BIOCHAR - Agriculture's Black Gold?

The Promise of BIOCHAR:

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Biochar

- What is Biochar
- How is it Made/Feedstocks
- Physical/Chemical Characteristics
- Effects on soil properties
- Effect on crop growth and Yield
- Other uses


Syngas

Bio-oil



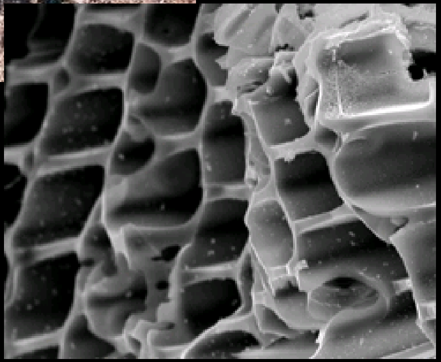
biochar

Biochar

<u>What is Biochar?</u>

- carbon-rich solid - a co-product of pyrolysis of biomass.
- also known as charcoal, biomass derived black carbon, Agrichar, C-Quest™

- formed under complete or partial exclusion of oxygen at temperatures between 700 and 1800 ºF.



- Origins - has been used for centuries
  - Cooking, health, water purification, etc

Active research into soil benefits was renewed by Johannes Lehmann at Cornell University in about 1998 resulting from studies of Terra preta soils of the Amazon.

How is Biochar Made?

- Major Techniques:
  - ***Slow Pyrolysis***
    - traditional (dirty, low char yields) and modern (clean, high char yields)
  - ***Flash Pyrolysis***
    - modern, high pressure, high char yields
  - ***Fast Pyrolysis***
    - modern, maximizes bio-oil production, low char yields
  - ***Gasification:***
    - modern, maximizes bio-gas production, minimizes bio-oil production, low char yields, highly stable, high ash
  - **Hydrothermal Carbonization**
    - under development, wet feedstock, high pressure, highest "char" yield but quite different composition and probably not as stable as pyrolytic carbons

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Feedstocks for Biochar Production

Any source of biomass:

- *Crop residues (wheat, corn stover, rice husks)*
- *Nut shells (groundnut, hazelnut, macadamia nut, walnut, chestnut, coconut, peanut hulls)*
- *Orchard , vineyard pruning's or replacement*
- *Bagasse from sugar cane production*
- *Olive or tobacco waste*
- *Forest debris, wood chips, sawdust, bark, etc*
- *Animal manure*
- *Grasses*
- *Other – sewage sludge, tires, peat, lignite, coal*

** Not all organic biomass is suitable for producing biochar*

Household, municipal and industrial waste may contain heavy metals or organic pollutants which could cause environmental contamination by land application of the resulting biochar.

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Why Make Biochar?

Technology Applications

- ***Biofuel***—process heat, bio-oil, and gases (steam, volatile HCs)
- ***Soil Amendment*** sorbent for cations and organics, liming agent, inoculation carrier
- ***Climate Change Mitigation***—highly stable pool for C, avoidance of N_2O and CH_4 emissions, carbon negative energy, increased net primary productivity

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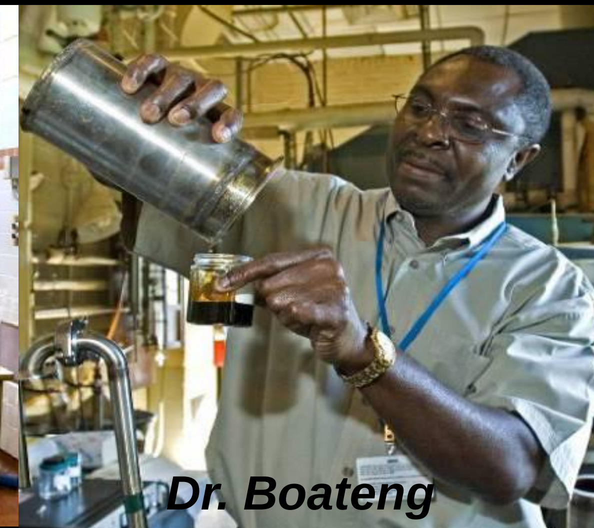
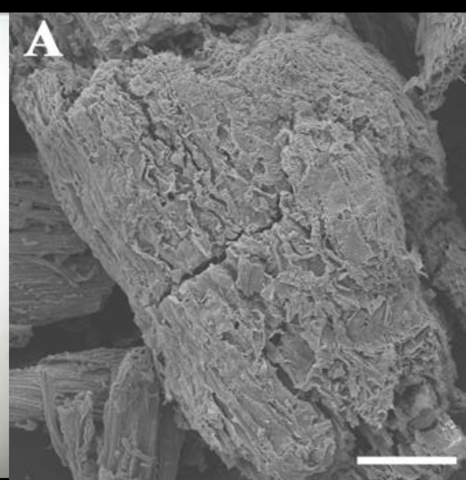
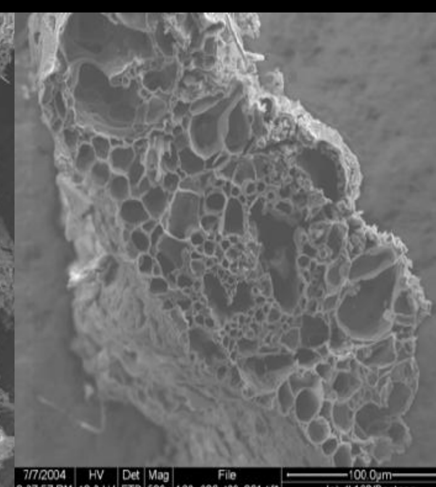
Pyrolysis of Crop Residues: USDA-ARS

