Biochar:
Impacts on Soil Microbes and the Nitrogen Cycle

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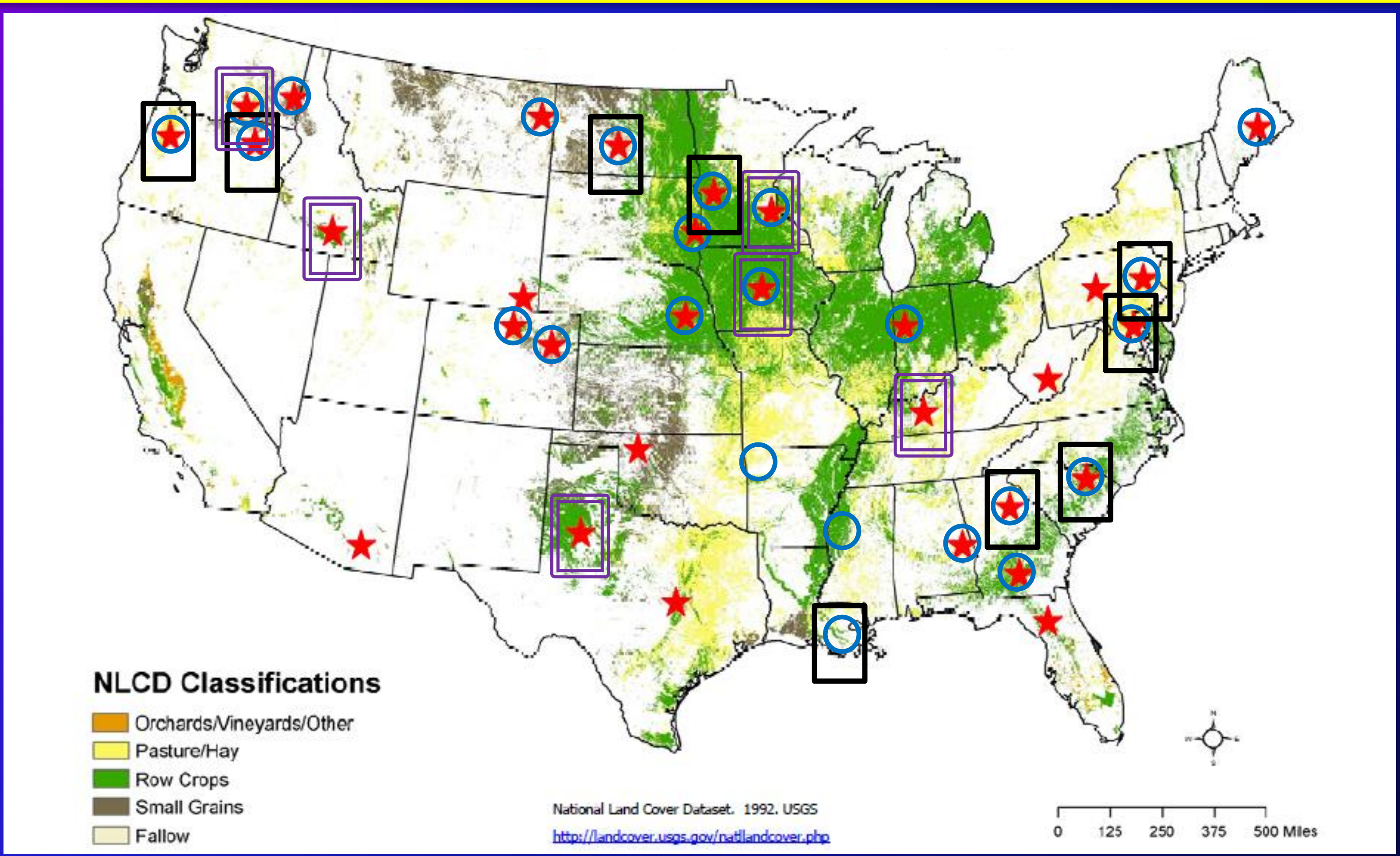
USDA-ARS Biochar and Pyrolysis Initiative



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)

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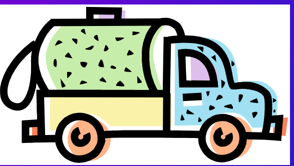
Biochar: New purpose not a new material

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

Except:

Prior emphasis:



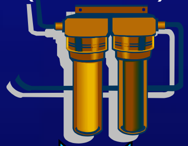
- Conversion of biomass to liquids (bio-oils) or gaseous fuels and/or fuel intermediates
- Solid byproduct (biochar) has long been considered a "*undesirable side product*"

(Titirici et al., 2007)

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

Used as fuel
(3000-4000 BC)

Water filtration
(2000 BC)



Charcoal production
(15^{th} century)

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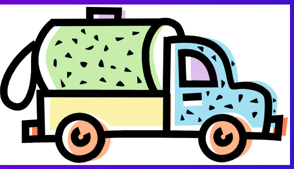

Conversion of biomass to liquids (bio-oils) or gaseous fuels and/or fuel intermediates

Solid byproduct (biochar) has long been considered an "*undesirable side product*"

(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)

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

Used as fuel
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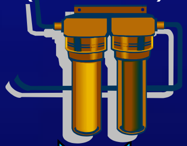
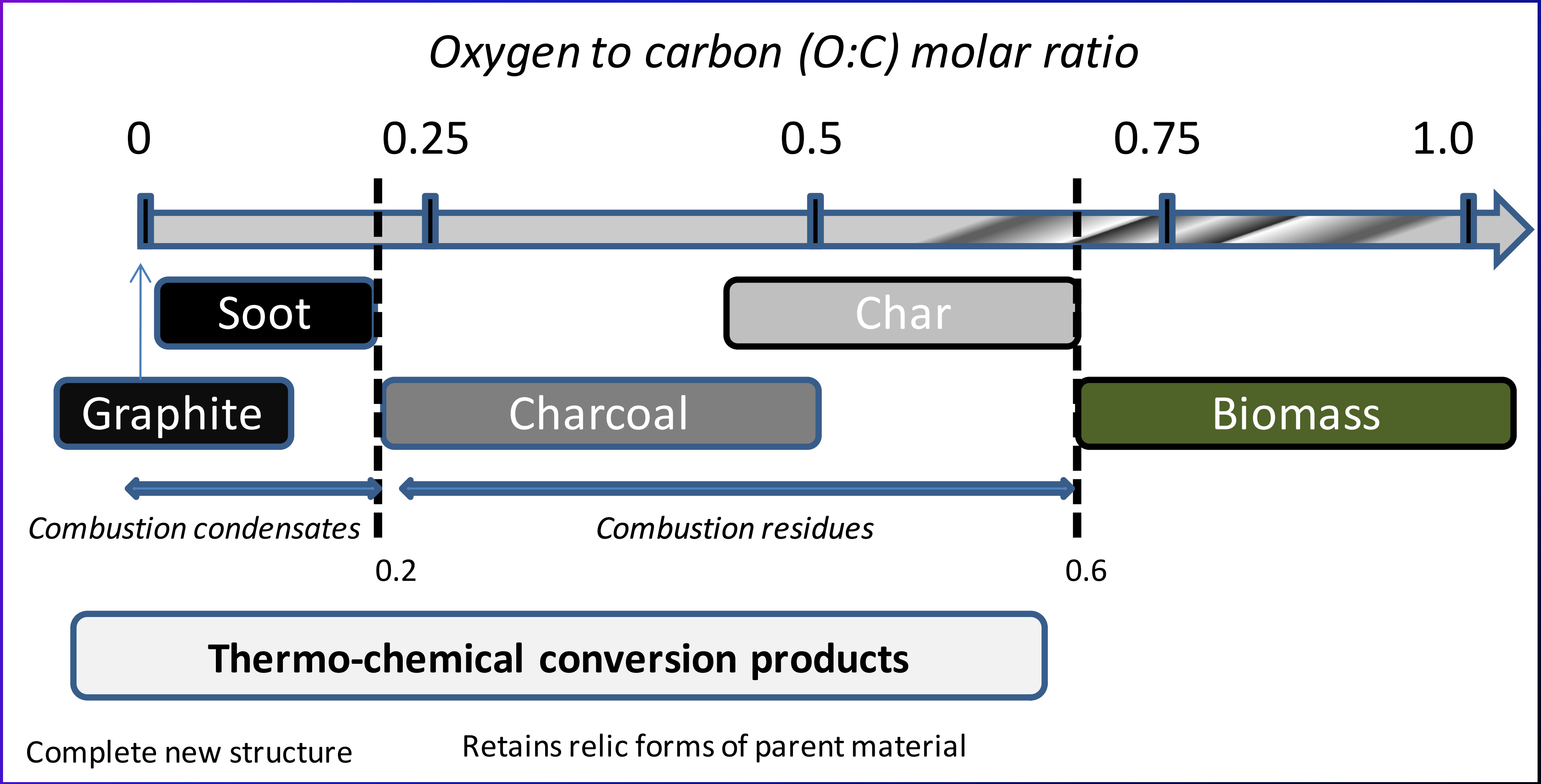


