Impacts of biochar additions on soil microbial processes and nitrogen cycling

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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:

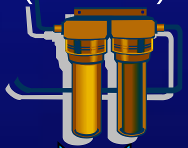
- Conversion of biomass to liquids (bio-oils) or gaseous fuels and/or fuel intermediates
- Solid byproduct (biochar) has long been considered a "*undesirable side product*"

(Titirici et al., 2007)

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

Used as fuel
(3000-4000 BC)

Water filtration
(2000 BC)



Charcoal production
(15th century)

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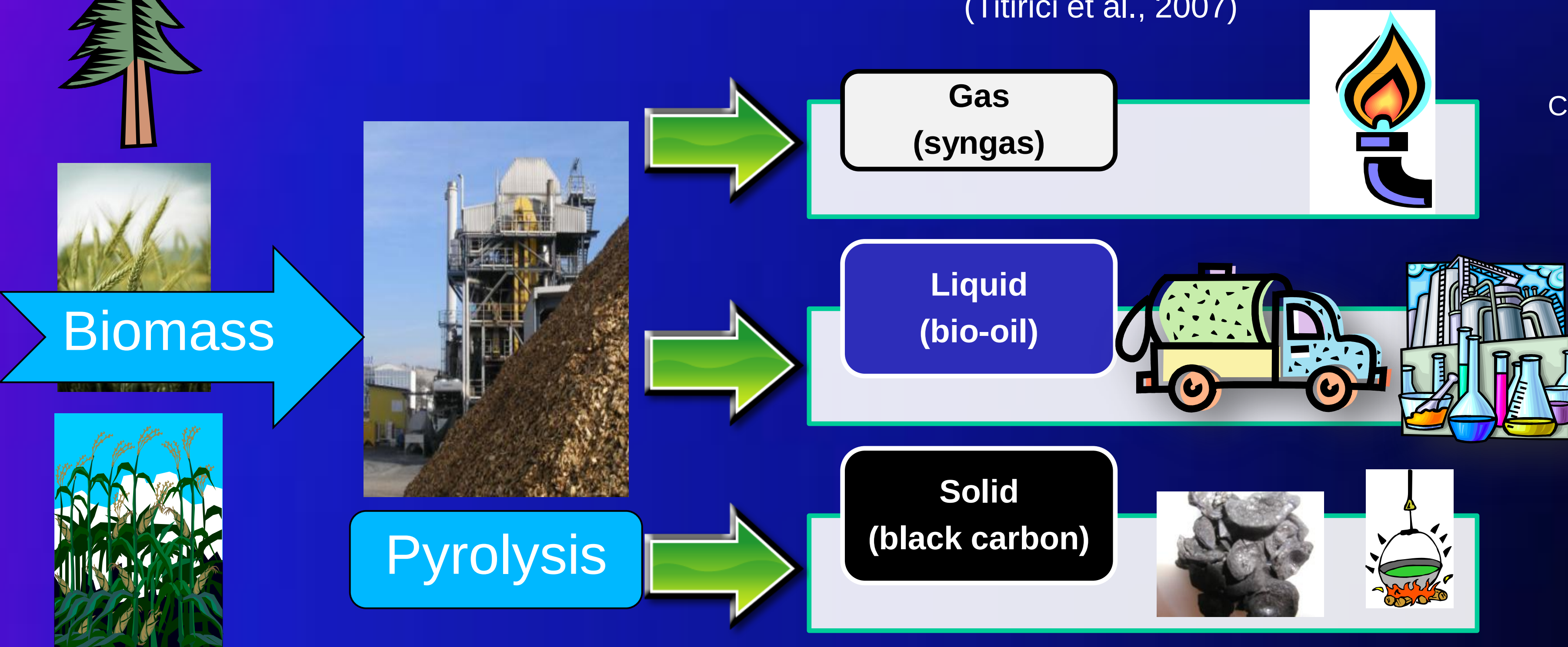

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- <u>What is new</u>

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

- <u>Atmospheric C sequestration</u>

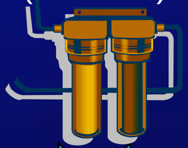
Dates to 1980's and early 2000's

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

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

Used as fuel (3000-4000 BC)

Water filtration (2000 BC)