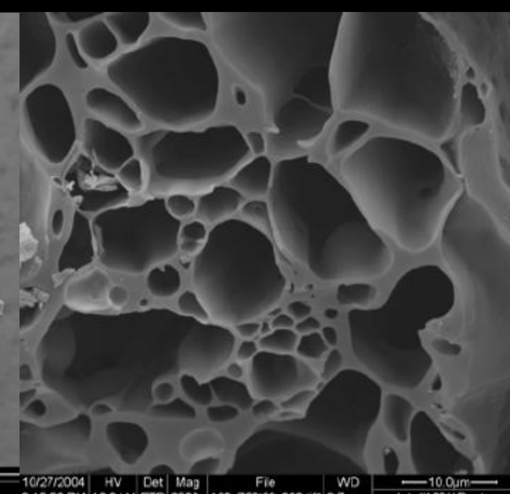


Bio-Oil

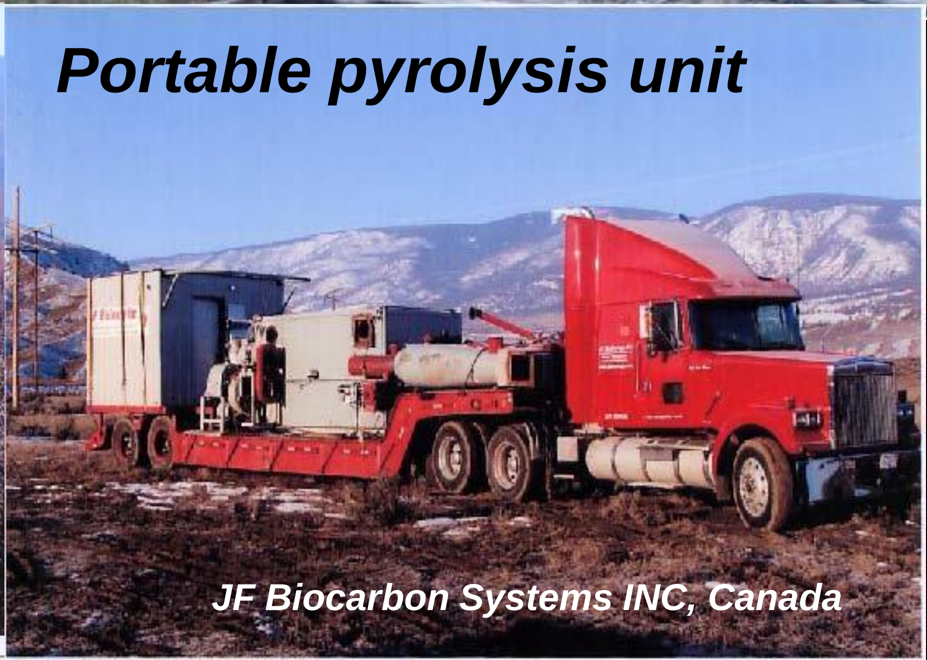
BioChar



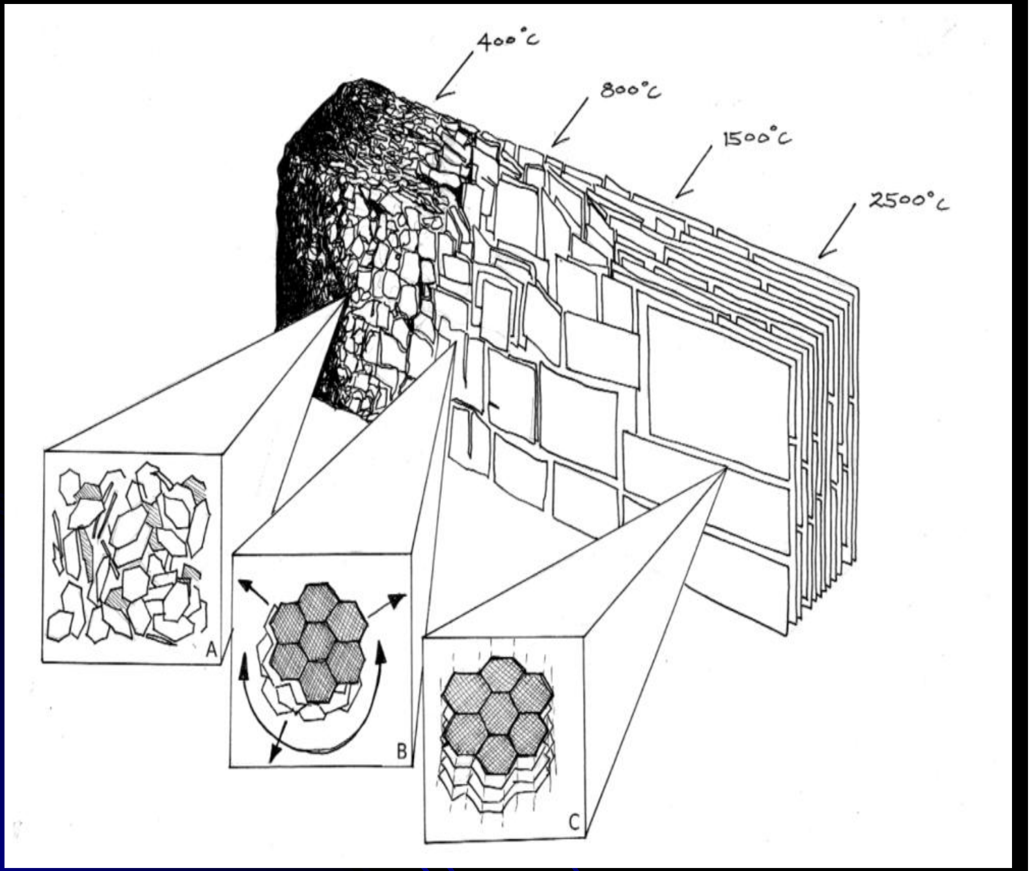




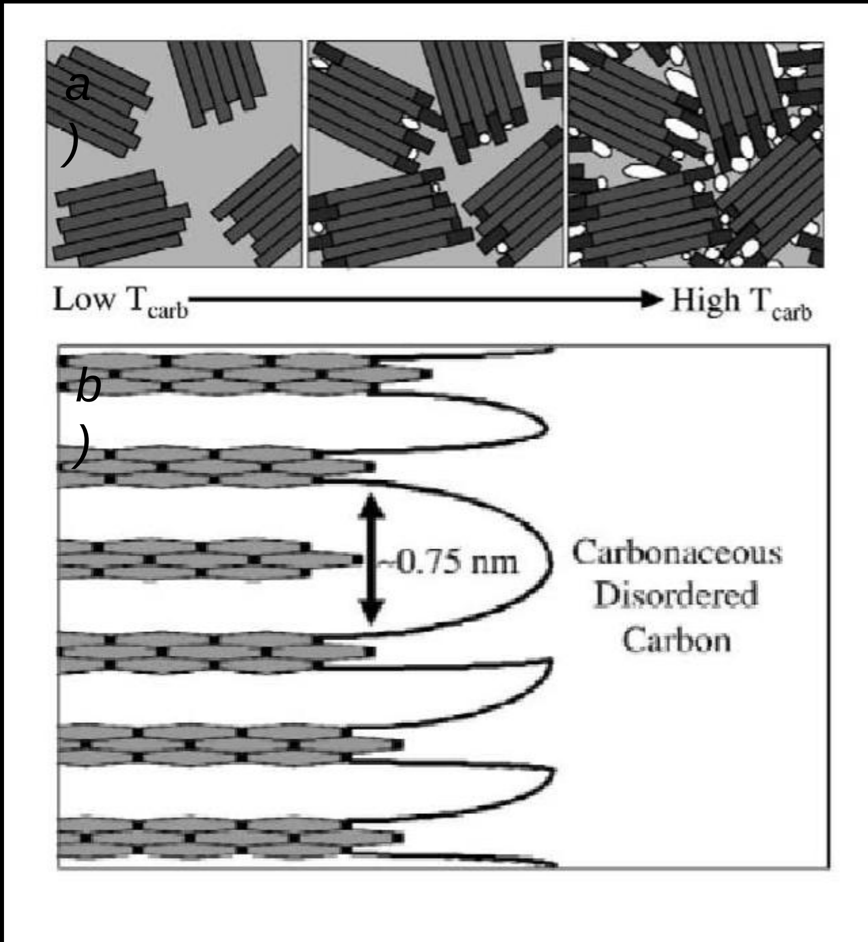
Pyrolysis of Forest Debris: USDA-FS



Physical Properties Change with Pyrolysis Temperature



Downie et al., 2009



Kercher and Nagle, 2003

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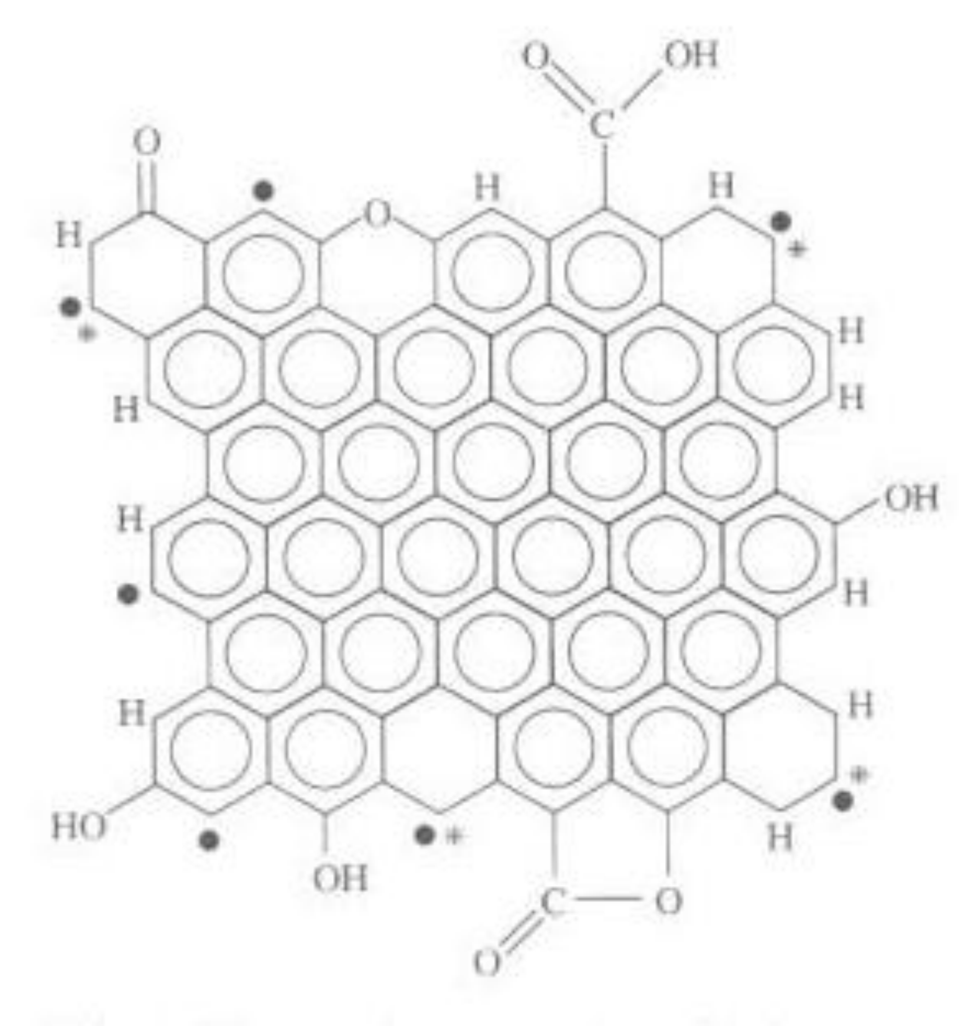
Physical Structure and Chemical Properties Depend on Carbon Bonding Network



Radovic et al., 2001

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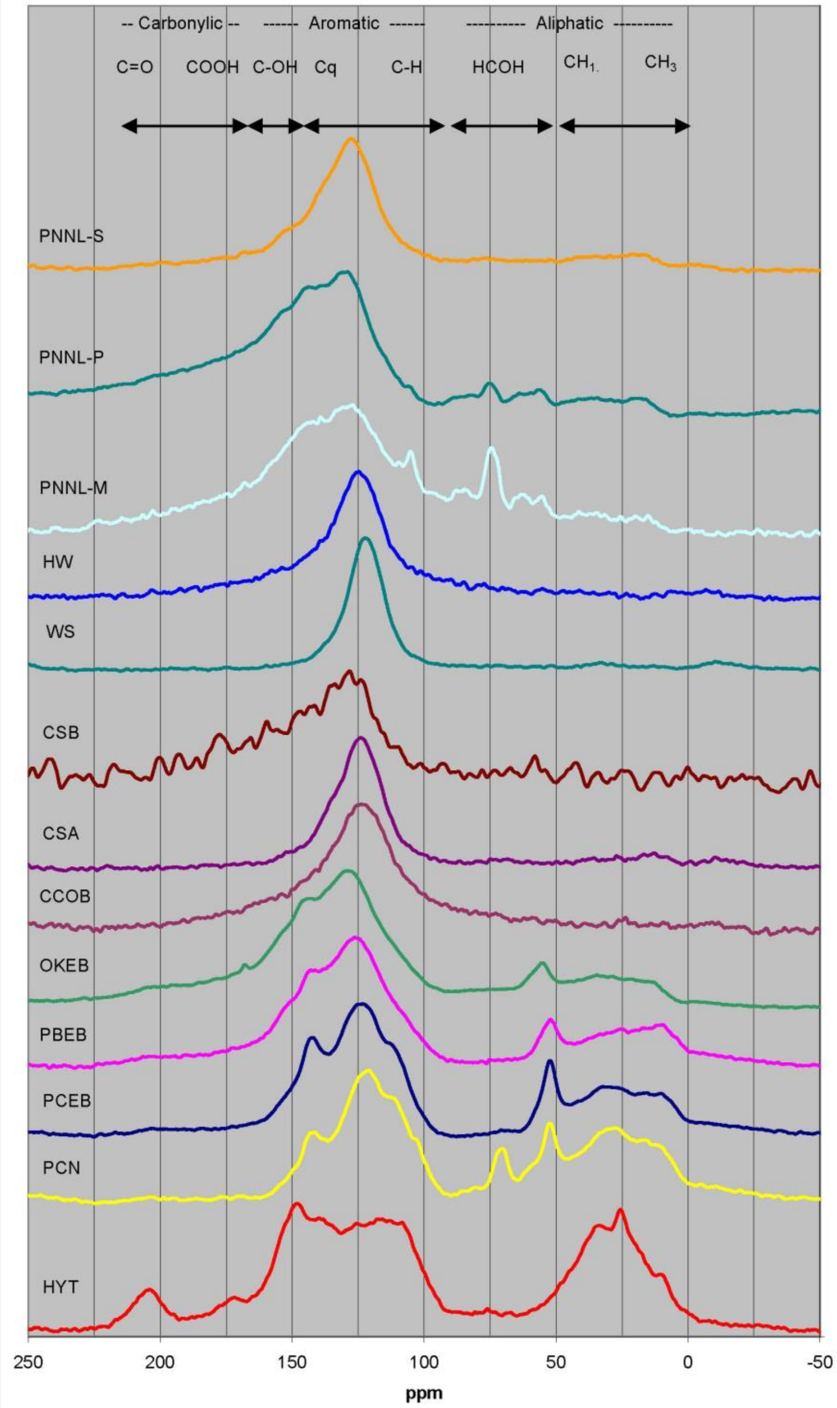
¹³C CP-MAS NMR
Amonette et al., 2008



Char Production

- *Biochar yield decreases as pyrolysis temperature increases from 350 to 600 ^oC*

Yield of char was 30-45%

- *Herbaceous feedstocks (DF and SG) lost 41 – 50% of their initial total C*
- *Woody feedstocks (SWP and SB) lost 40 – 45% of their initial total C.*
- *For each 100 ^oC rise in pyrolysis temperature C concentration of the resulting char increased an average of 41 g C kg^{-1} among feedstocks .*
- *As pyrolysis temperature increased from 350 to 600 ^oC, feedstocks lost 60 - 70% of total N .*

Biochar Characteristics

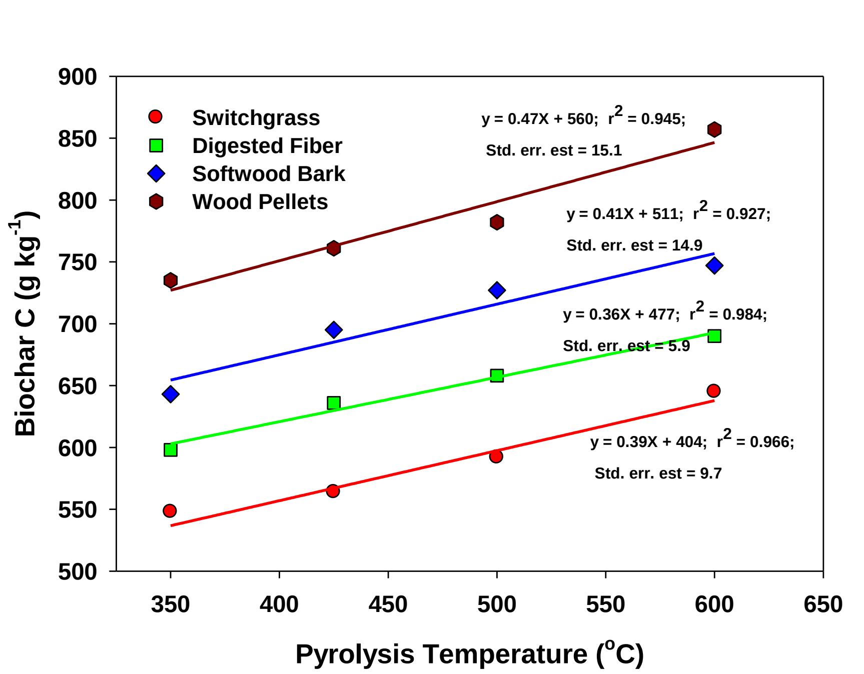


Figure 4.1. Relationship between pyrolysis temperature and the C concentration of the resulting biochar.