Charcoal production
(15th century)

Climate Change Mitigation
(1980's)

Biochar: Black Carbon Continuum

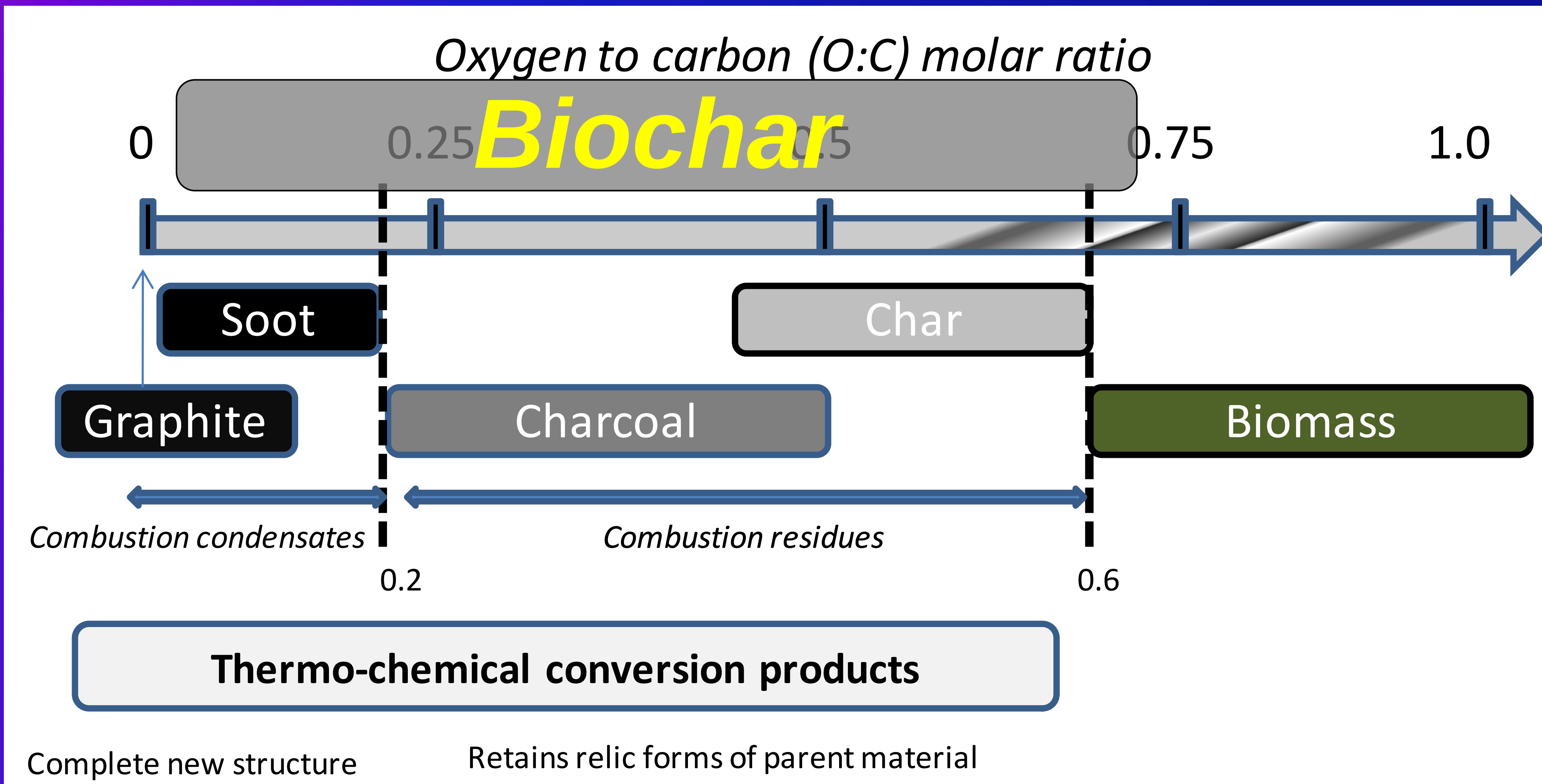
Problem → Lack of nomenclature uniformity (Jones et al., 1997)



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

Biochar Stability: C-Sequestration ?

- 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)
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
Middelburg et al. (1999)	10,000 to 20,000
Steinbeiss et al. (2009)	<30
Swift (2001)	1,000-10,000
Zimmerman (2010)	100's to >10,000

