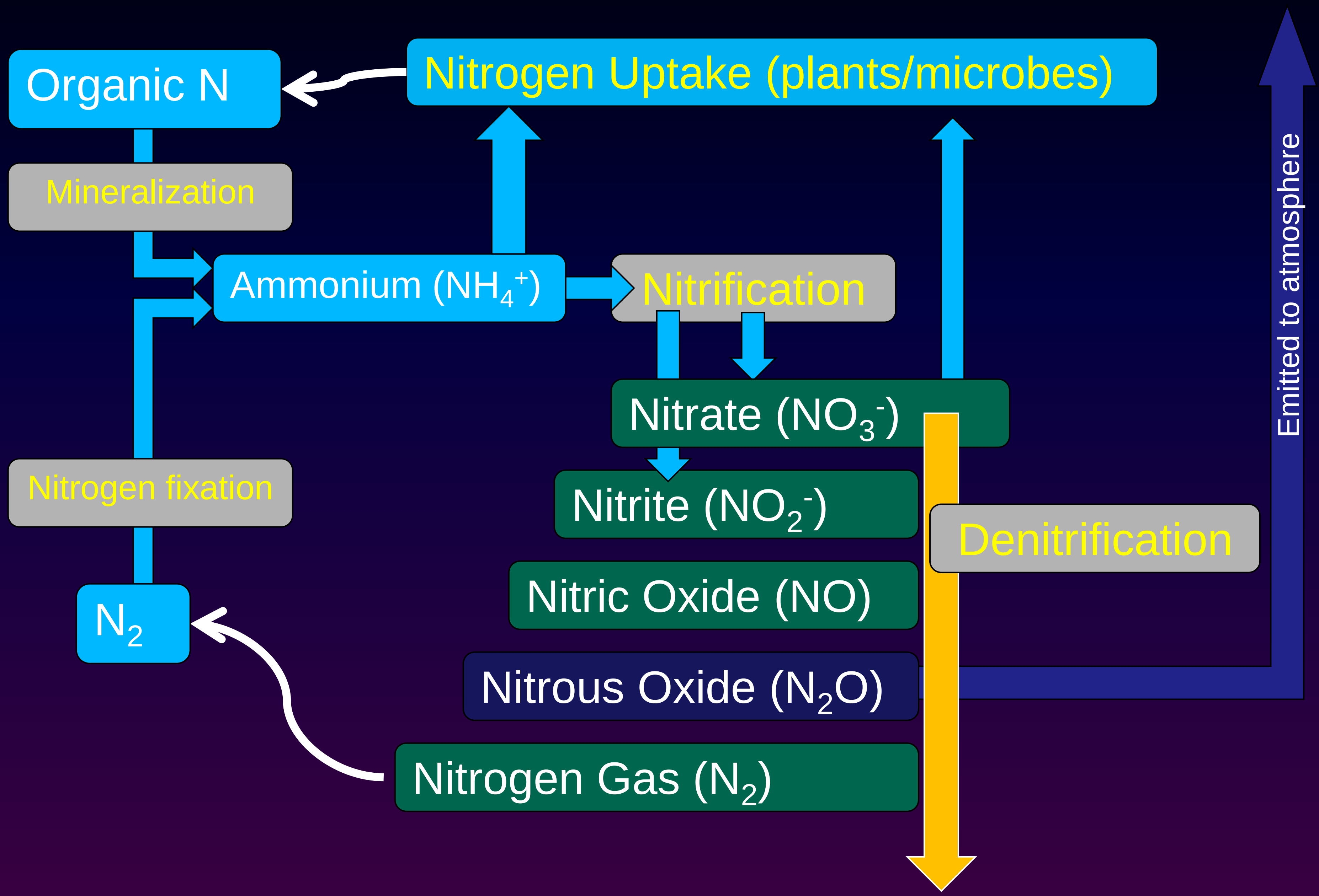
Ethylene Headspace Concentration (0 to 275 ppmv)