Yield of char was 30-45%

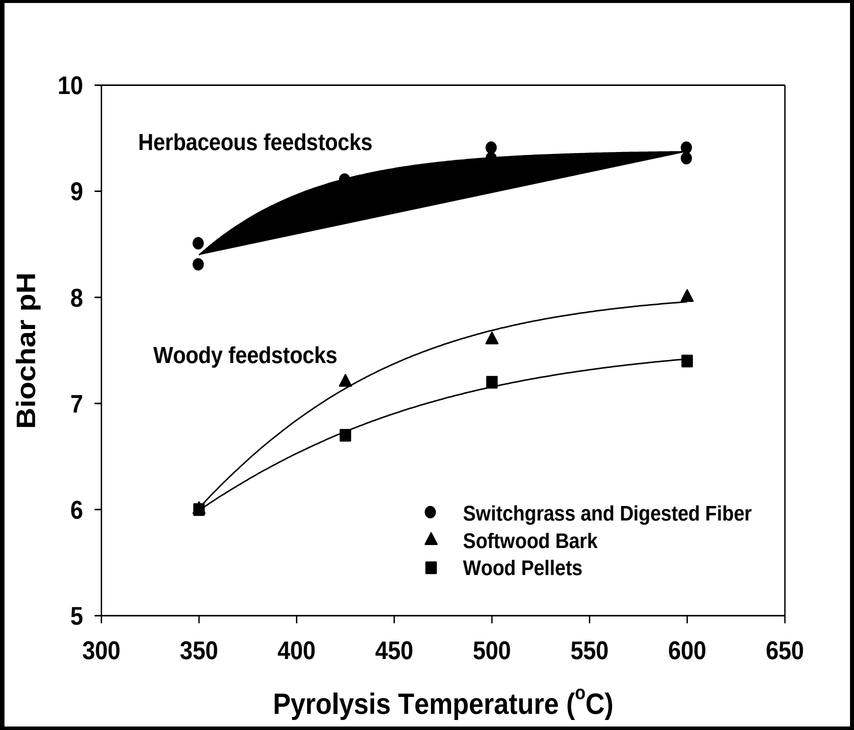


Figure 4.2. Influence of pyrolysis temperature on the pH of a variety of biochars.

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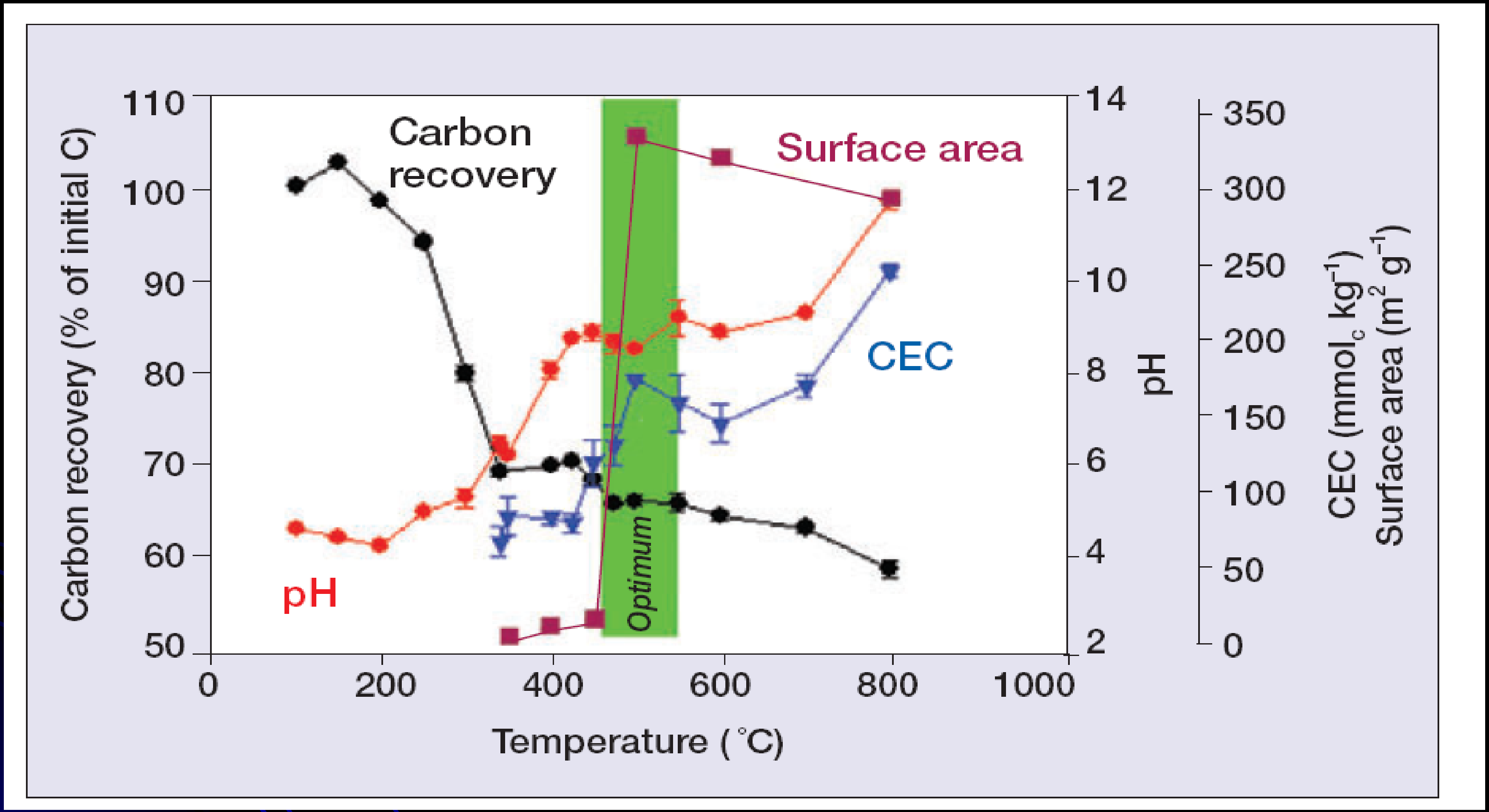
Characteristics of biochar

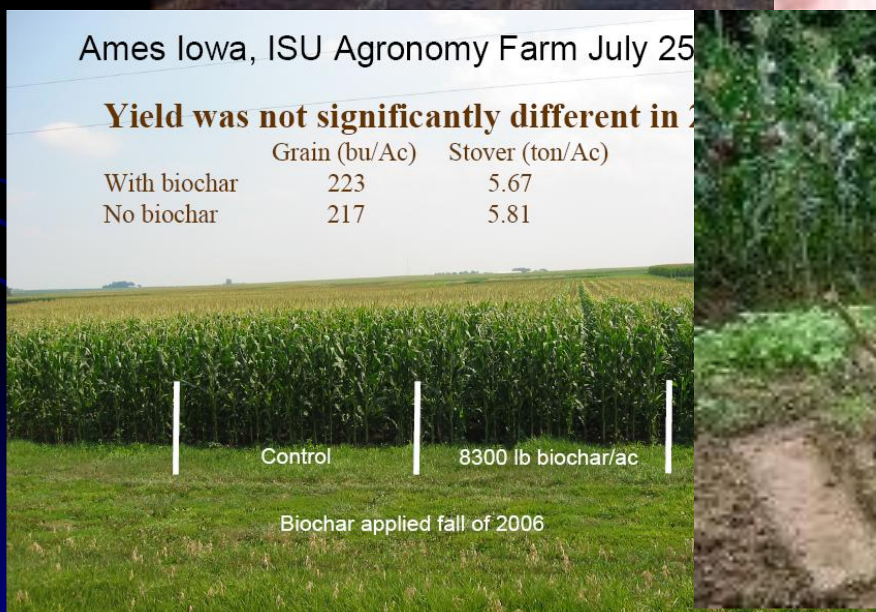


• The properties of biochar greatly depend upon the production procedure. Temperature effects on C recovery, CEC, pH and surface area. *from Lehmann (2007), Front. Ecol. Environ. 5:381-387.*

Soil Applications: Biochar

Richard Haard
Four Corner Nurseries
Bellingham, WA

Potting soil mixes



Tropical Soils

Temperate soils

What we know: Terra Preta

Terra preta do indio **or the "black earth of the Amazons"**

- ***fine dark loamy soil***
  - ***up to 9% carbon**, (**adjacent soil 0.5% C)***
  - ***high nutrient content and high fertility***
  - ***3 times the phosphorous and nitrogen***

developed over thousands of years by human habitation correspond to ancient settlements

- ***results from long-term mulching of charcoal production from hearths and bone fragments with soil application of food wastes and animal manures***
- ***persistents in soil, recalcitrant, resistant to decomposition.***
- ***forest fires and slash-and-burn contribute very low amounts of charcoal-C (~3%) "Slash and Char"***

Marris. 2006. Nature 442: 624-626; Lehmann, et al., 2003. Plant Soil 249: 343-357; Lehmann, et al., 2003. Kluwer Academic Publishers. 105-124.

Crop Yields: tropical soils

- **Comparisons of Terra Preta to Adjacent Soils show crop yield increases of 2-3 fold.**
- **Yields typically increase w/applications to 65 T/ha**
- **Increases result from improvements in:**
  - **- Nutrient availability (N, P, S, etc.) - Storage**
  - **- increased CEC**
  - **- increased soil pH**
  - **- Changes in physical properties**
    - **water retention**
    - **reduced soil density**
    - **increased porosity/aeration**

Impact on Temperate soils?