Possible Stability Explanation → O:C Ratio

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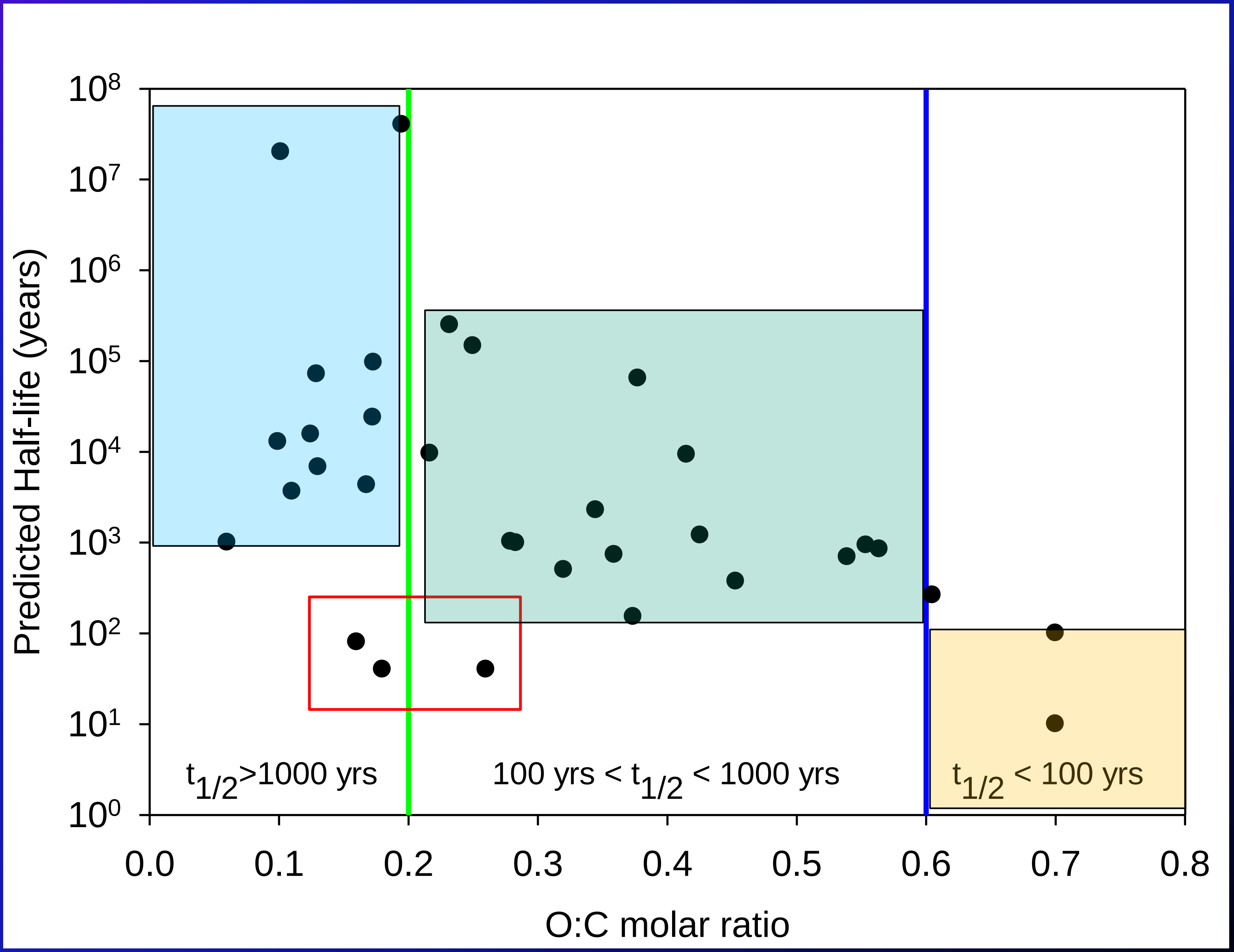
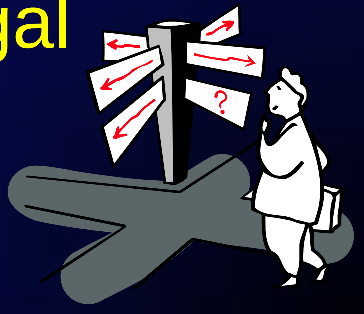


Summary of existing literature studies (n=35) on half-life estimation of biochar [Figure from Spokas (2010)]

Proposed Biochar Mechanisms

Warnock et al (2007)

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



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

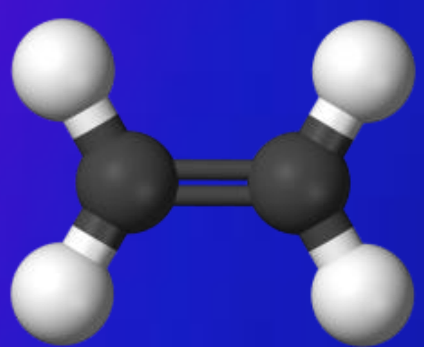
- 44 different biochars evaluated
- 11 different biomass parent materials
  - Hardwood, softwood, corn stover, corn cob, macadamia nut, peanut shell, sawdust, algae, coconut shell, turkey manure, distillers grain
- Represents a cross-sectional sampling of available “biochars”
  - C content 1 to 84 %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