Closer look at N-cycling

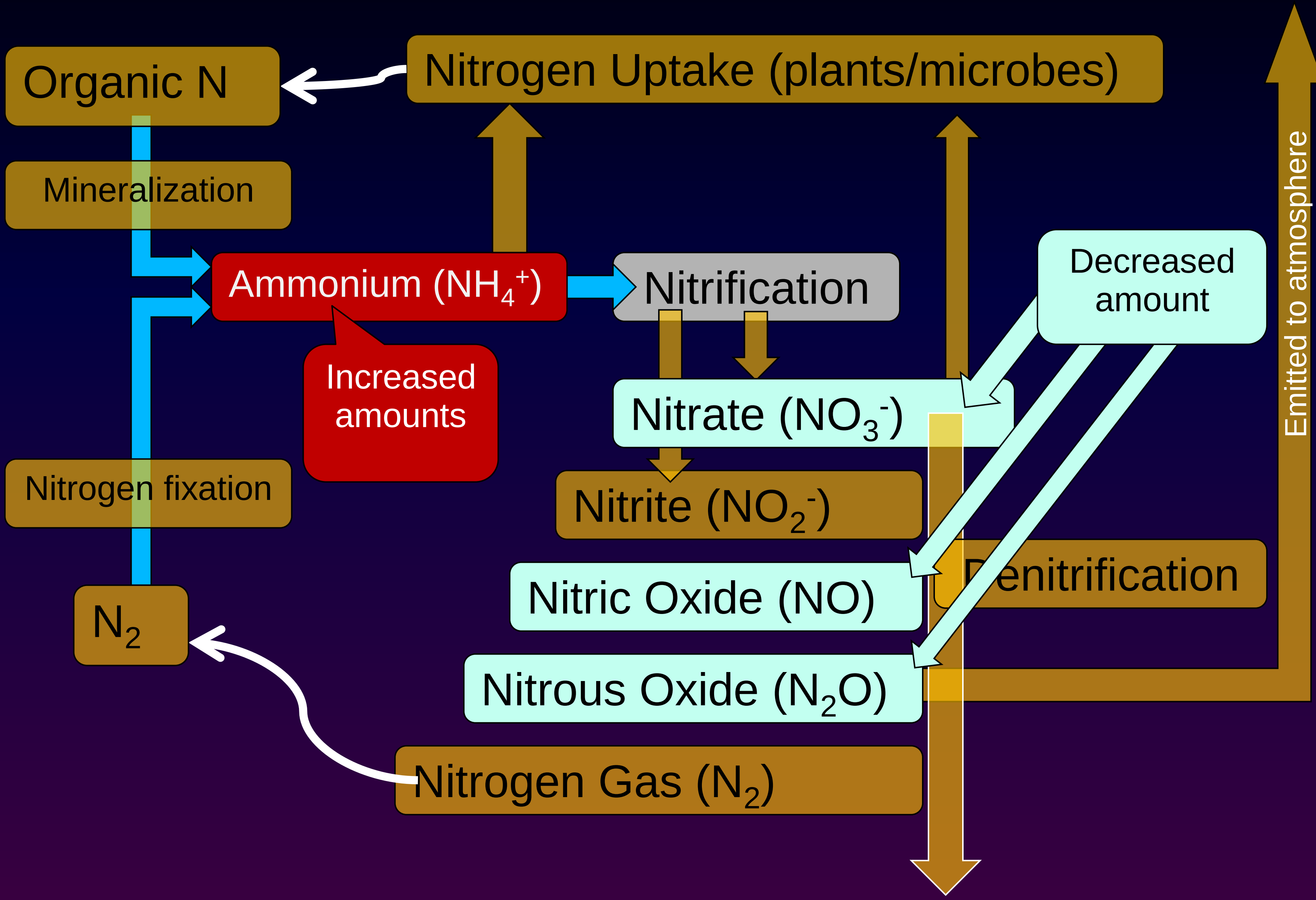
(hardwood sawdust biochar)