Effect of Biochar additions on Soil pH

Rate	Hale SiL	Quincy Sand
0	4.5	7.1
5	4.7	7.4
10	4.9	7.7
20	5.0	8.1
Change	0.2 / 5-ton	0.3 / 5 ton

Implications: Can use char to improve soil pH

- heavy textured soils have greater buffering capacity
- reduce the use of lime and CO_2 emissions
- placement issues (broadcast vs. seed row)
- could impact soilborne diseases

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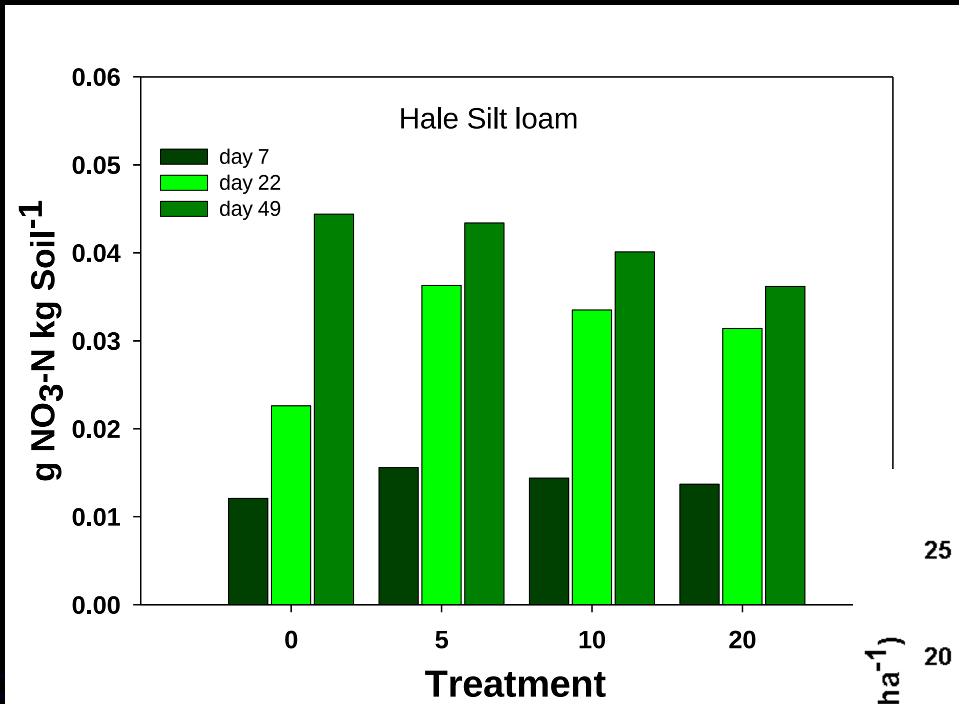
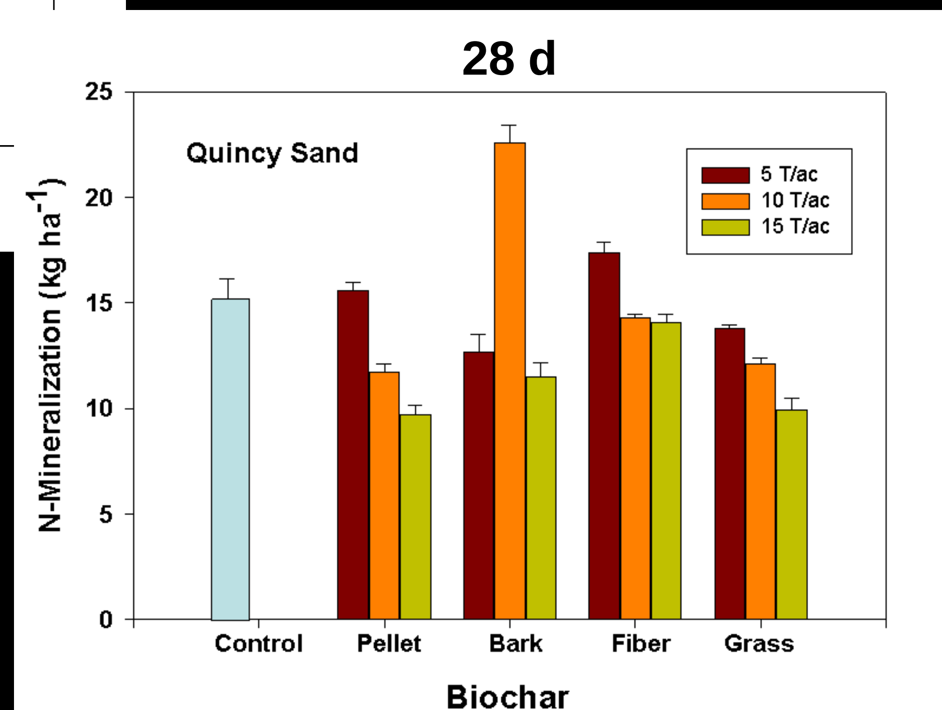
Effect of Biochar on Nitrogen Mineralization

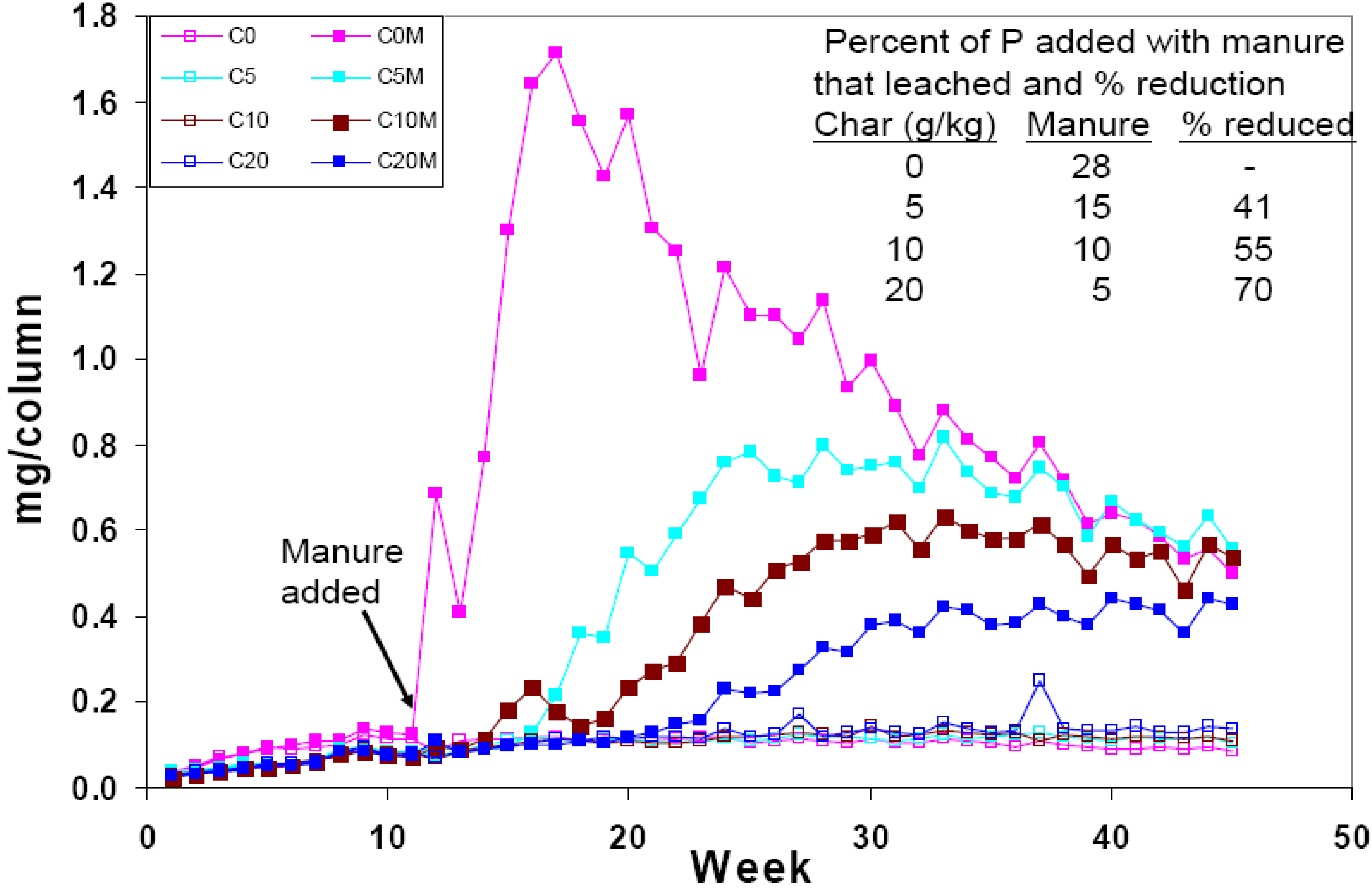


Peanut Hull Char

%	T/ac
0.4	5
0.8	10
1.5	20

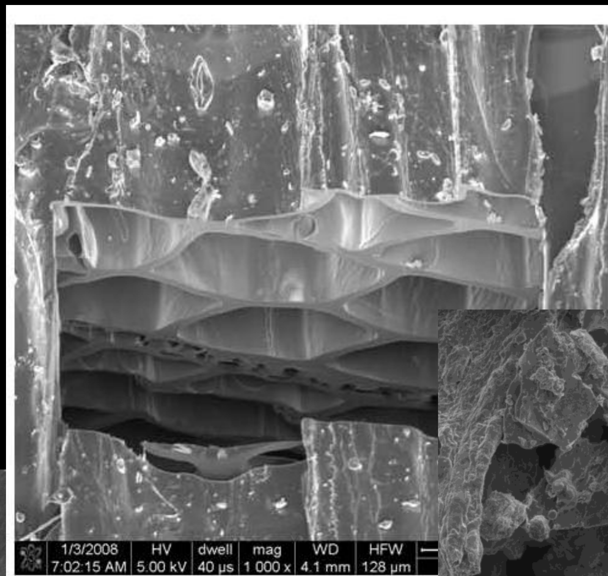


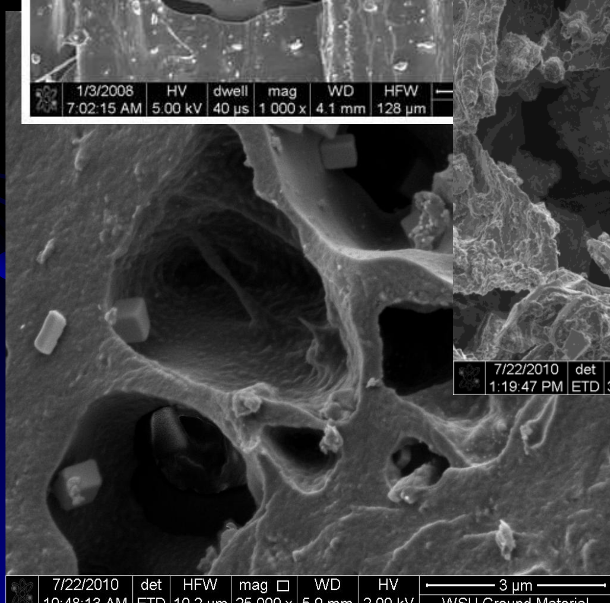
Impact of biochar and manure on P leaching

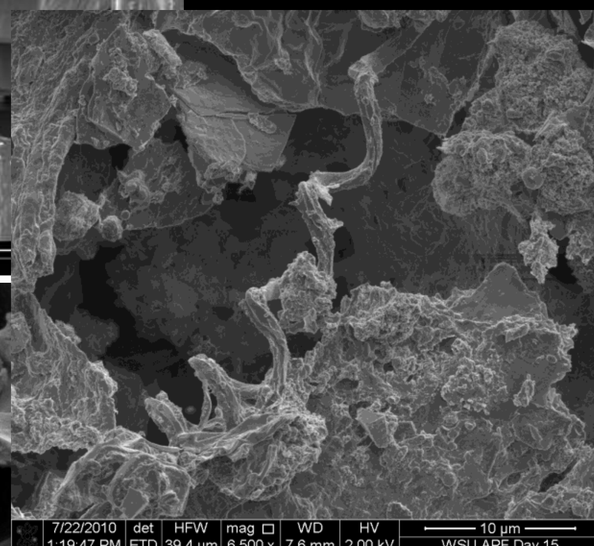


David A. Laird
USDA, ARS, National, Soil Tilth Laboratory

Soil Microflora and Biochar







Colonization sites for soil bacteria, fungi.