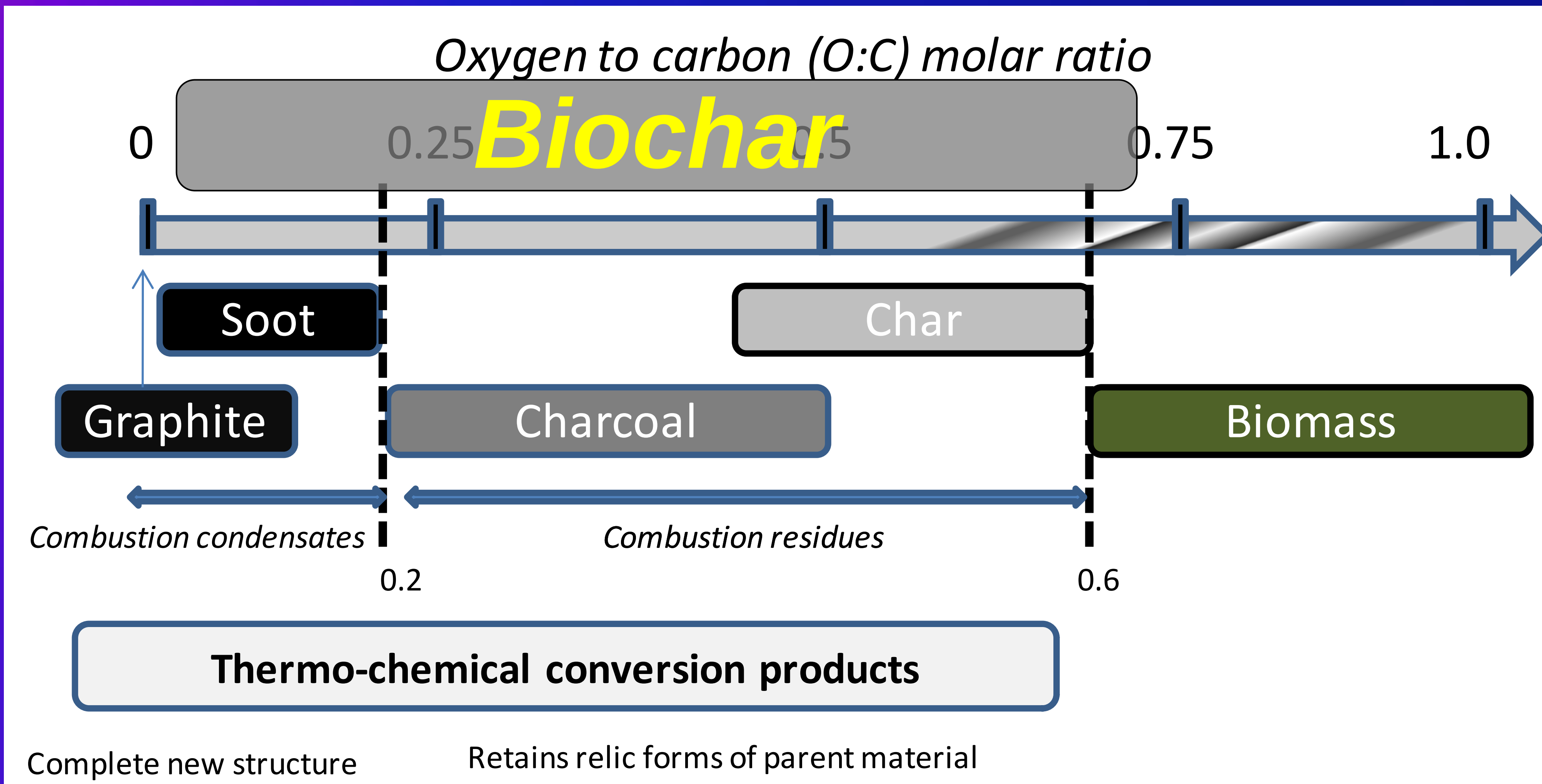


Charcoal production (15^{th} century)

Climate Change Mitigation (1980's)

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: Soil Application

- The assumed target for biochar has been soil application
- Focus has been on “creating” *Terra Preta* soils

Observations of increased soil fertility and productivity.
Postulated from ‘slash and burn’ historic charcoal additions

- Biochar (BC) Hypothesized also involved in humic acid formation

(Haumaier and Zech, 1995)

Biochar: Soil Application

However, on the other side:

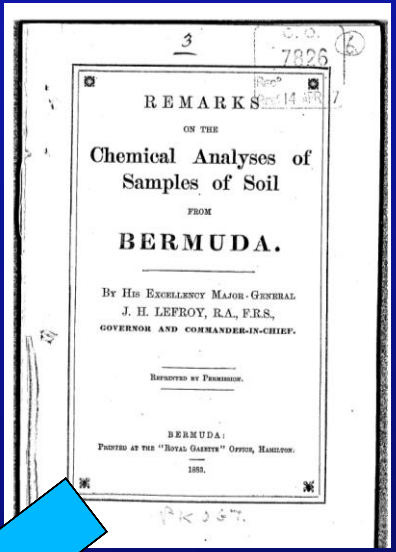
- Wood distillation plants [1800-1950's]
  - Wood pyrolysis – source of chemicals and energy prior to petroleum
  - Some historic plants on US-EPA Superfund site list
- Other charcoal sites
  - Not always productive
    - Reduced seed germination
    - Reduced plant growth

(BEGLINGER AND LOCKE, 1957)

Soil Application… Long History

Applications date back to the beginning of modern science [1800's]:

Ashes (see also *Potash*) "constitute an important class of manures, differing, however, in their effects according to the substance which has undergone the process of burning, and the manner in which the process has been accomplished. The ashes of all vegetable substances consist principally of those substances which plants require, as charcoal, lime, phosphoric acid, and alkaline salts. Of these charcoal or carbon is the most valuable, and hence to secure it in the greatest quantity the process of burning should be carried on as slowly as possible, and this is best effected by covering up the mass while burning and admitting no more air than just sufficient to keep up a smouldering fire. The ashes of all vegetables contain almost the same constituent parts, and are found useful in all soils and to the majority of crops. They should always be applied when newly burned, as they lose much of their value by keeping even although kept under cover. A medium quantity of ashes may be taken as 1 lb. weight to the square yard."* Coal ashes finely screened are also useful as manure, but less so than wood ashes. The ashes of sea weed, known in England as kelp, contain carbonate of soda and salts of potash, and are much used



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REMARKS

ON THE

Chemical Analyses of Samples of Soil

FROM

BERMUDA.

By His Excellency Major-General J. H. LEFROY, R.A., F.R.S., GOVERNOR AND COMMANDER-IN-CHIEF.

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BERMUDA:
Printed at the "Royal Gazette" Office, Hamilton.
1883.

(LeFroy, 1883)

Soil Application… Long History

Applications date back to the beginning of modern science [1800's]:

And even earlier…

Fire pits built on soil…

Ancient Egyptians - pyroligneous acid (bio-oil)

-used for embalming

Soil Application… Long History

- Recent compilation of historical and recent biochar applications:

- 50% positive,
- 30% no effect, and
- 20% negative impacts on growth and/or yield

(Spokas et al., 2011)

- *However, <u>should not</u> be used as a basis for forecasting outcomes → Publication bias*

(Møller and Jennions, 2001)

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

Biochar impacts on Soil Microbes & N Cycling

- 70+ different biochars evaluated
- Various biomass parent materials
  - Hardwood, softwood, corn stover, corn cob, macadamia nut, peanut shell, sawdust, algae, coconut shell, turkey manure, distillers grain,

    chicken feathers, bamboo, coconut shell
- 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,