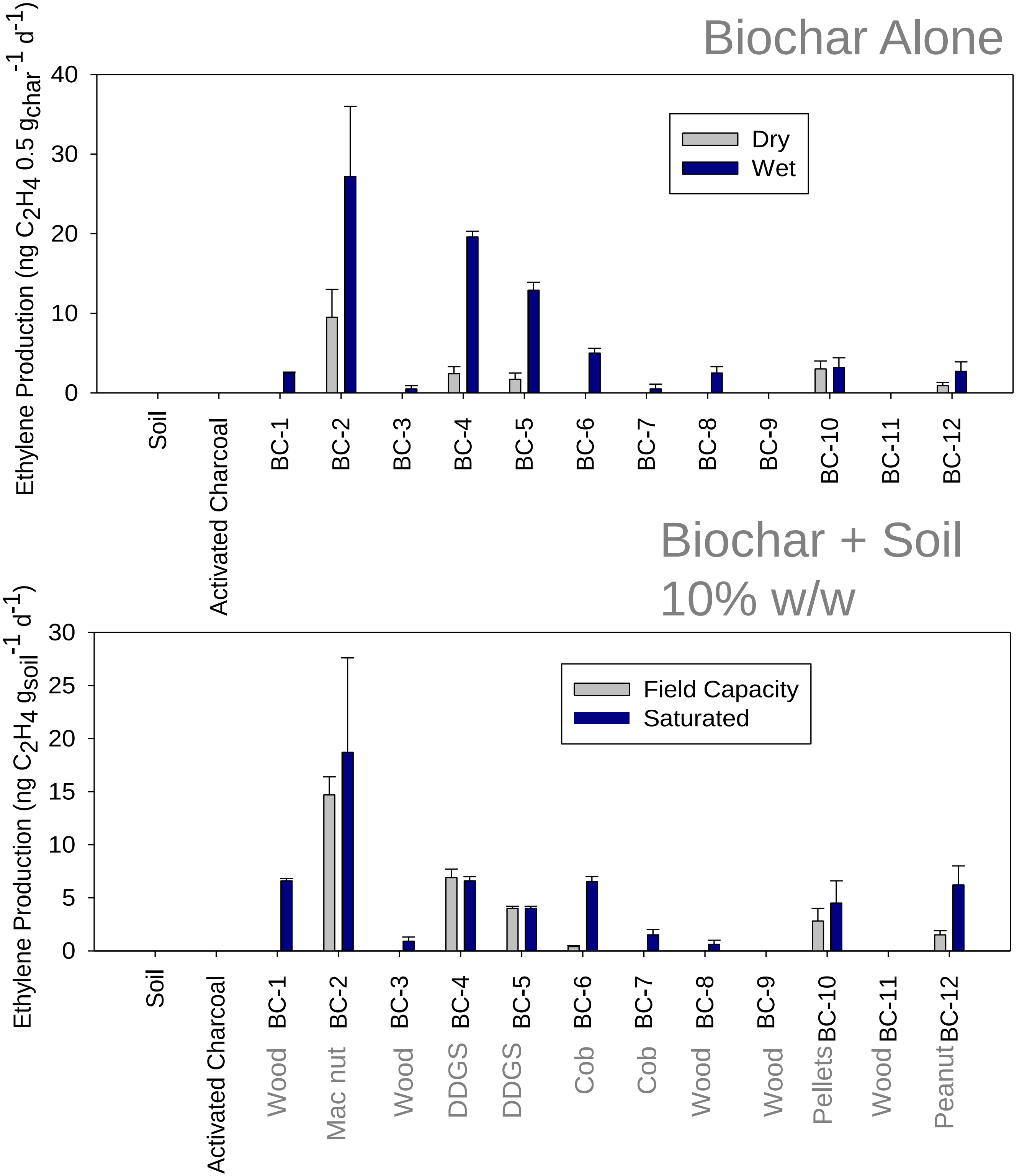
Laboratory Biochar Incubations

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

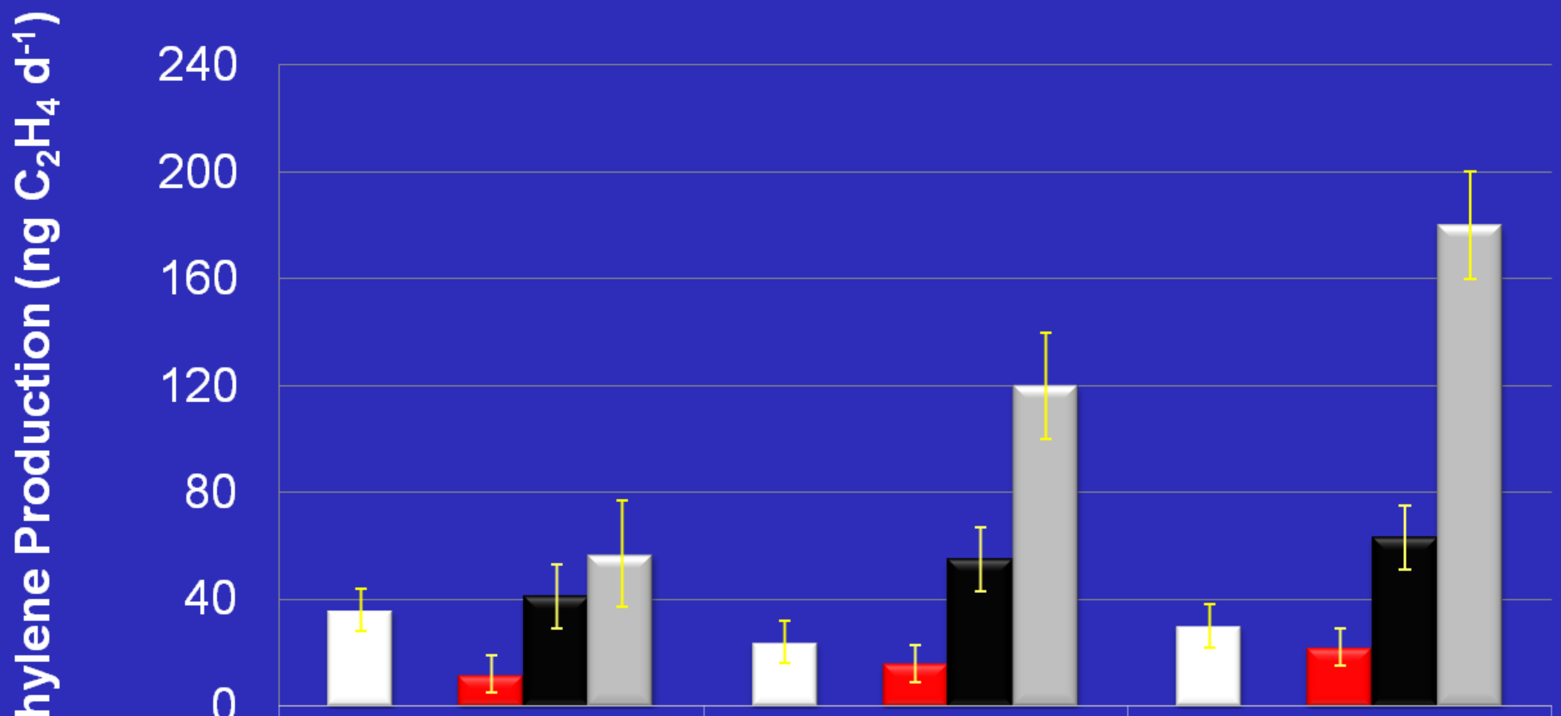
  - Mason Jar (soil + biochar/isolated)
    - Looking at impact of biochar without mixing with soil