Use as delivery system of specialized organisms:

- ***Rhizobium***
- ***PGPRB***
- ***Mycorrhizae***

C Sequestration Potential of Biochar

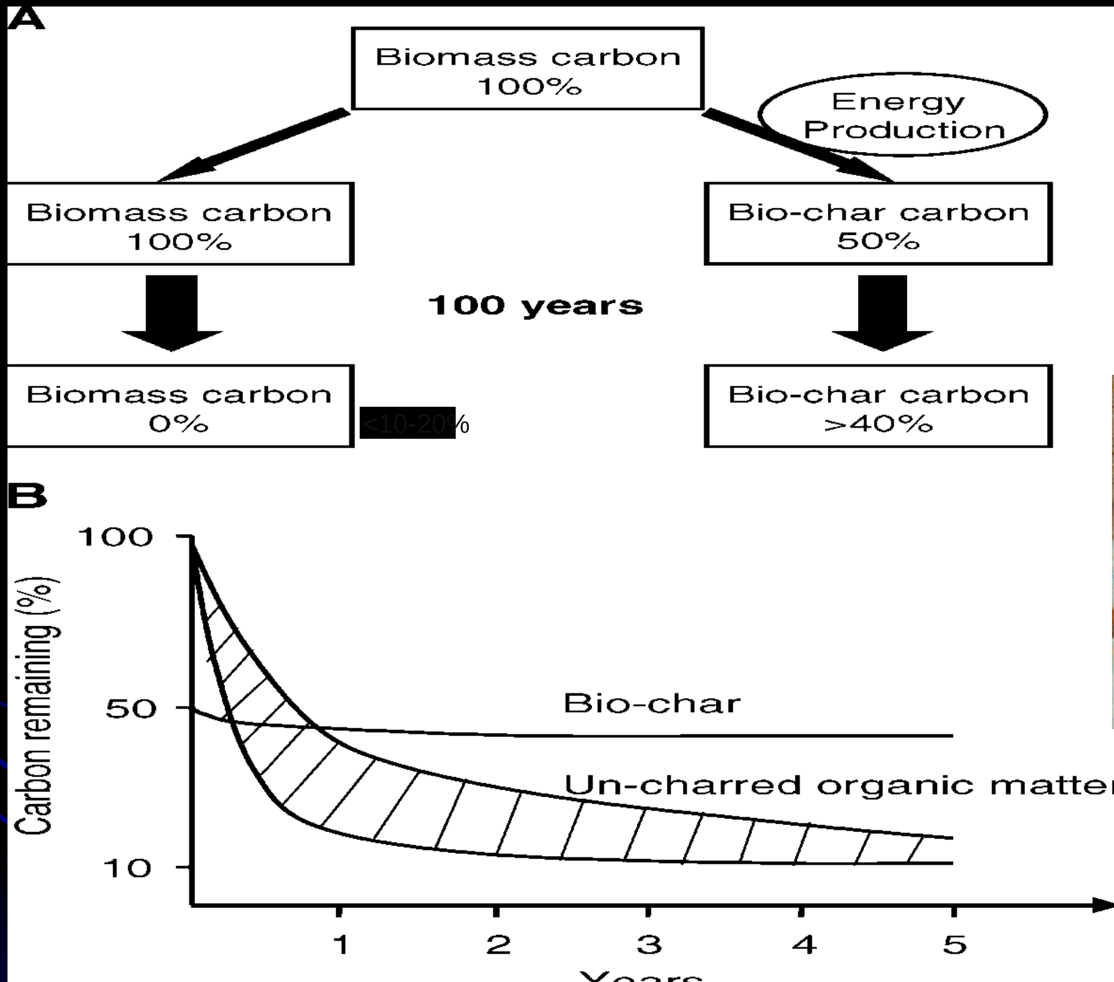


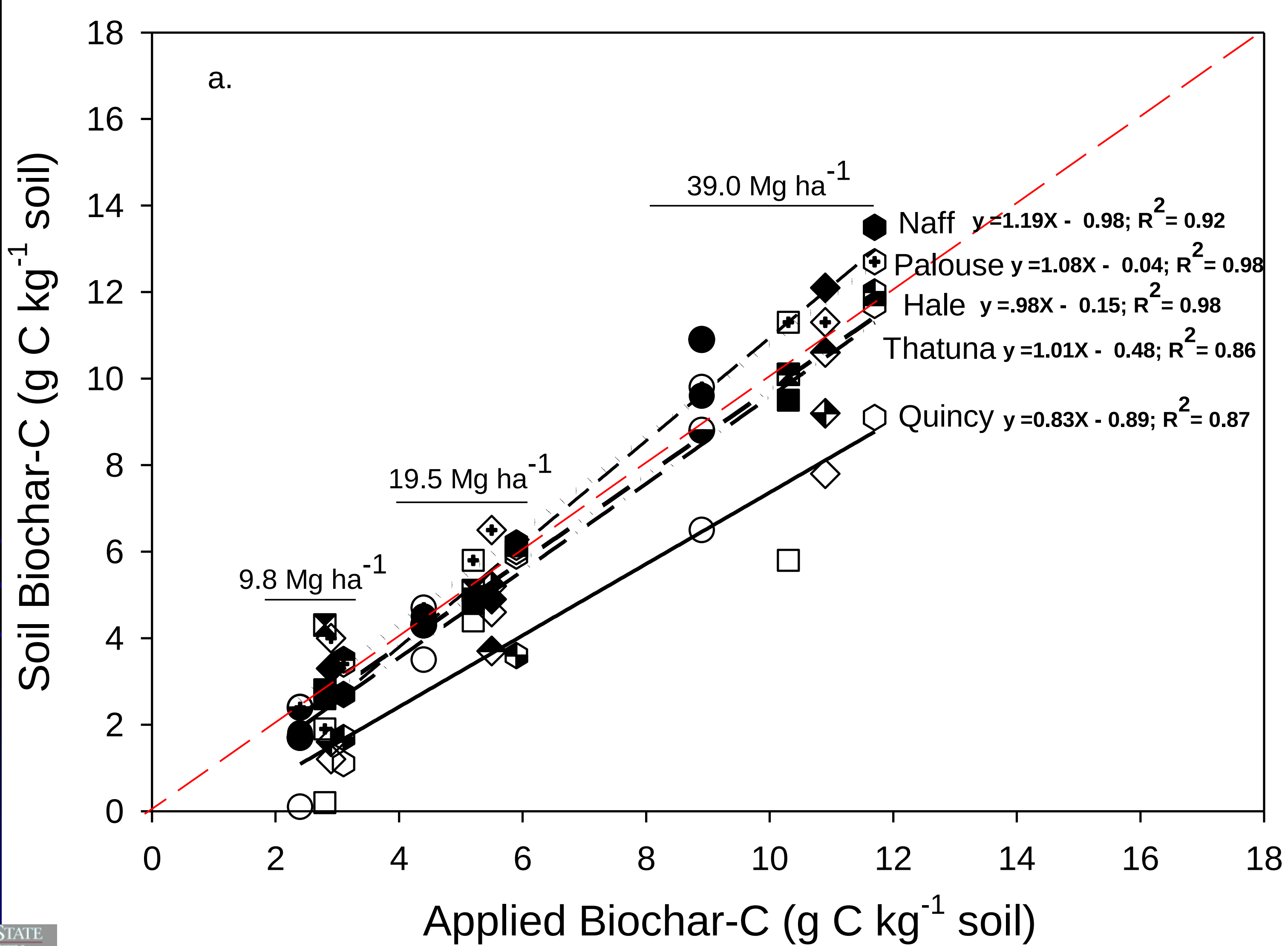
Figure 1. Schematics for biomass or bio-char remaining after charring and decomposition in soil. _from Lehmann et al., 2006. Mitigation Adap. Strat. Glob. Change 11: 403–427_.

Change in Soil C and N with BioChar

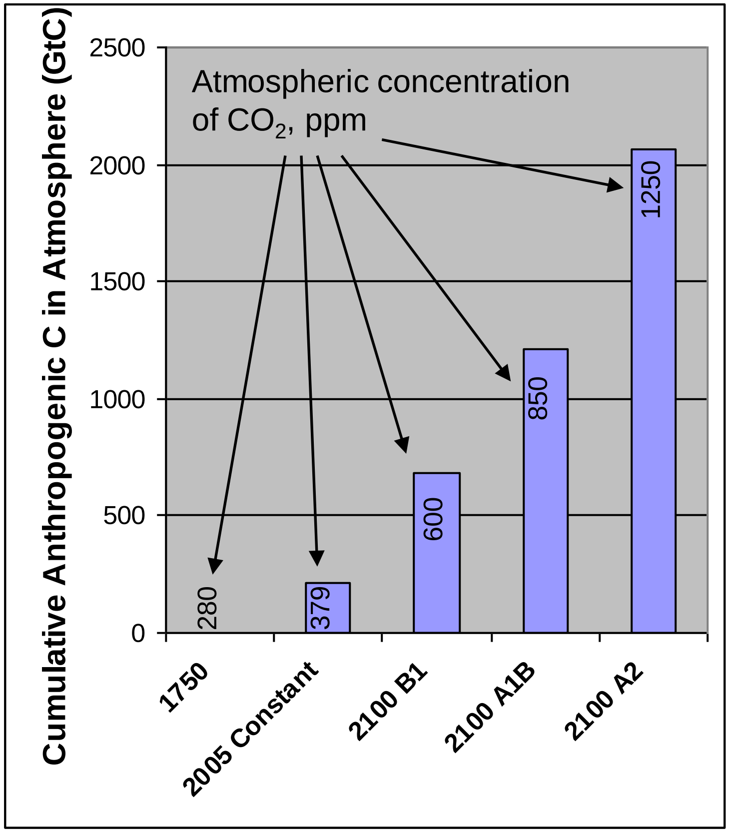
		‡Soil + Biochar Characteristics					
Soil Series	Biochar	†Rate	C	N	S	C:N	C:S
		t/acre	---------	%	---------		
Quincy	Switchgrass	0	0. 23	0.01	0.010	23	23
		5	0.24	0.02	0.012	15	21
		10	0.56	0.02	0.011	23	49
		20	1.19	0.06	0.011	30	151
	Digested Fiber	0	0.23	0.01	0.010	23	23
		5	0.29	0.02	0.018	17	17
		10	0.57	0.03	0.014	18	39
		20	1.14	0.05	0.014	22	82
	Bark	0	0.23	0.01	0.010	23	23
		5	0.75	0.01	0.016	13	47
		10	0.93	0.01	0.060	17	16
		20	1.79	0.01	0.052	29	35
	Pine Pellets	0	0.23	0.01	0.010	23	23
		5	0.53	0.01	0.034	28	7
		10	1.12	0.01	0.029	53	38
		20	1.60	0.02	0.026	86	62