Brief Overview of N-cycle



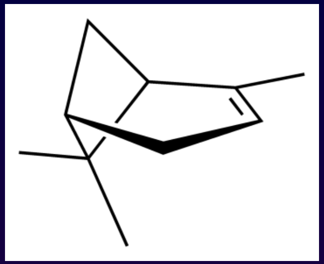
Putting the pieces together: Not quite a full picture yet…



Ethylene Production

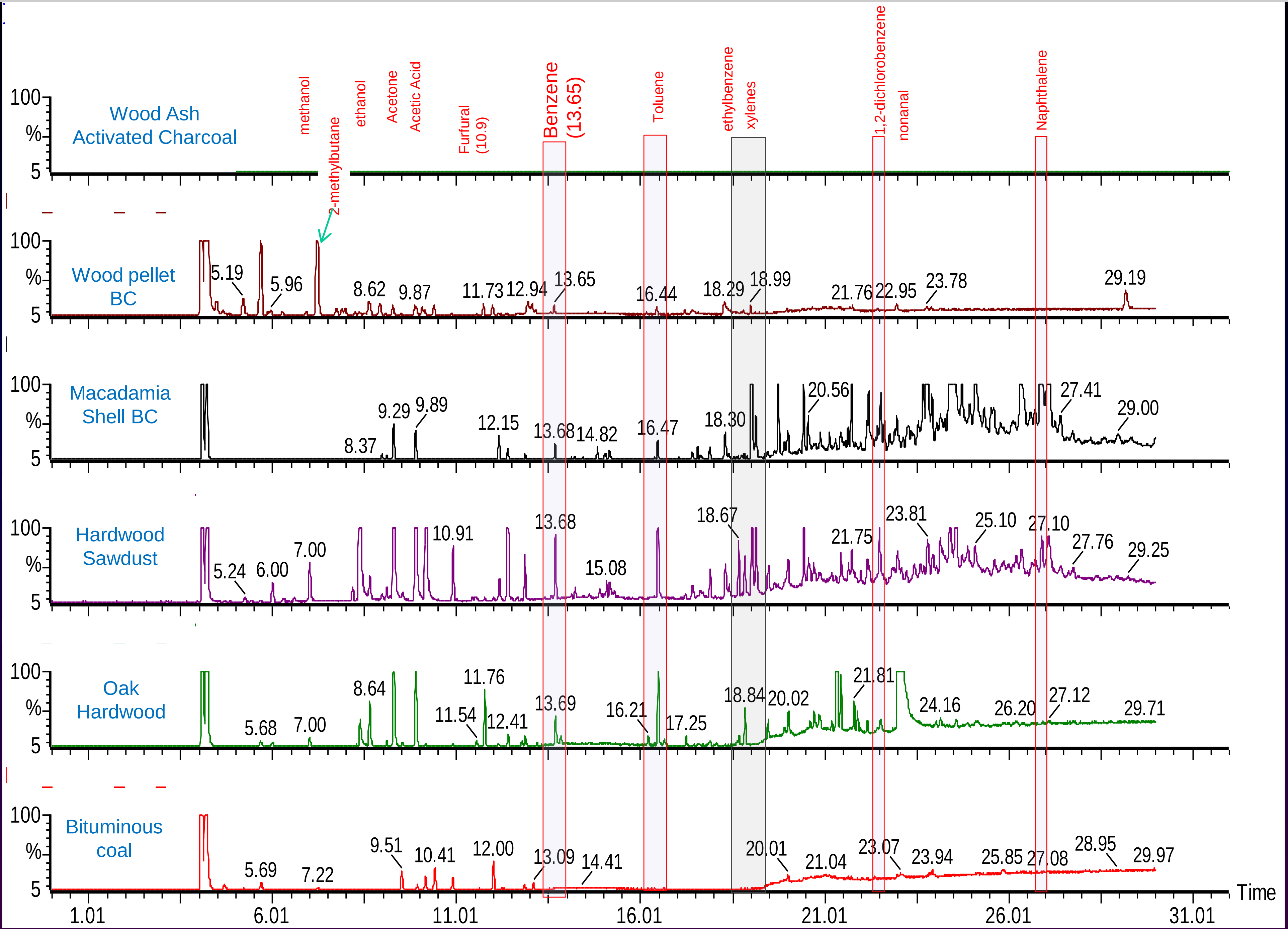
- Ethylene could provide a mechanism behind reduced nitrification/denitrification activity