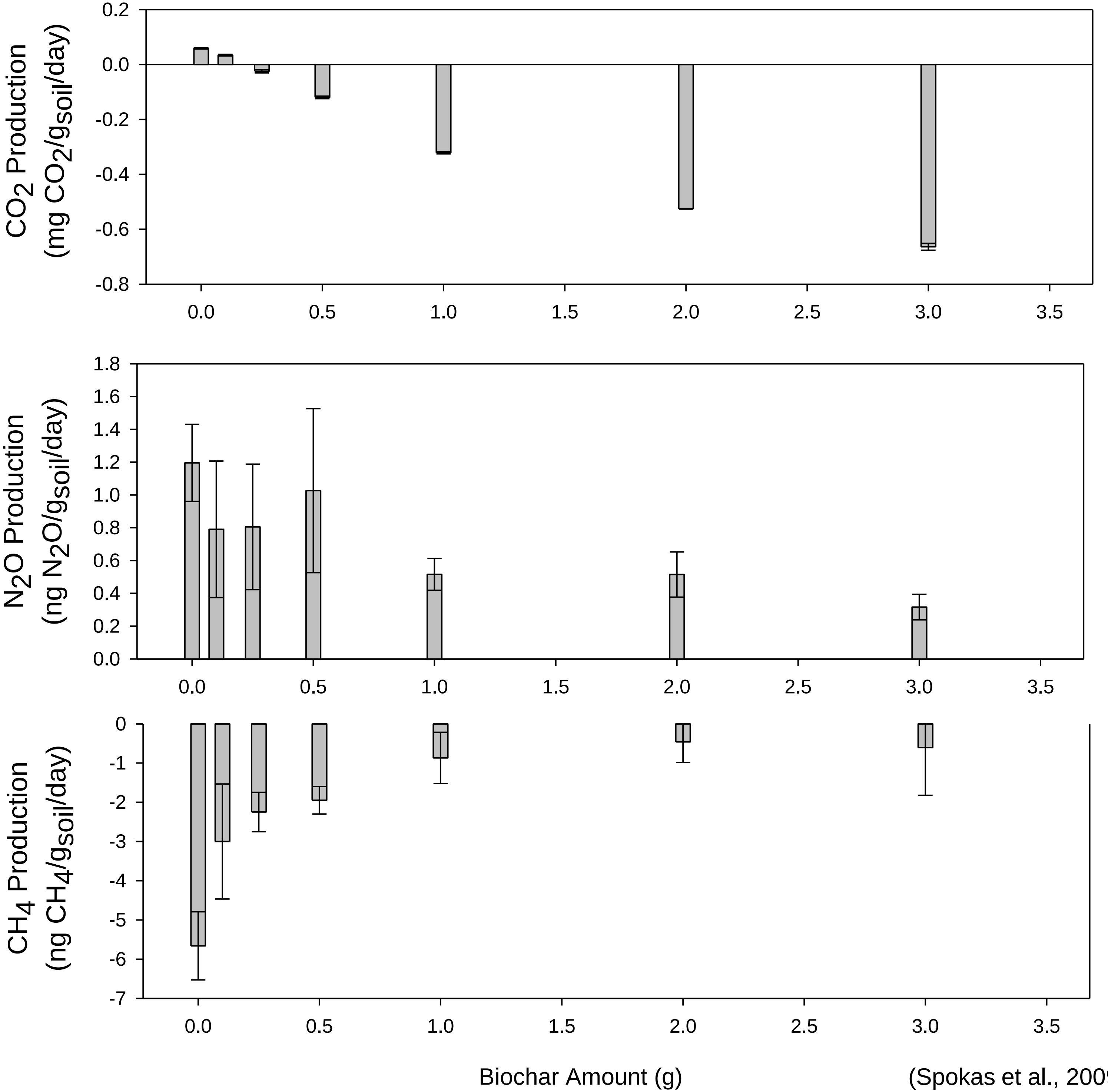
      and microwave assisted pyrolysis.

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

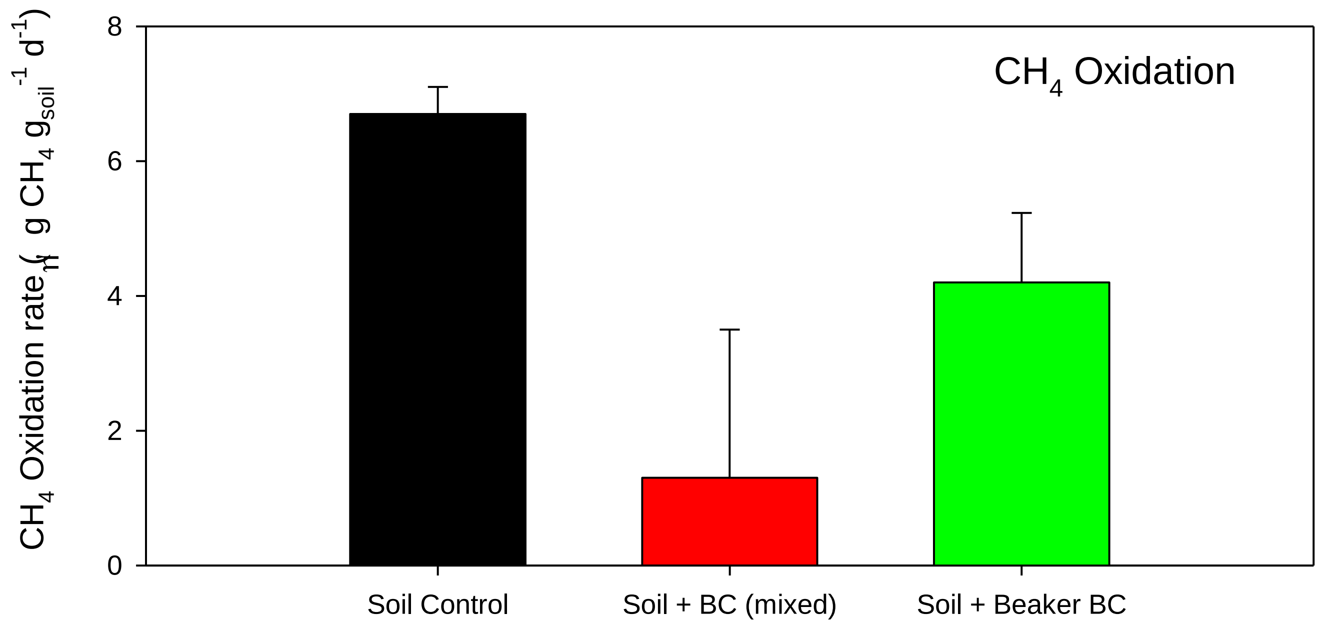
  - Mason Jar (soil + biochar/isolated)
    - Looking at impact of biochar without mixing with soil