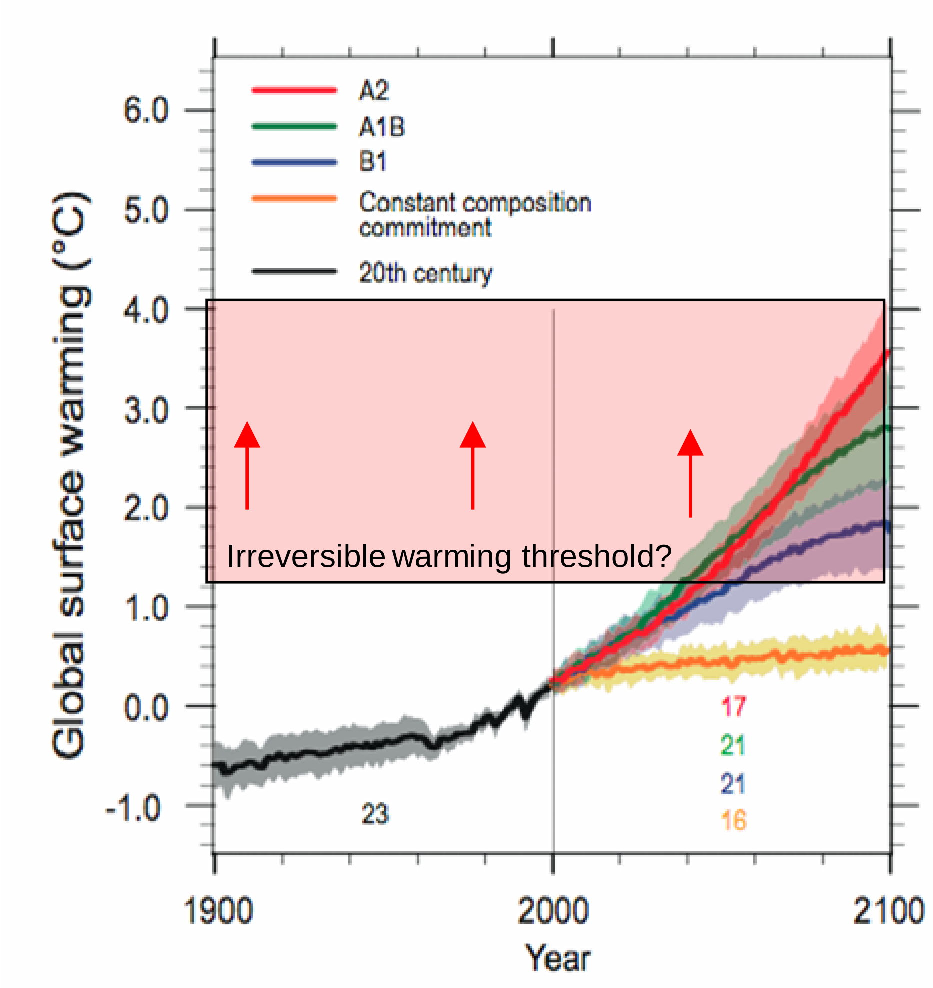
400-600% increase in soil-C and N with a 20 T/acre amendment

Accounting of Biochar C



Projected Atmospheric Carbon Levels and Associated Global Warming

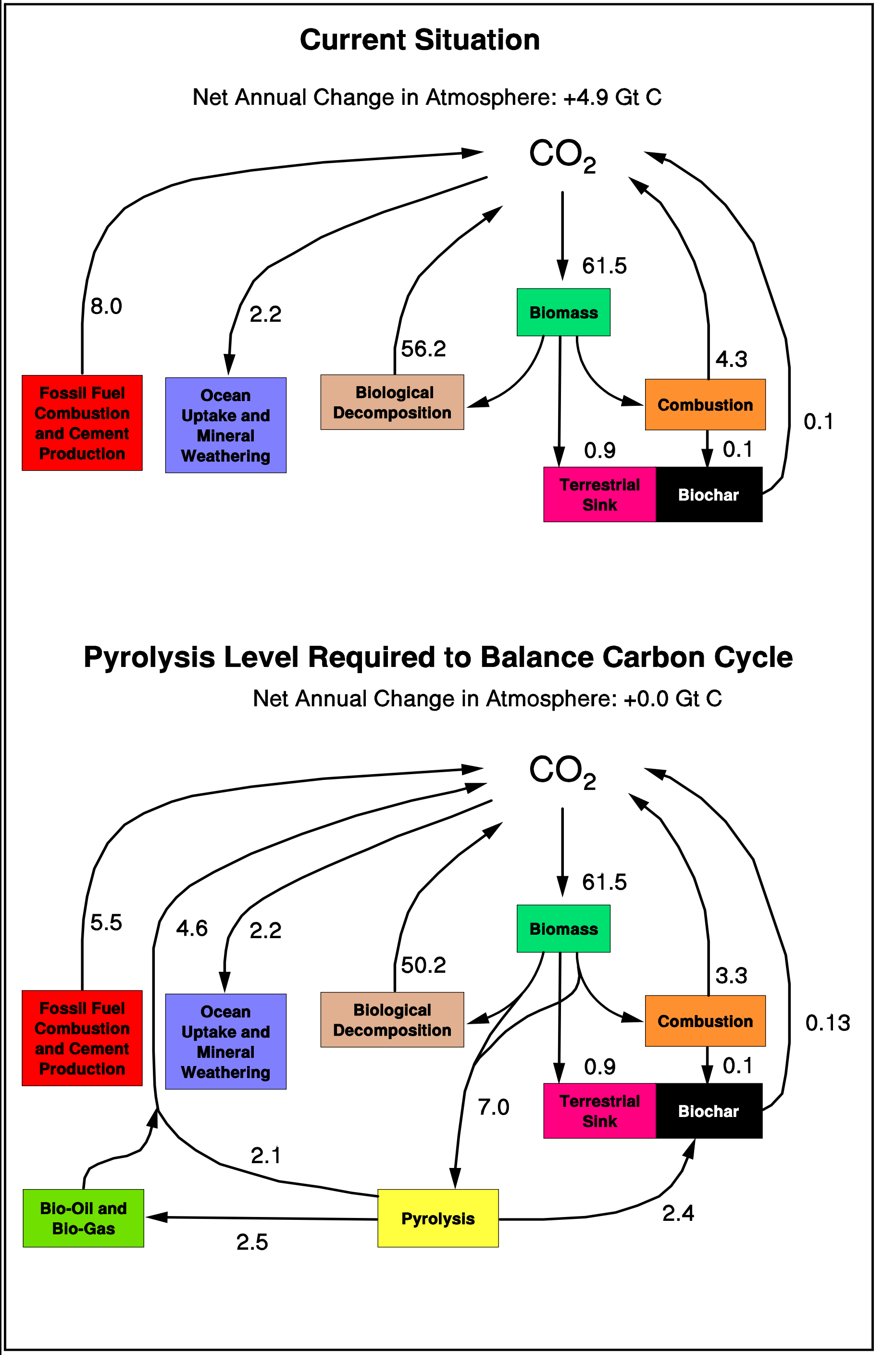




IPCC (2007) WG1-AR4, SPM, p. 14, modified to show zone where irreversible warming of Greenland ice sheet is projected to occur (ibid., p. 17)

How can biochar help mitigate CO_2 Imbalance?

- Create stable C pool using biochar in soil
- Use energy from pyrolysis to offset fossil C emissions
- Avoid emissions of N_2O and CH_4
- Increase net primary productivity of sub-optimal land
- Boundary conditions for biochar contribution shown to right
    - Maximum levels are not sustainable
    - Biochar cannot solve climate change alone



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Effects of Biochar Applications on Yield

Crops

Clover
Corn
Cotton
Oats
Rice
Sugarcane
Wheat
Beans
Cowpea
Cucumber
Peas
Peppers
Tomato
Mushrooms

Literature Review - 53 Trials

23 - Increases** **(10-150%)

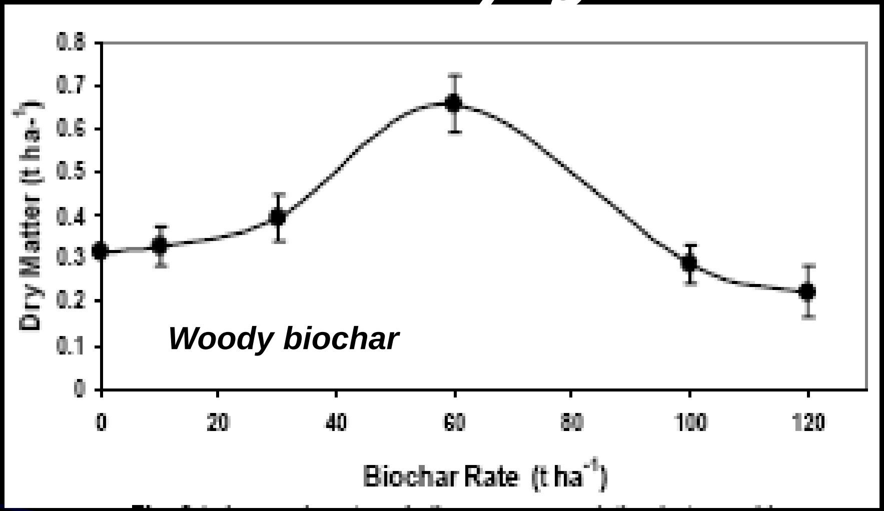
15 - Decreases** **(10-85%)

15 - No Difference

Biochars were derived from:
herbaceous – woody feedstocks
Rates of Biochar Application: 5 – 100 t/acre
Majority of increases were in tropical soils

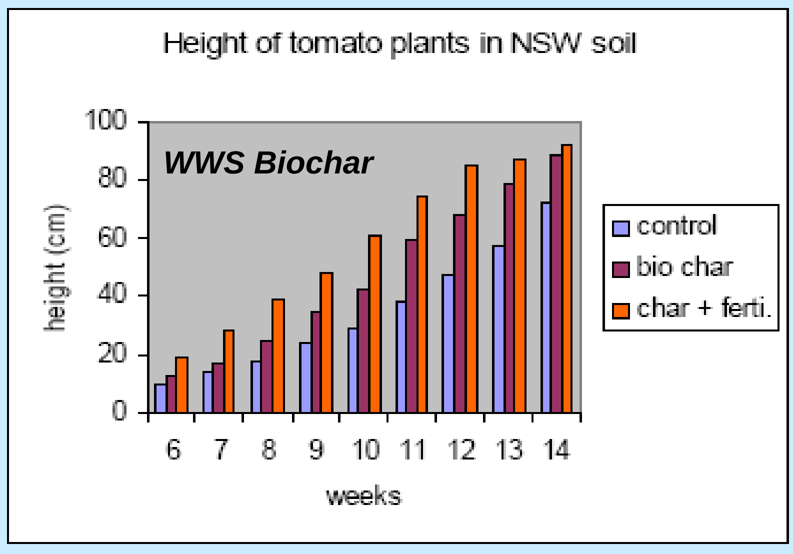
Rate studies

Yield Response of Perennial Ryegrass



Baronti et al. 2008.
Institute of Biometeorology (IBIMET)

Response of Tomato



Hossain et al., 2008
Macquarie University NSW, Australia

Wheat root and shoot growth in Quincy sand amended with two biochars.