Ethylene Production Rates





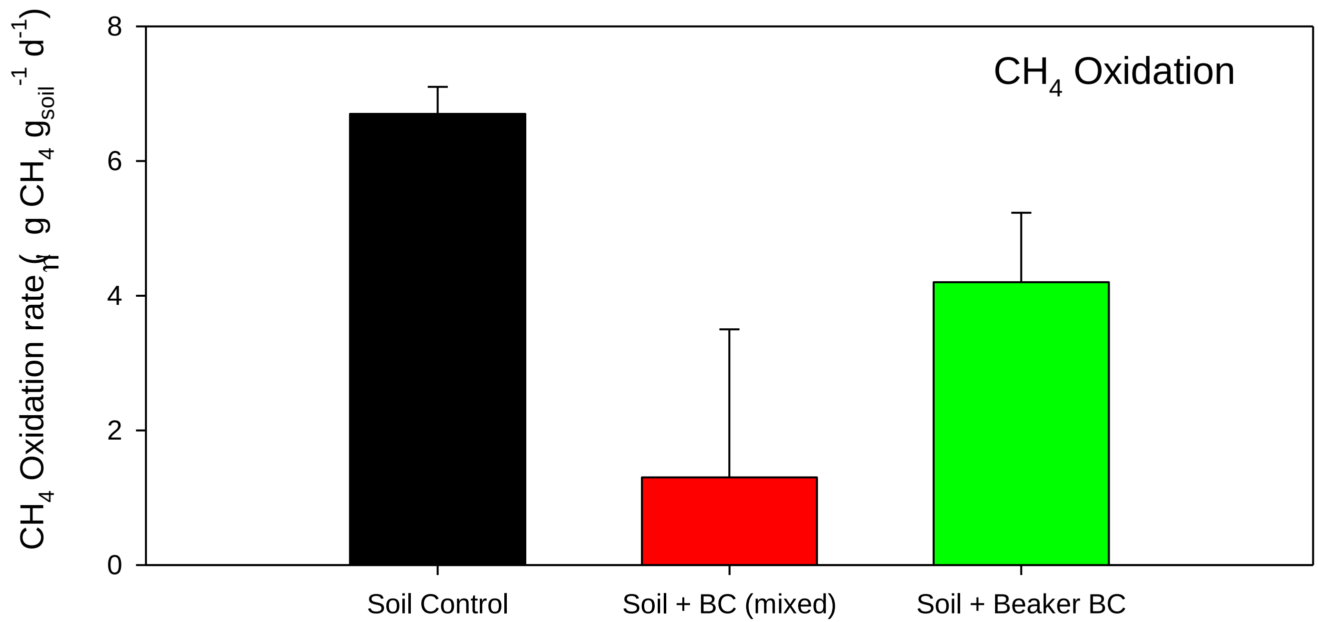
Oxygen and Soil Sterilization Impacts

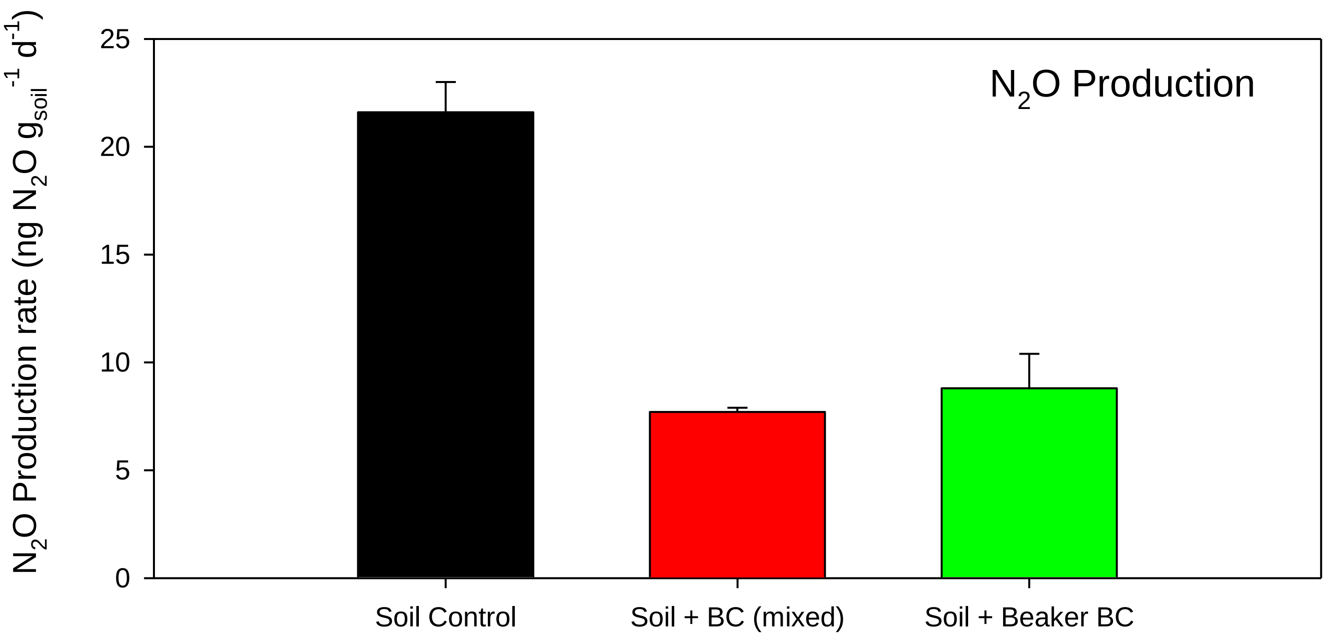


	0% Oxygen	20% Oxygen	40% Oxygen
Biochar Alone	36	24	30
Non-Sterile Soil	0	0	0
Sterile Soil	12	16	22
Biochar+ Sterilized Soil	41	55	63
Biochar+Non-sterilized Soil	57	120	180