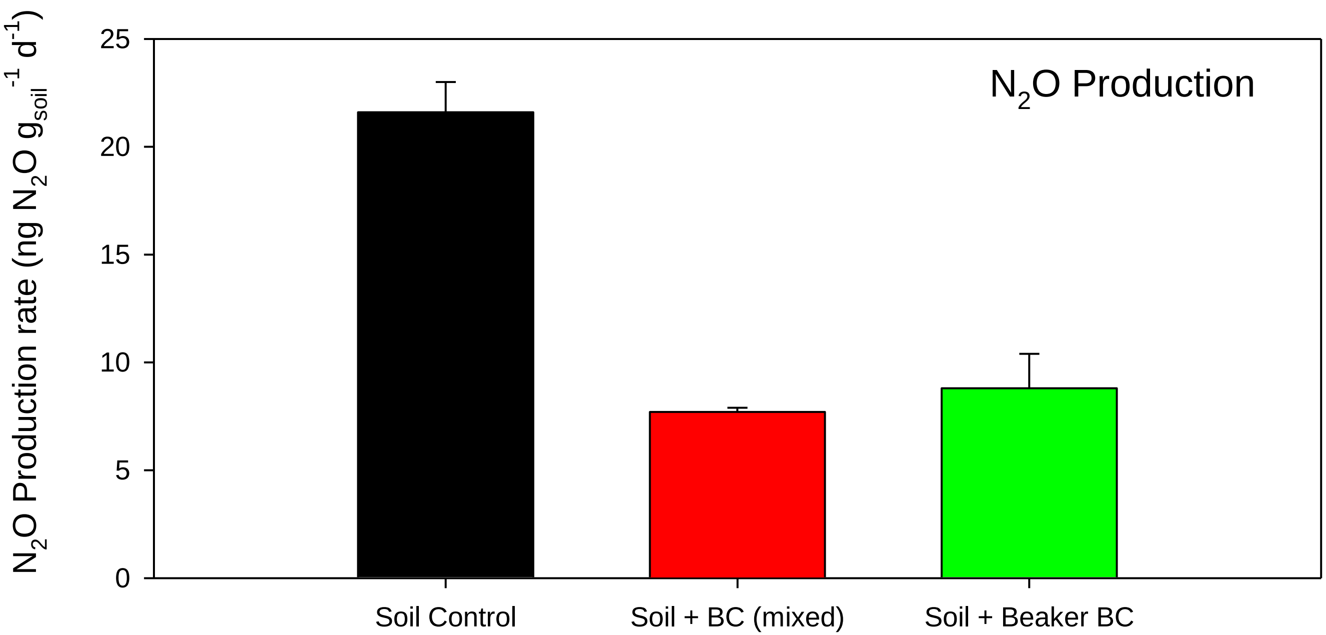
Influence of biochar addition on GHG Production



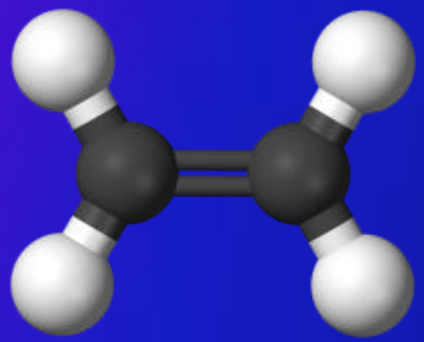
(Spokas et al., 2009)