		‡Plant Characteristics			
Soil Series	Biochar	†Rate	Root	Shoot	Total
		T ac^{-1}	--------- g ---------		
Quincy	Peanut Hull	0	2.1NS	7.8NS	9.9NS
		5	1.8	8.2	10.0
		10	1.7	9.5	11.2
		20	1.9	7.9	9.8
	Bark	0	3.3NS	8.8	12.1
		5	3.1	12.9*	16.0*
		10	4.1	15.5*	19.6*
		20	3.0	10.2	13.2

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Field Studies

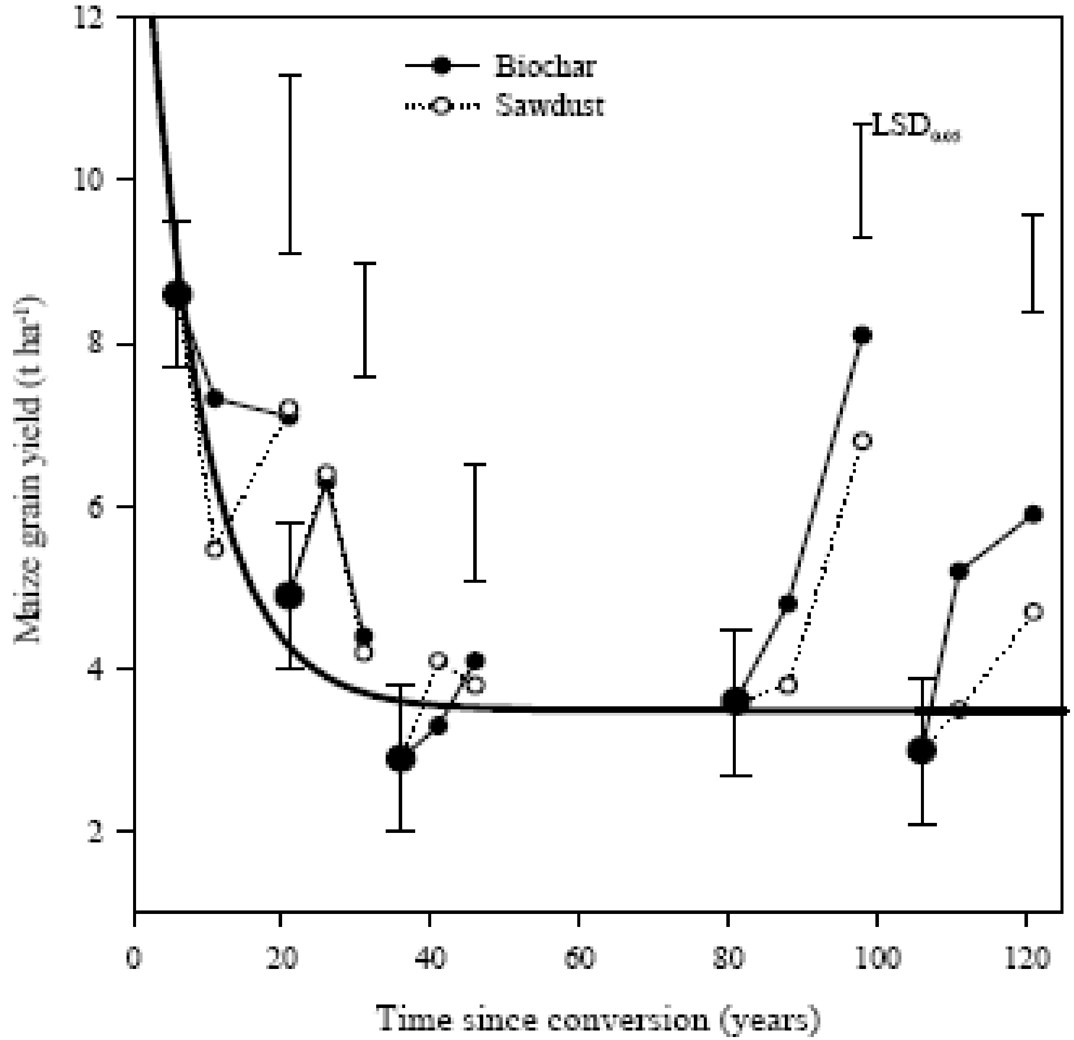


Figure 1: Influence of organic matter additions on maize grain yield across a chronosequence of soil degradation in 2005-06

Western Kenya

Woody biochar
6 tons/ha
2- applications

Kimetu rt al., 2008

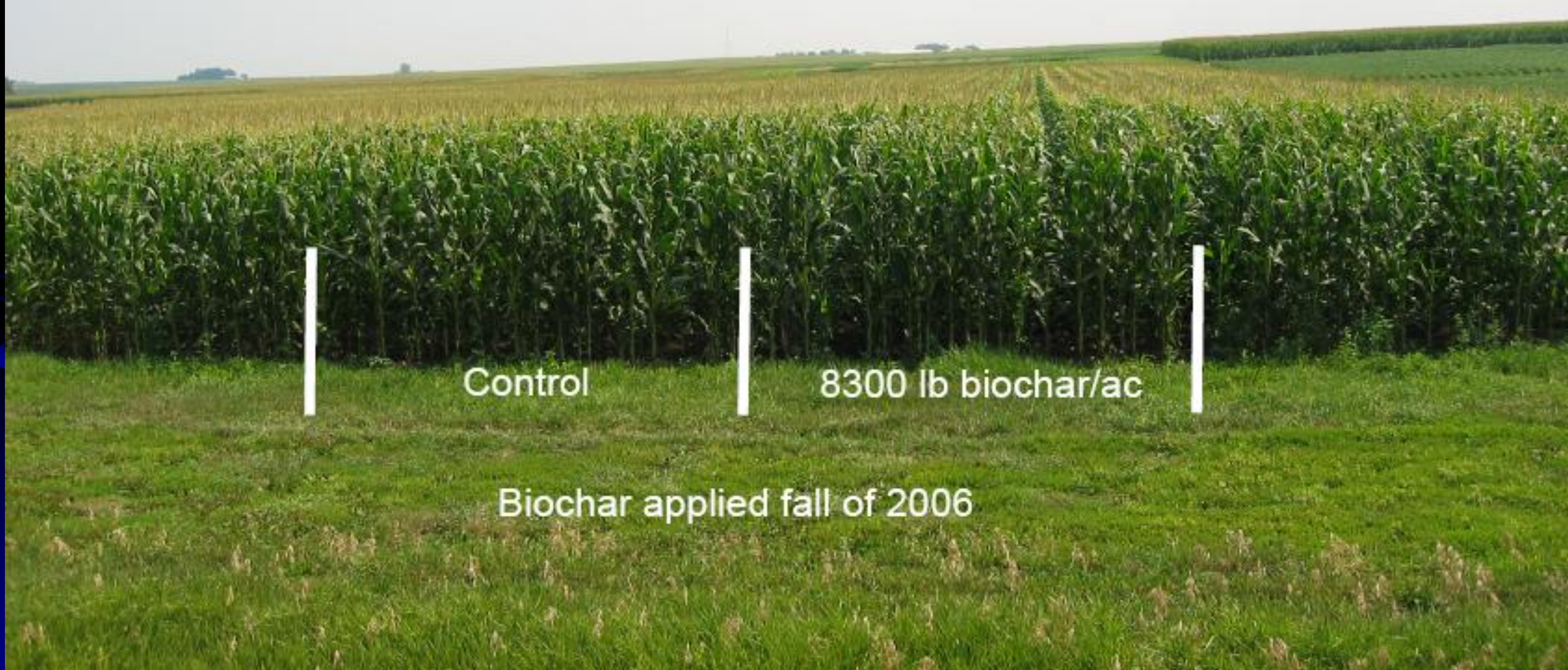
USDA-ARS Research

- ***National Programs***
  - ARS Biochar/Pyrolysis Initiative
- ***Five research sites***
  - ***Prosser, WA***
  - ***Kimberly, Idaho***
  - ***Ames, IA***
  - ***St. Paul, MN***
  - ***Florence, SC***

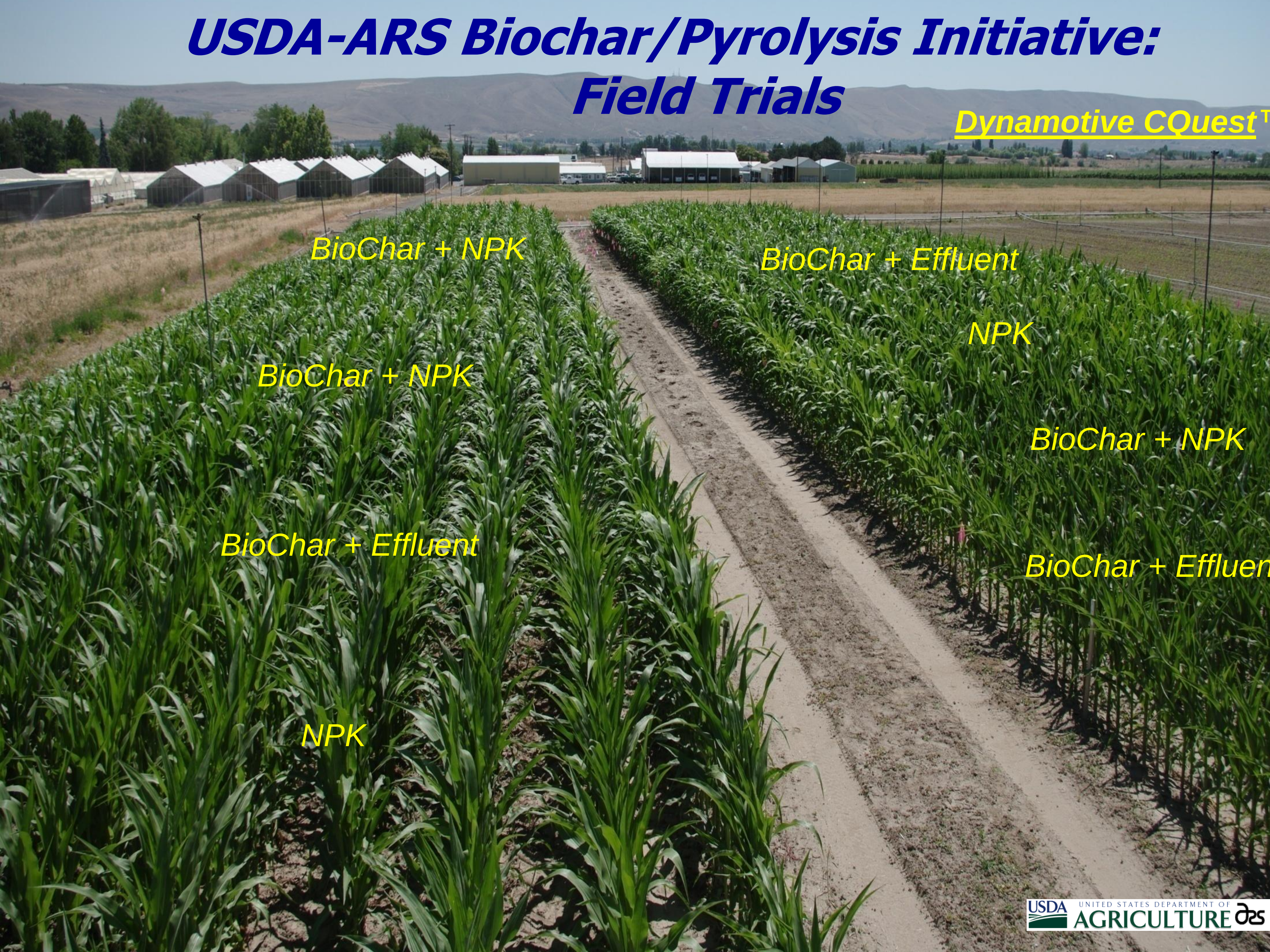
Ames Iowa, ISU Agronomy Farm July 25, 2007