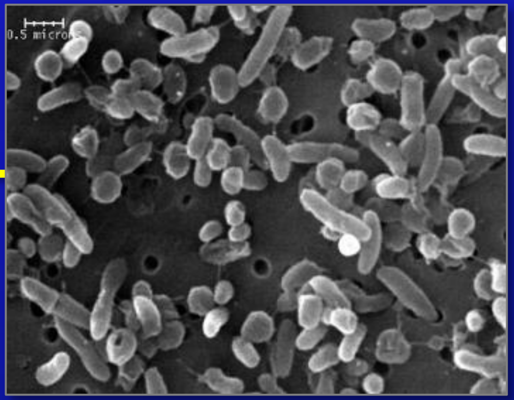
Macadamia nut biochar presented above

Biochar isolated or mixed with soil





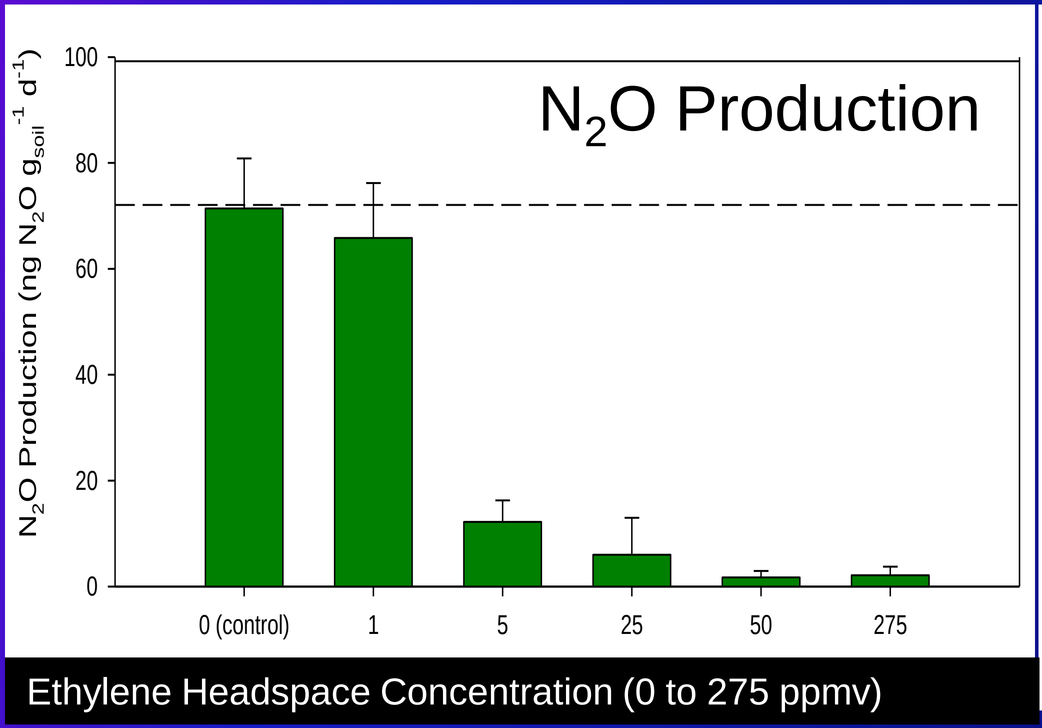
Ethylene Impacts

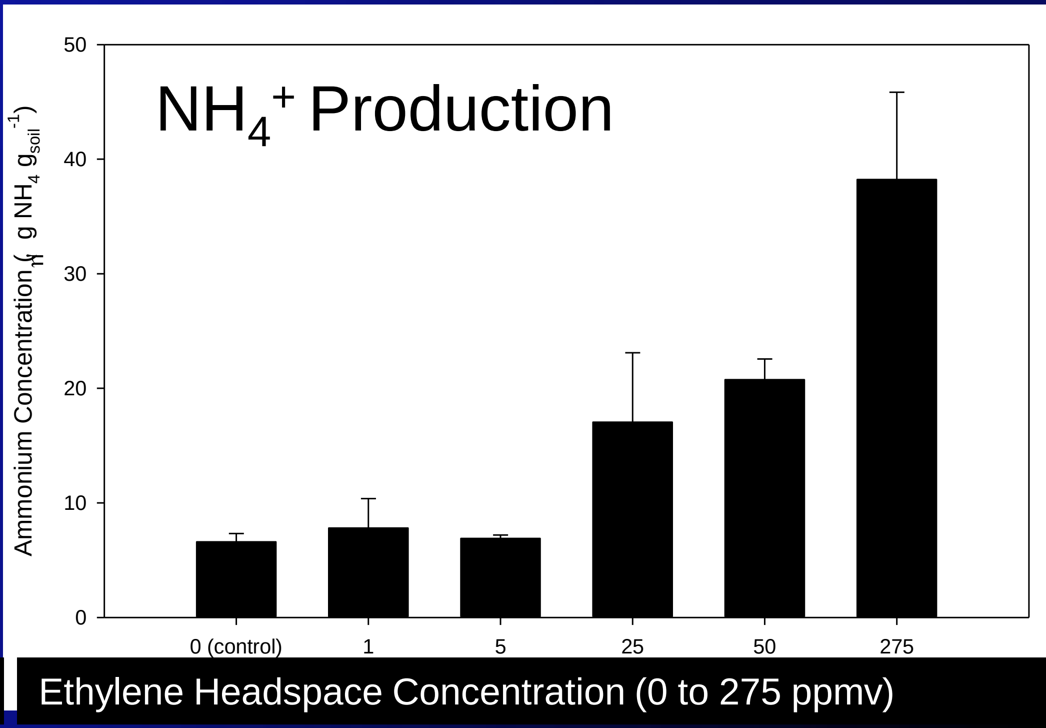


Soil Microbial Impacts

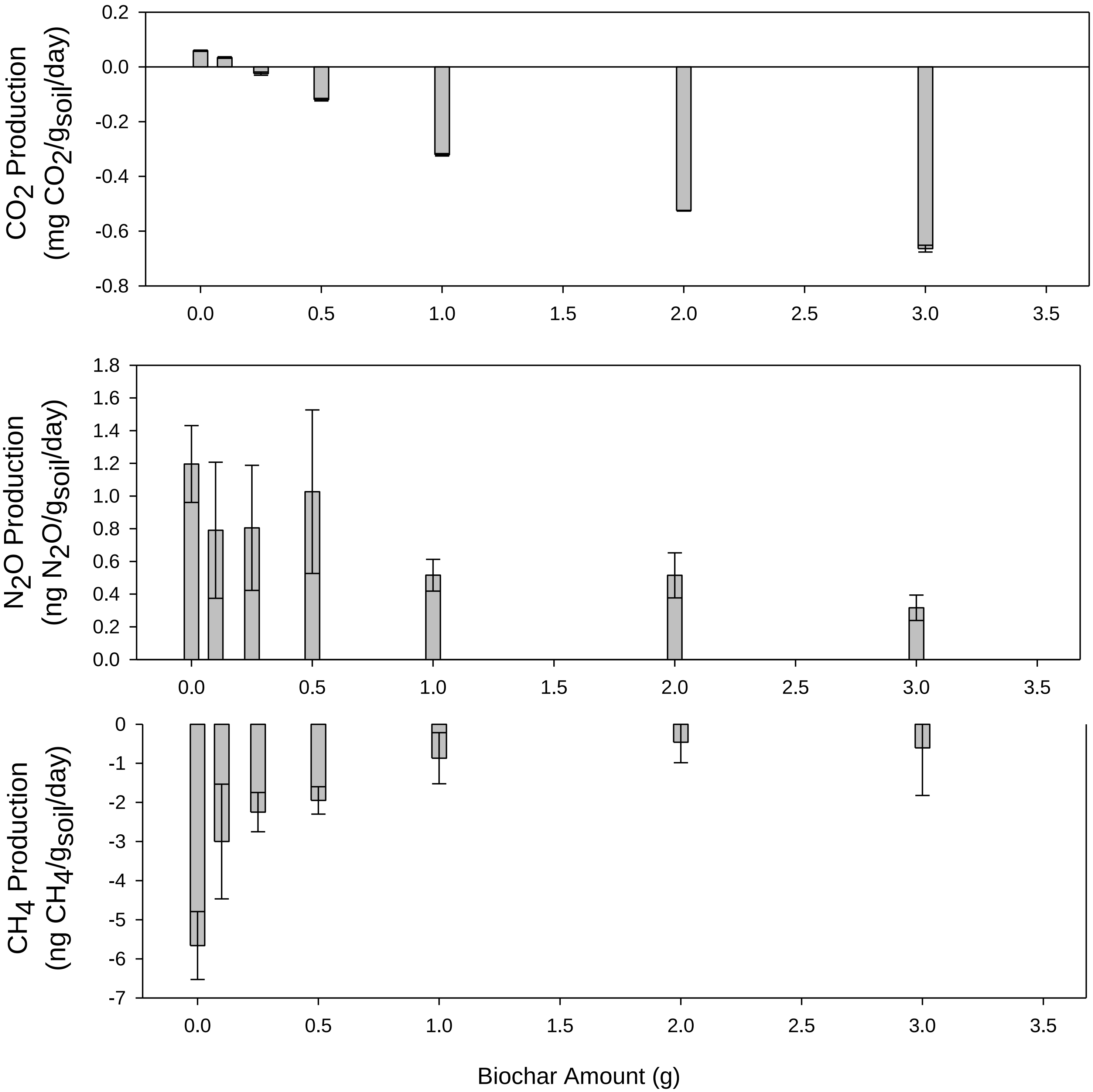
- ✓Induces fungal spore germination
- ✓Inhibits/reduces rates of nitrification/denitrification
- ✓Inhibits CH_4 oxidation (methanotrophs)
- ✓Involved in the flooded soil feedback

  Both microbial and plant (adventitious root growth)