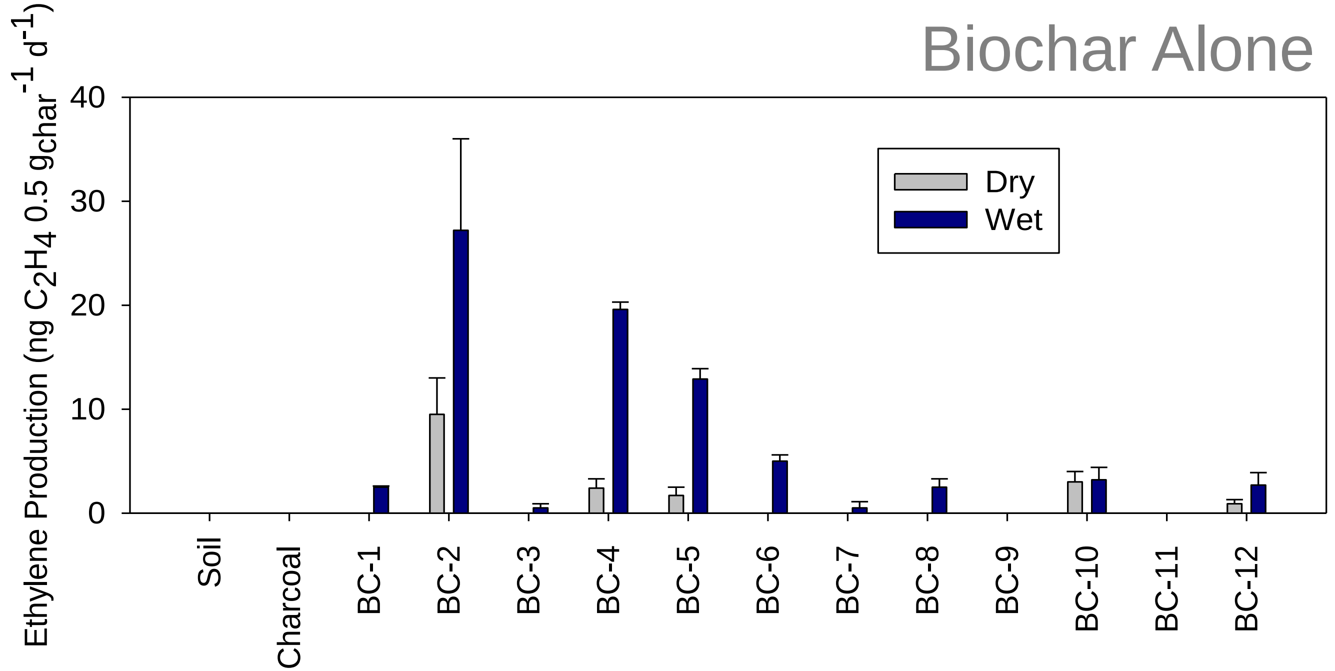
Biochar isolated or mixed with soil

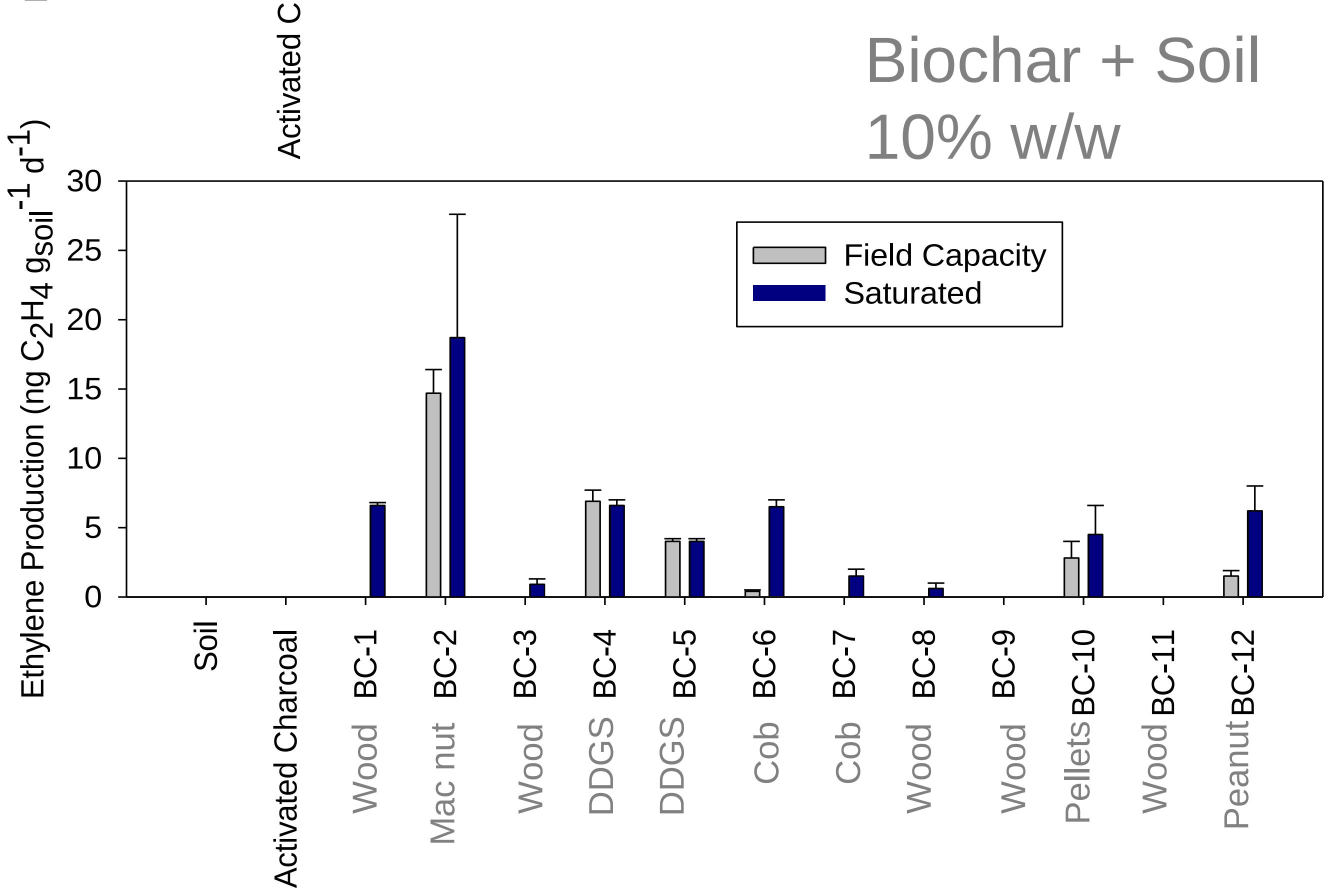




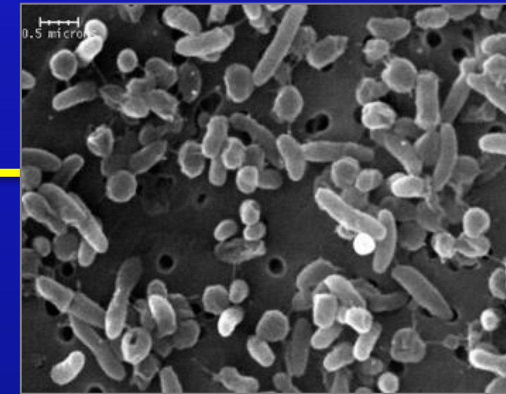
Ethylene Production Rates





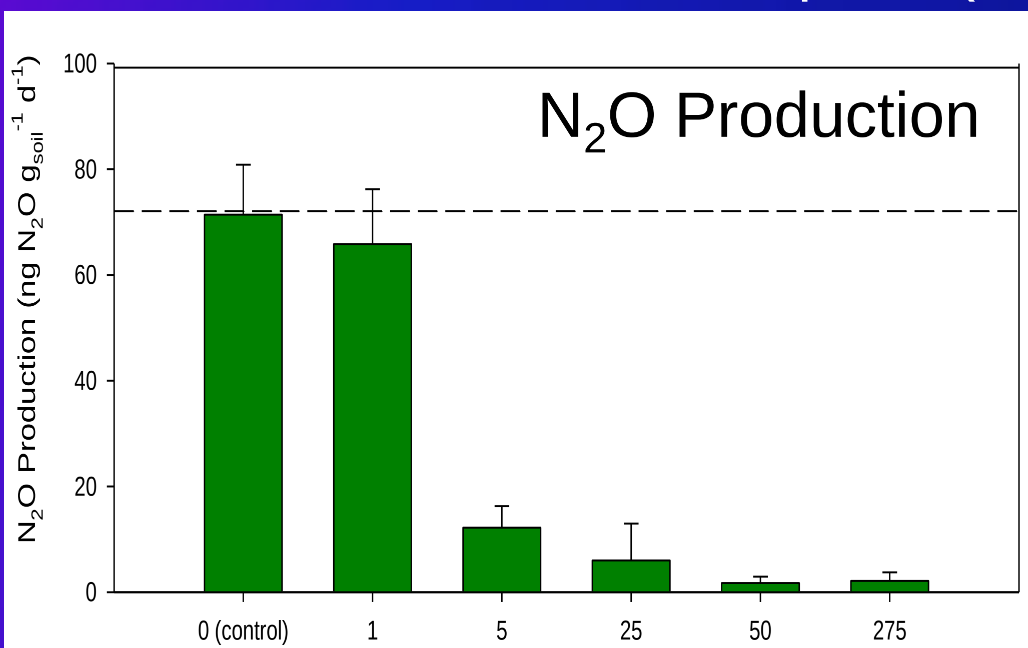


Ethylene Impacts