- Clough et al. (2010) also hypothesized that **α-pinene** could be involved as a nitrification inhibitor
  - α-pinene observed as volatile from vegetation
  - involved in insects' chemical communication system



- Despite the different chemicals – Same mechanism:
  Chemical inhibitors behind the suppression of N_2O production

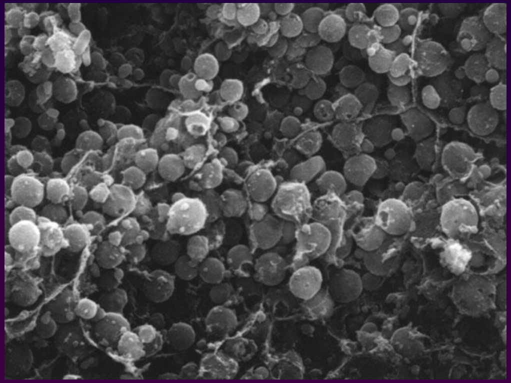
Headspace Thermal Desorption GC/MS scans of biochars



Biochar has a variety of sorbed volatiles = range of potential microbial inhibitors

Impact of Biochar Volatiles in Soils

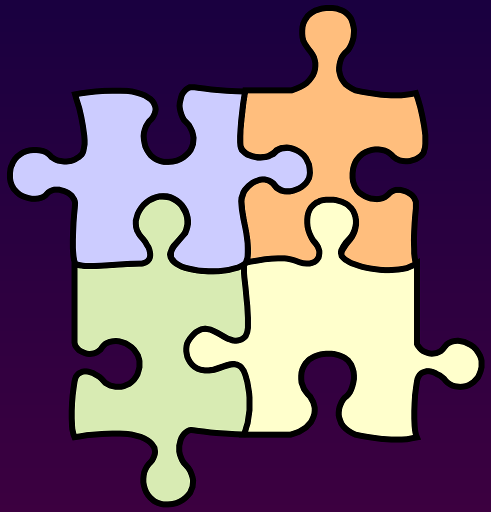
- Volatile organic compounds can interfere with microbial processes
  - Terpenoids – interfere with nitrification [Amaral et al., 1998; White 1994]
  - Furfural + derivatives – inhibits microbial fermentation & nitrification (Couallier et al., 2006; Datta et al. 2001)
  - Benzene, Esters – Also inhibit microbial reactions
  - Still ongoing and developing research area in the plant/microbe research area
- Alterations in VOC content could be sensitive indicators of soil conditions (Leff and Fierer, 2008).
- Sorbed BC volatiles could interfere with microbial signaling (communication): Releasing or sorb signaling compounds



Conclusions

- Another piece to the puzzle: Ethylene + sorbed VOC's
  - Sorbed volatiles and degradation products (ethylene) should be included in the potential biochar mechanisms
  - Microbial inhibitors – Could also explain plant effects
- Reduction in N_2O production : Consequence of sorbed volatiles impacting the nitrification process
  - Accumulation of NH^+_4 and decreased NO^-_3 production
  - Length of impact ?
- No absolute "Biochar" consistent trends: Highly variable and different responses to biochar as a function of soil ecosystem (microbial linkage) & position on black carbon continuum:

  Typically:
  - <u>Reduced</u> basal CO_2 respiration
  - <u>Reduced</u> CH_4 oxidation activity
  - <u>Reduced</u> N_2O production activity
  - <u>Reduced</u> NO_3 production (availability)
  - <u>Increased</u> extractable NH_4 concentrations
  - Exceptions DO exist



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Fast pyrloysis char (CQuest™) through non-funded CRADA agreement

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Chip Energy

AECOM

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"The Nation that destroys its soil destroys itself"

Franklin D. Roosevelt