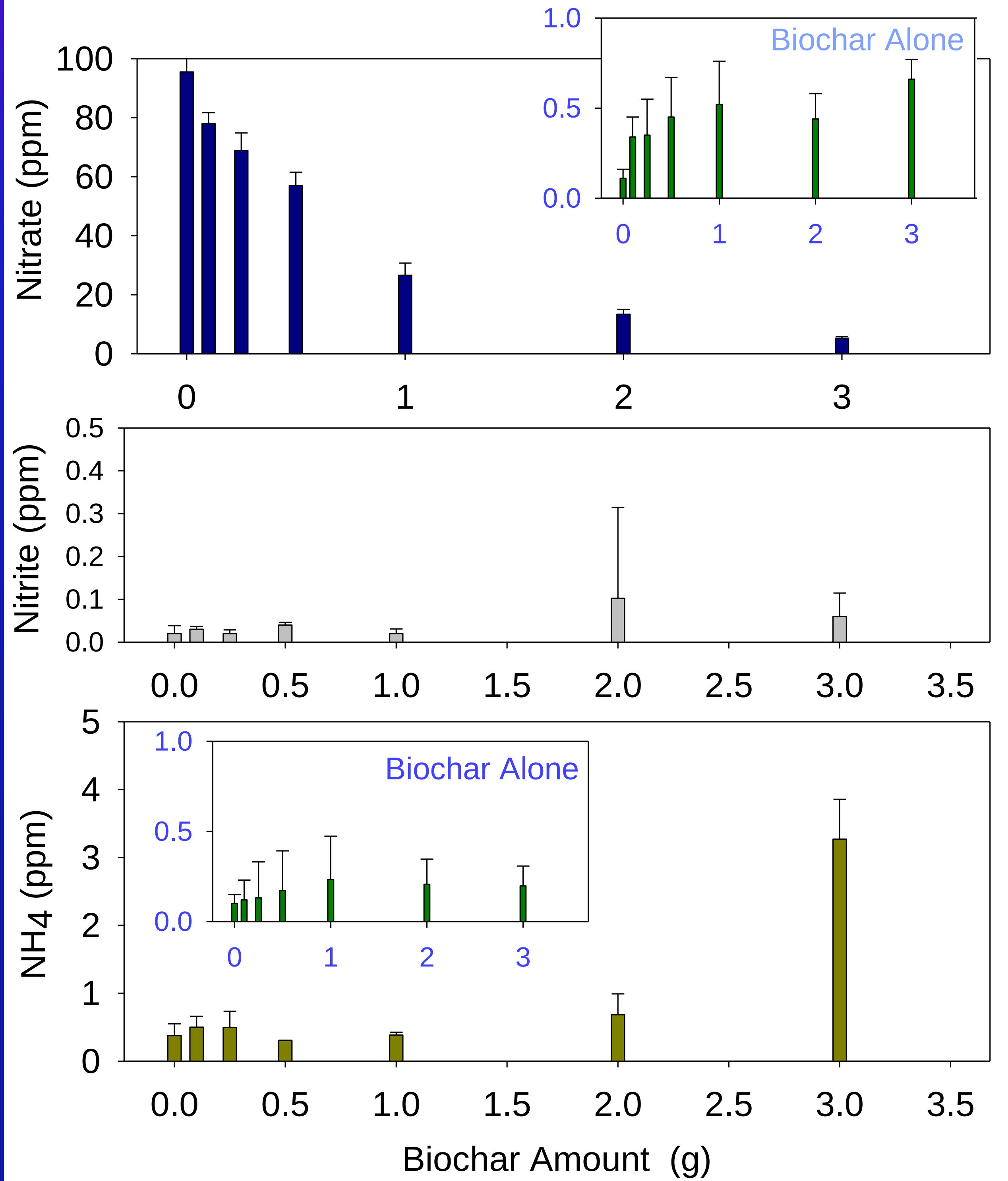


Influence of biochar addition on GHG Production

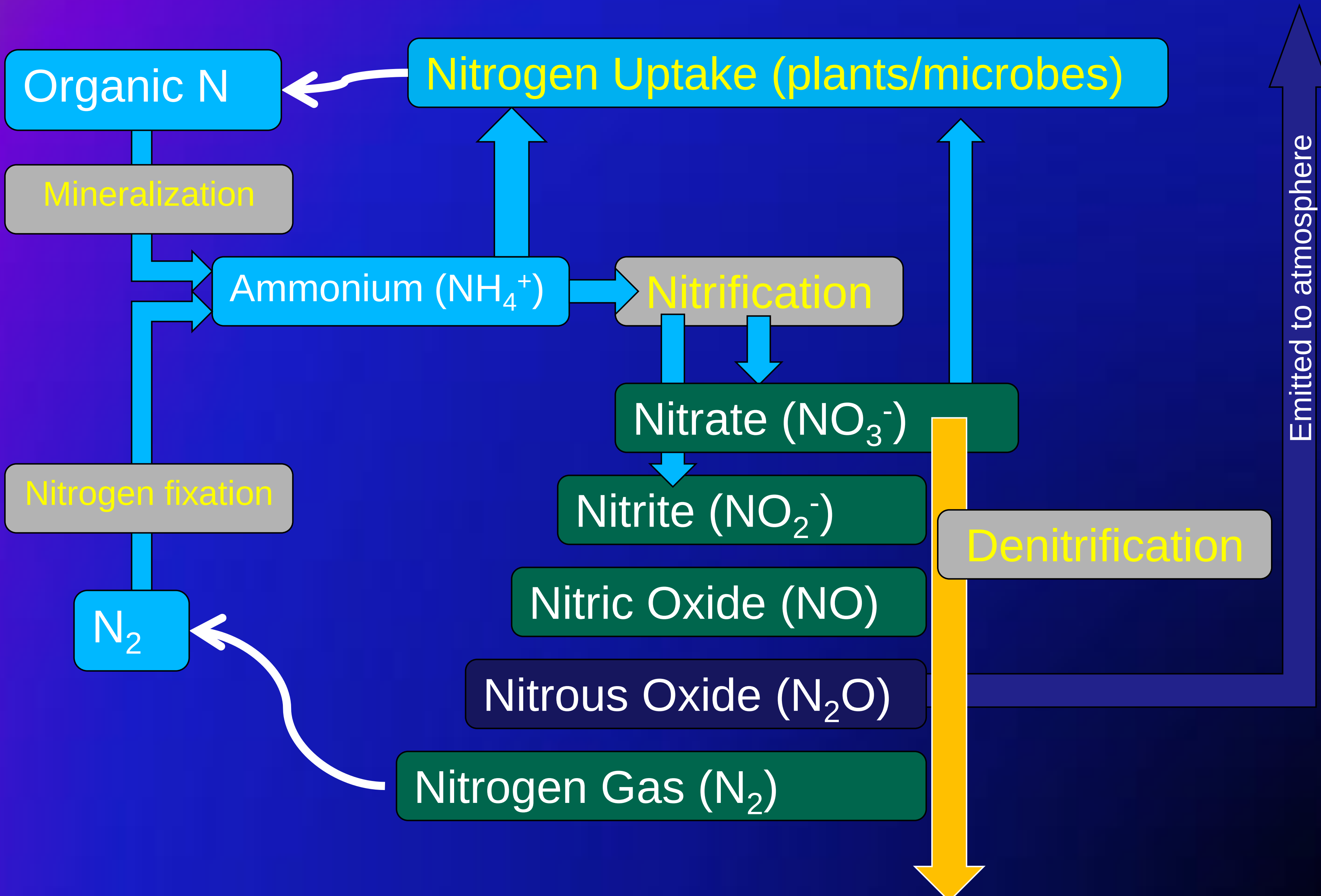


Closer look at N-cycling

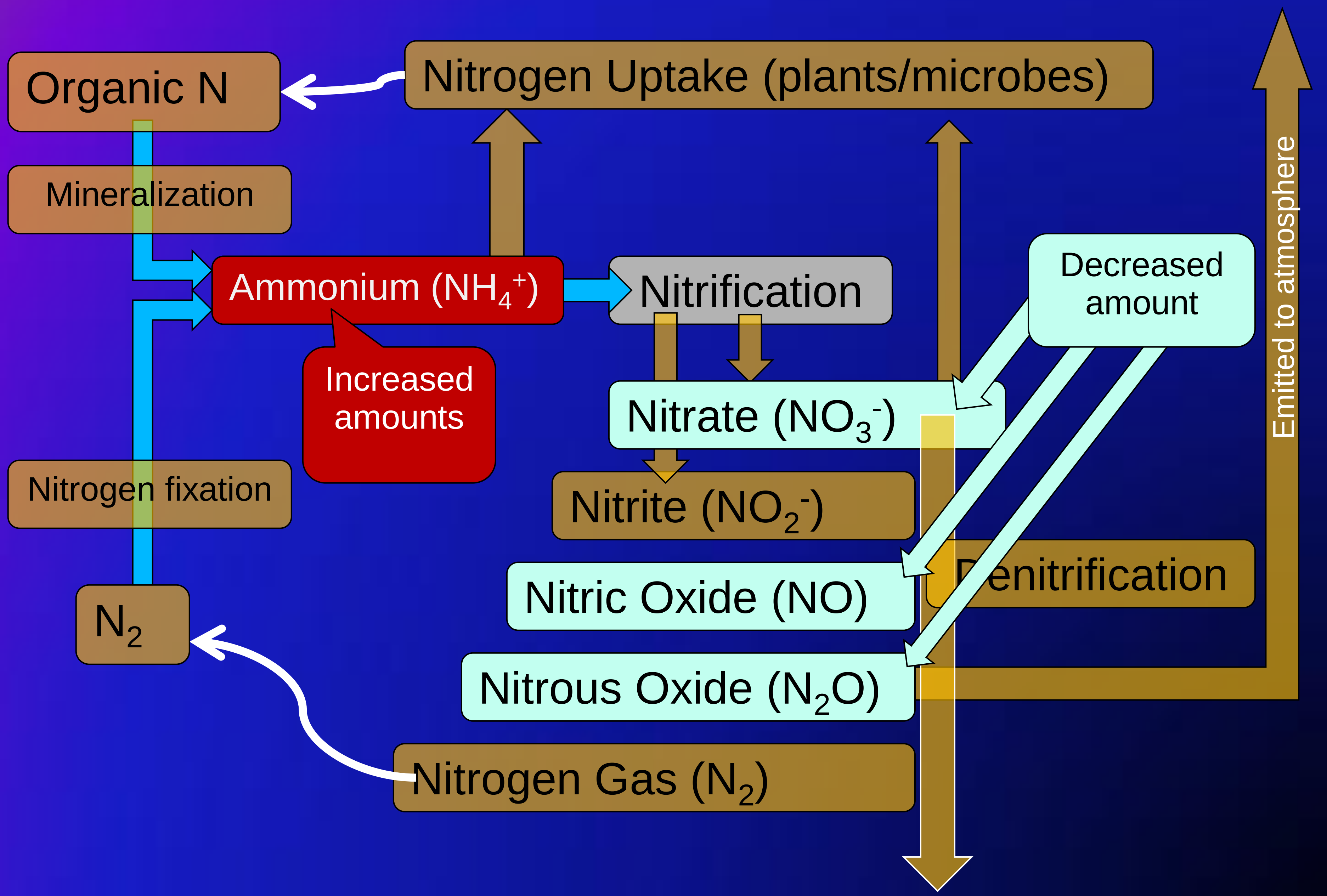
(hardwood sawdust biochar)