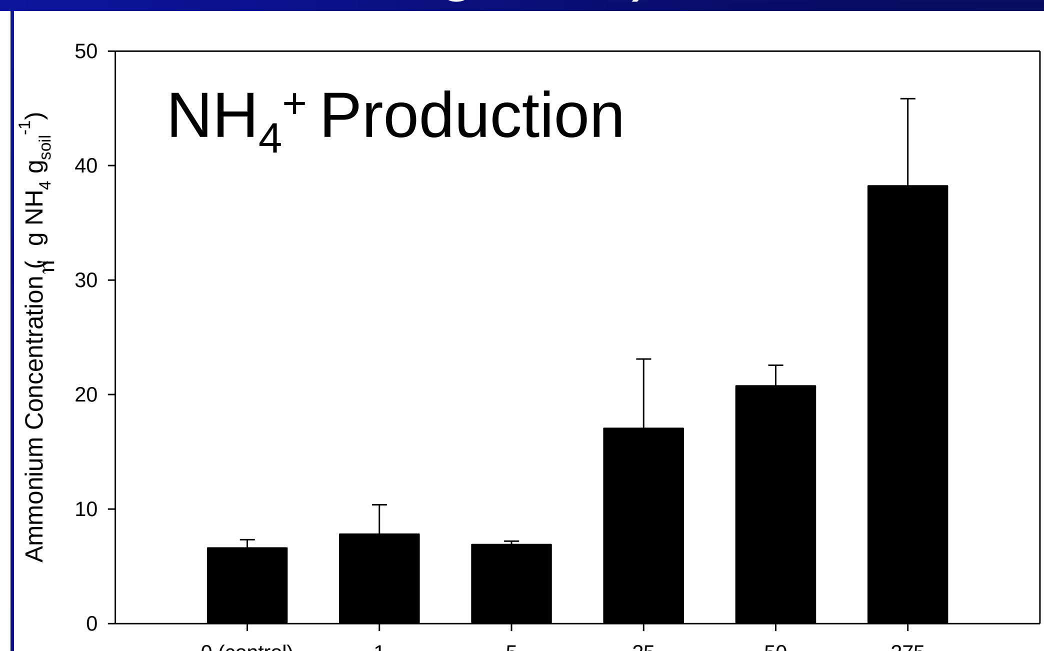


Soil Microbial Impacts

- ✓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)

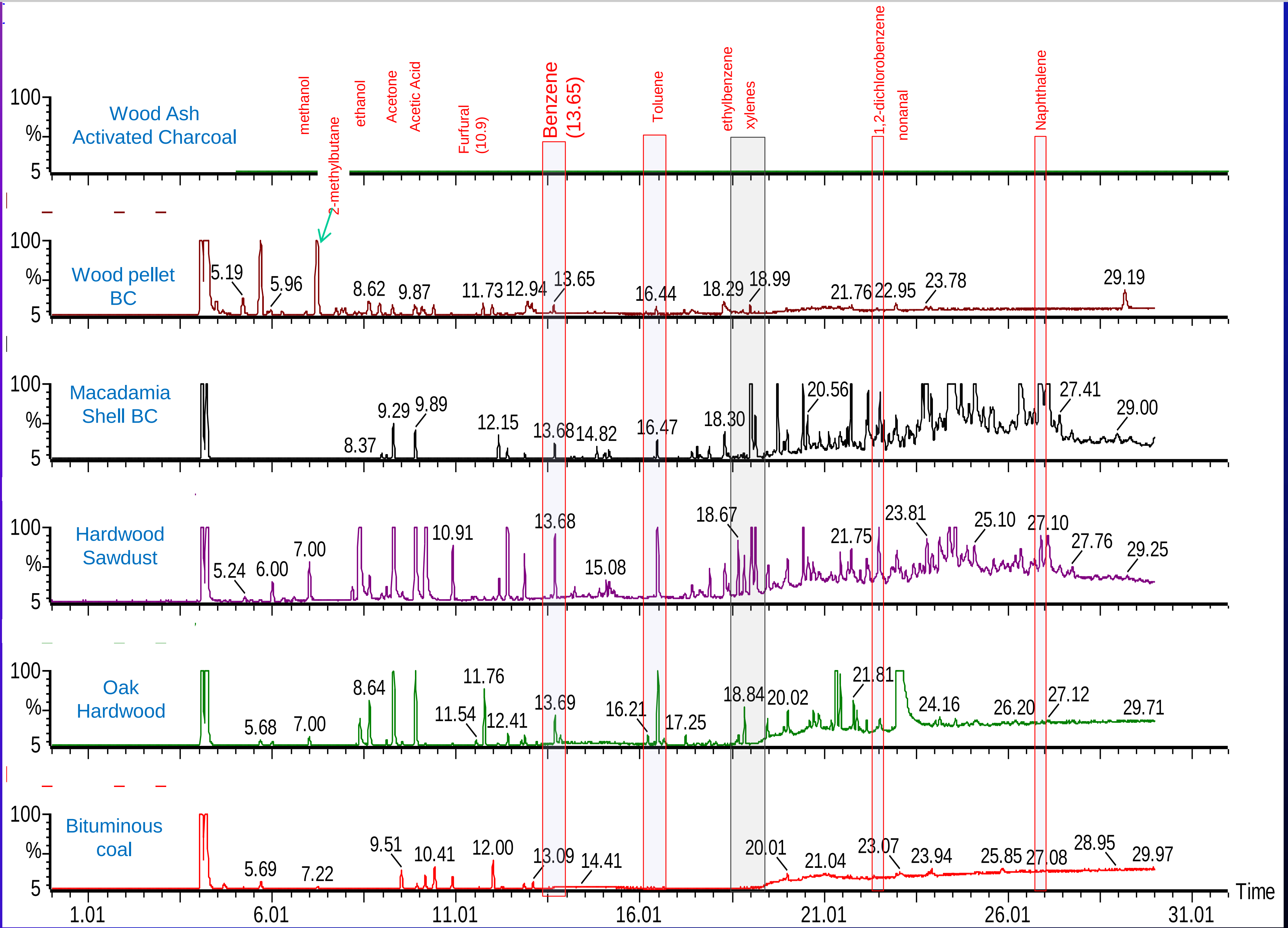


Ethylene Headspace Concentration (0 to 275 ppmv)



Ethylene Headspace Concentration (0 to 275 ppmv)

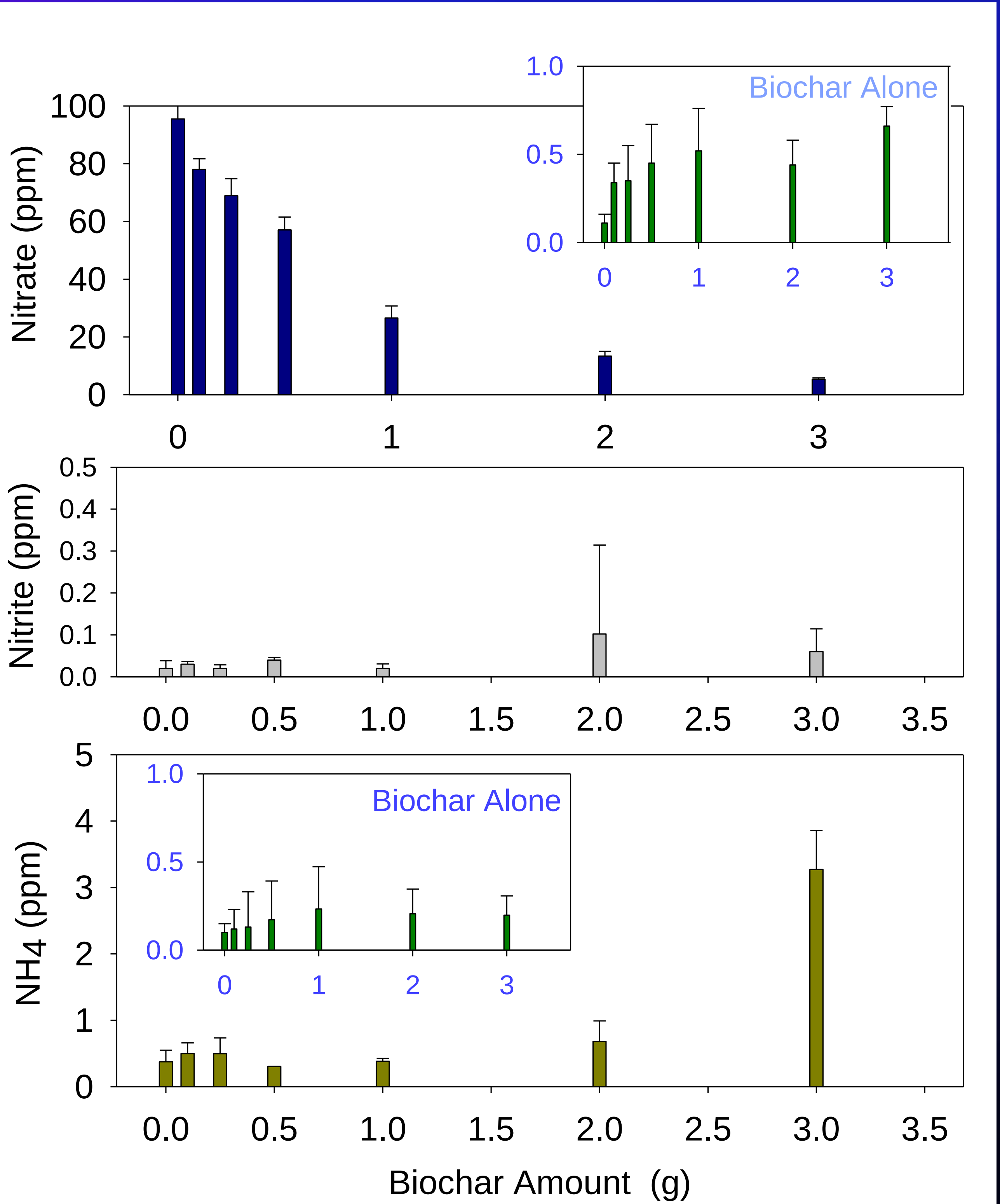
Headspace Thermal Desorption GC/MS scans of biochars



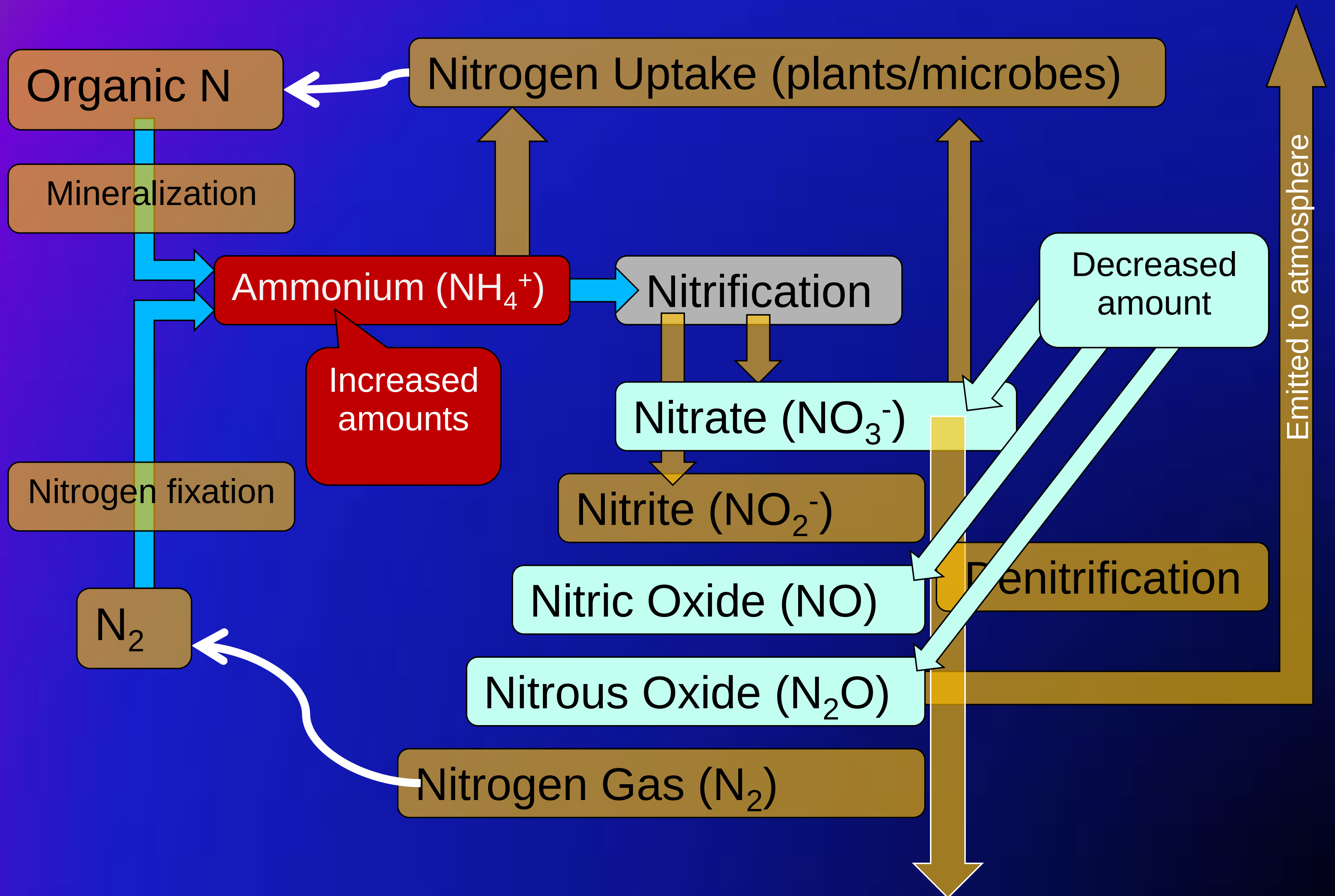
Biochar has a variety of sorbed volatiles = range of potential microbial inhibitors