Brief Overview of N-cycle



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

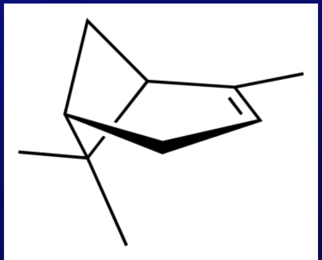


Ethylene Production

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

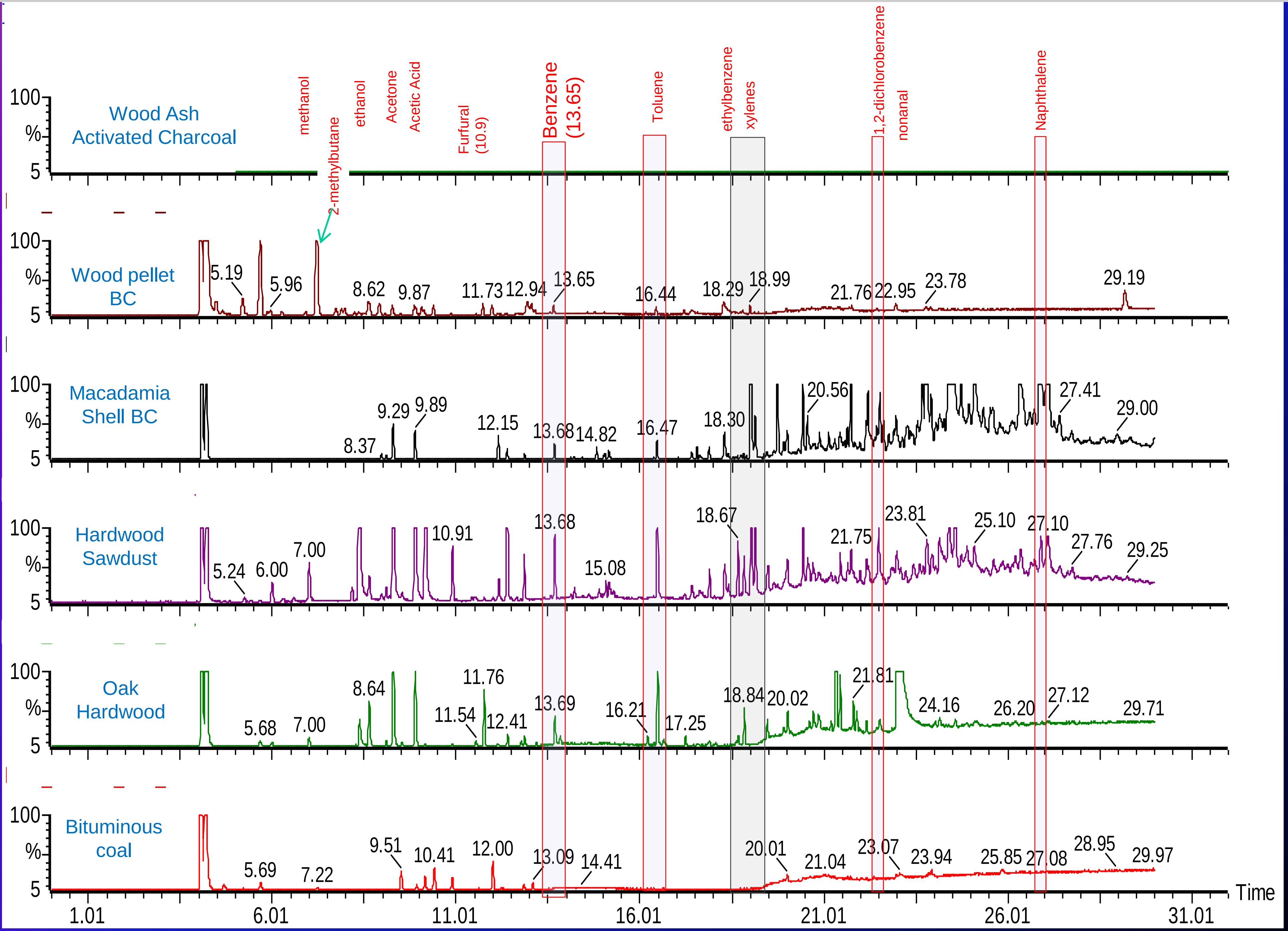
•Clough et al. (2010) also hypothesized that α-pinene could be involved as a nitrification inhibitor

- α-pinene observed as volatile from vegetation
- involved in insects' chemical communication system



•Despite the different chemicals – Same hypothesis: Chemical inhibitors behind the suppression of N_2O production

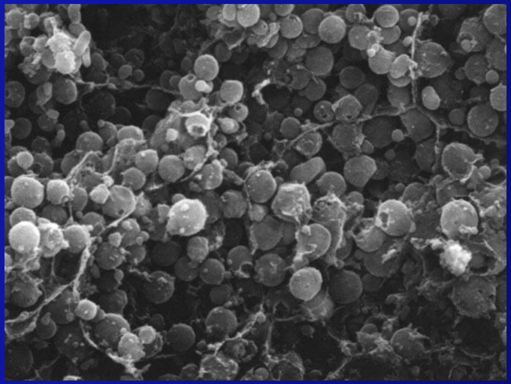
Headspace Thermal Desorption GC/MS scans of biochars



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:
  - Reduced basal CO_2 respiration
  - Reduced CH_4 oxidation activity
  - Reduced N_2O production activity
  - Reduced NO_3 production (availability)
  - Increased extractable NH_4 concentrations
  - Exceptions DO EXIST

Acknowledgements

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

Best Energies

Slow pyrolysis char through a non-funded CRADA agreement

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Biochar Brokers

Chip Energy

AECOM

USDA-ARS Biochar and Pyrolysis Initiative

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"The Nation that destroys its soil destroys itself"

Franklin D. Roosevelt