Closer look at N-cycling

(hardwood sawdust biochar)



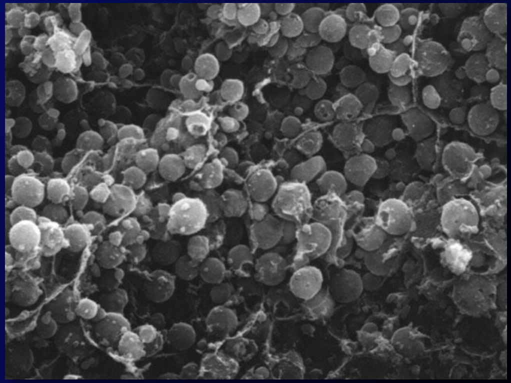
Putting the pieces together: Not quite a full picture yet…



However – no consistent trends

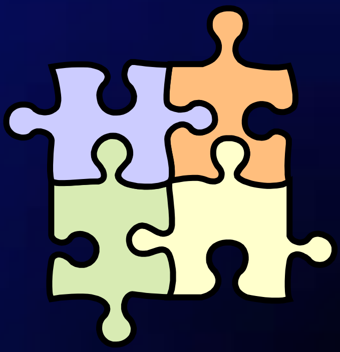
Impact of Biochar Volatiles in Soils

- Sorbed BC volatiles could interfere with microbial signaling (communication): Releasing or sorb signaling compounds
- 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)



Conclusions

- Despite the long research history –
  - No absolute “biochar” consistent trends
    - Highly variable material
      – Production & post-production handling
    - Different responses to biochar
      - Function of soil ecosystem (microbial linkage) & position on black carbon continuum
  - Importance of fully documenting methods of creation, handling, and properties
    - – Allow future elucidation of factors
  - Several inter-related mechanisms



- Biochar does act as a carbon sequestration agent
  - As long as biochar has low O:C ratio (Spokas, 2010)

Conclusions

Economics caused the shift from biomass to fossil fuels in the early 1920's: We at the cusp where environmental stewardship is returning the pendulum back to biomass as the source for human's energy, chemical and agronomic needs

Research is needed to optimize both:

1. Advanced pyrolysis system development for energy and chemical production
2. Subsequent utilization of biochar in a sustainable and environmentally responsible manner

"I have but one lamp by which my feet are guided, and that is the lamp of experience. I know of no way of judging the future but by the past." *(Patrick Henry, 1775)*

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National Council for Air and Stream Improvement (NCASI)

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AECOM

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USDA-ARS Biochar and Pyrolysis Initiative

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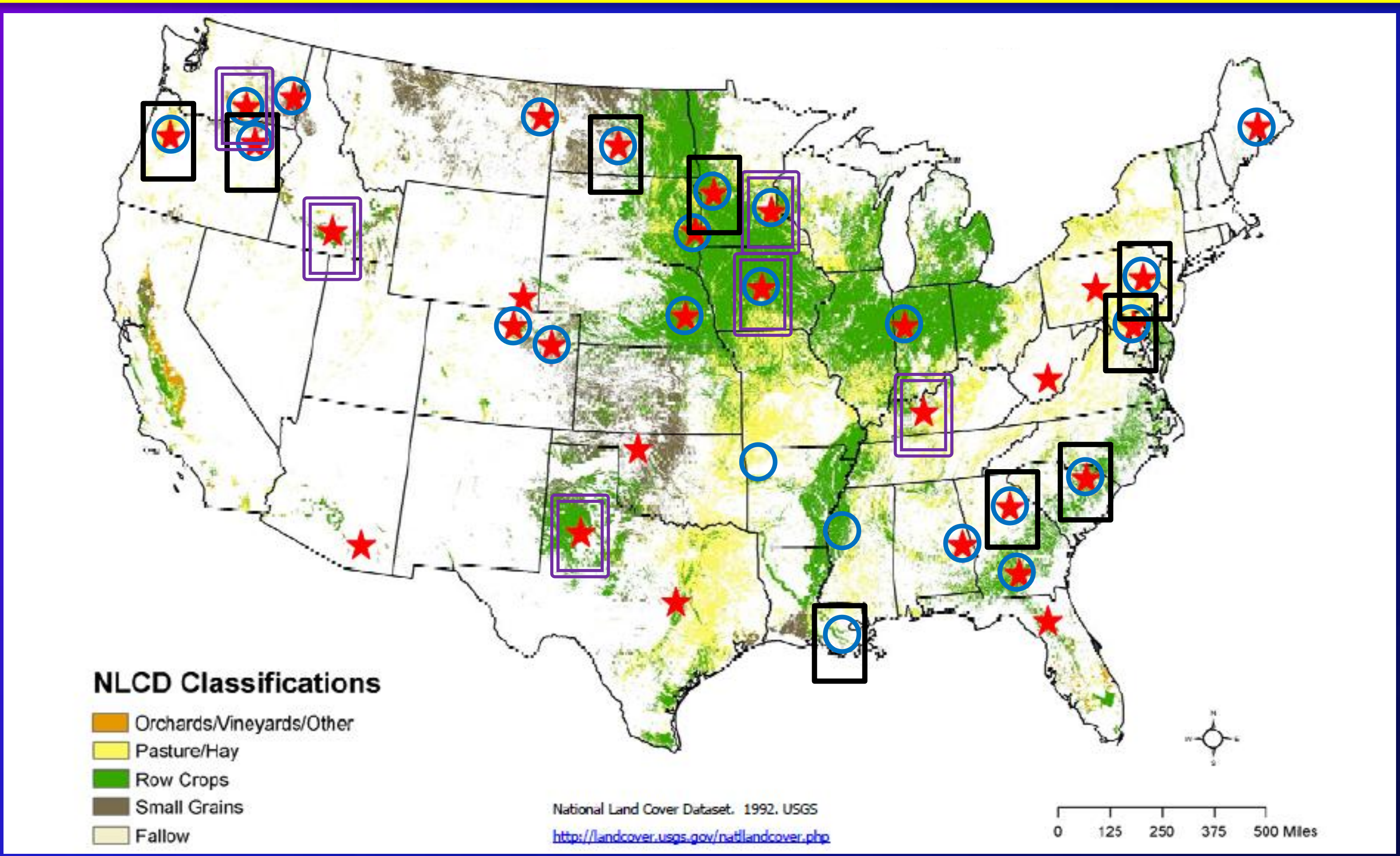
USDA-ARS Biochar and Pyrolysis Initiative



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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