Yield was not significantly different in 2007

	Grain (bu/Ac)	Stover (ton/Ac)
With biochar	223	5.67
No biochar	217	5.81

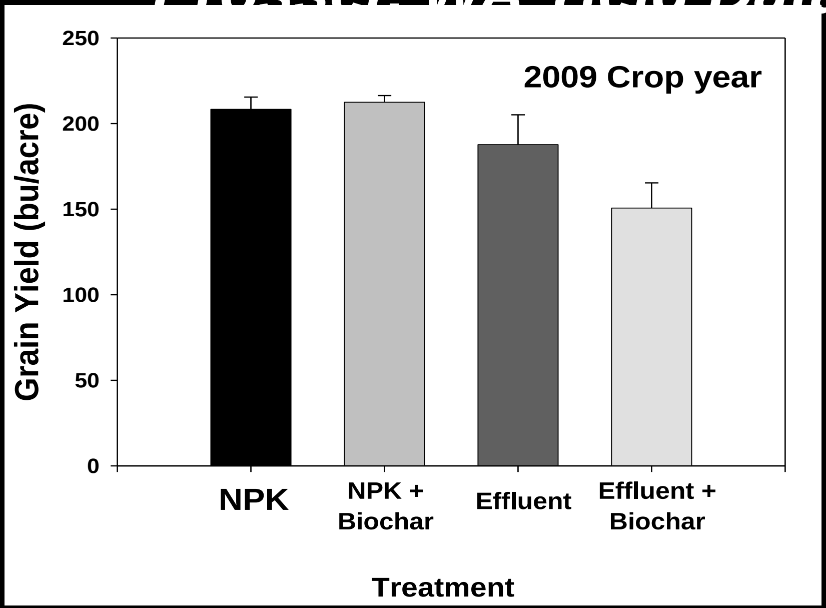


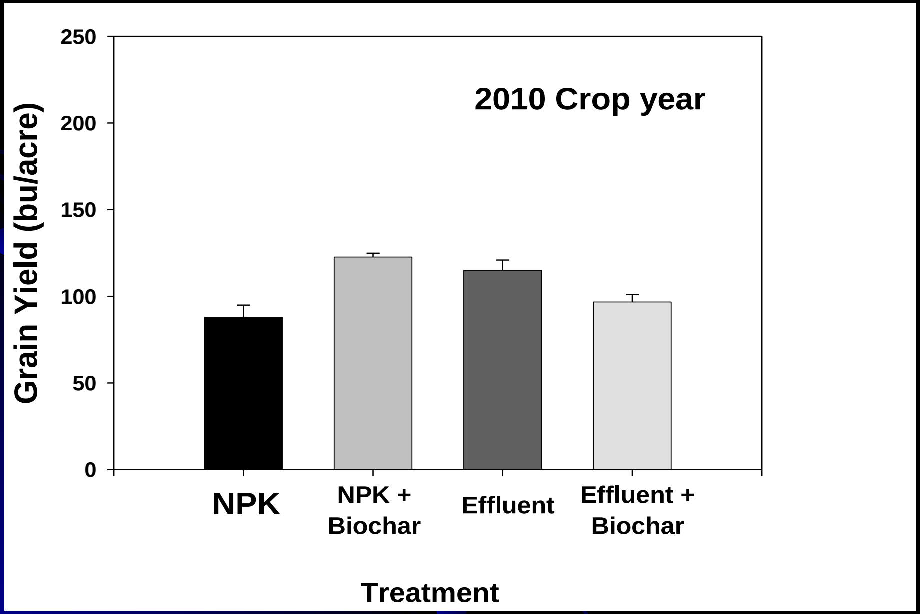
USDA-ARS Biochar/Pyrolysis Initiative: Field Trials



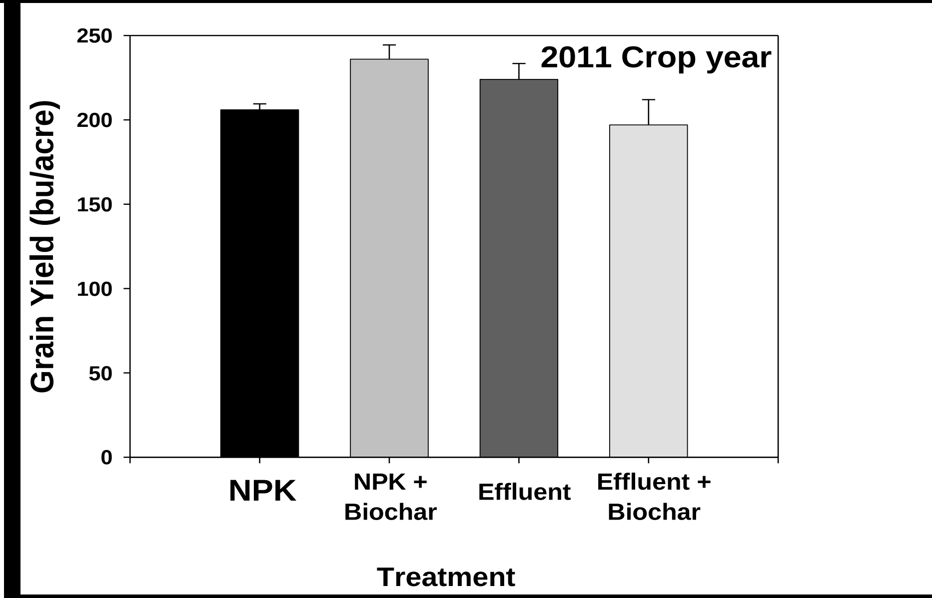
Dynamotive Biochar Field Trials

Prosser, WA Yield Data





Yield reduction attributed to poor stands under No-till and cool crop year



Yields returned to 2009 levels after eliminating no-till.

Other Uses for Biochar

"Currently sourcing enough biochar for application at the commercial farm scale is nearly impossible, due to lack of supply. The success of biochar production will depend on the economic values of the various products that can be produced or the potentially value-added uses of biochar that can be envisioned".

Yoder and Galinato, 2009

- *Conversion to activated carbon, commonly utilized in industrial filtration processes or water treatment*
- *Nutrient recovery*
- *Soil herbicide and pesticide management*
- *Reduce the bioavailability and mobility of toxic trace metals in contaminant mitigation*
- *Metallurgy - reductant in the production of iron or steel*

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Dairy Manure: Nutrient Recovery

- *Increase in dairy herds in Eastern WA ~8% y^{-1}*
- *Large dairy herds; 4,000 - 25,000 cows*
- *1000 lb milking cow produces ~100 lbs manure d^{-1}*
- *Lagoons – 5 - 20 million gals (emptied twice y^{-1})*
- *Small land base with application of 560 - 900 lbs N ac^{-1} and 120 - 450 lbs P ac^{-1}*

Global Objective:

- ***Combine technologies of anaerobic digestion and pyrolysis to reduce nutrient loss and soil and water contamination.***

04/12/2007

USDA ARS

Manure

- Dairy and Cattle manure –
  > 1.5 million dry tonnes of manure produced each year in WA State.

Pyrolysis of Manure:

AD Dairy Manure Fiber

Pelletized Manure

Slow Pyrolysis *$500^{o}C$*

Biochar

Dairy AD Manure Effluent Collection

Lagoon 378 L

Manure fiber Coating the Char

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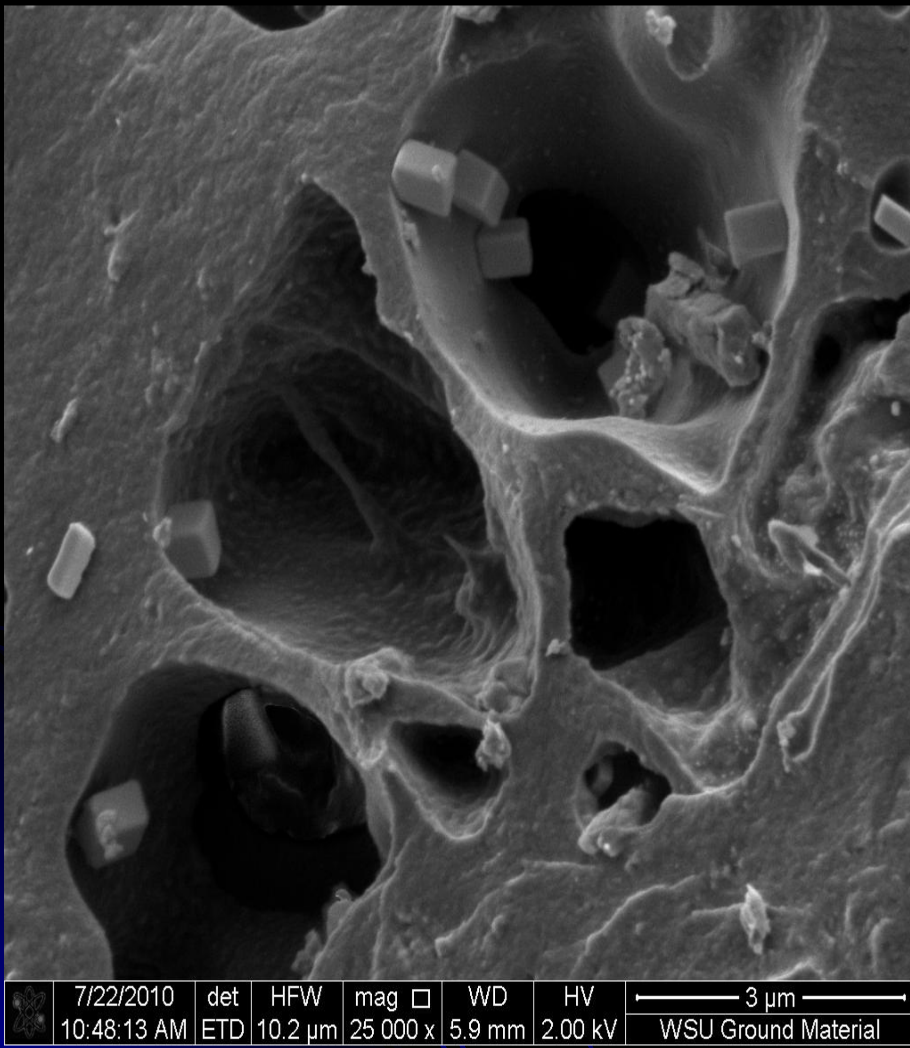
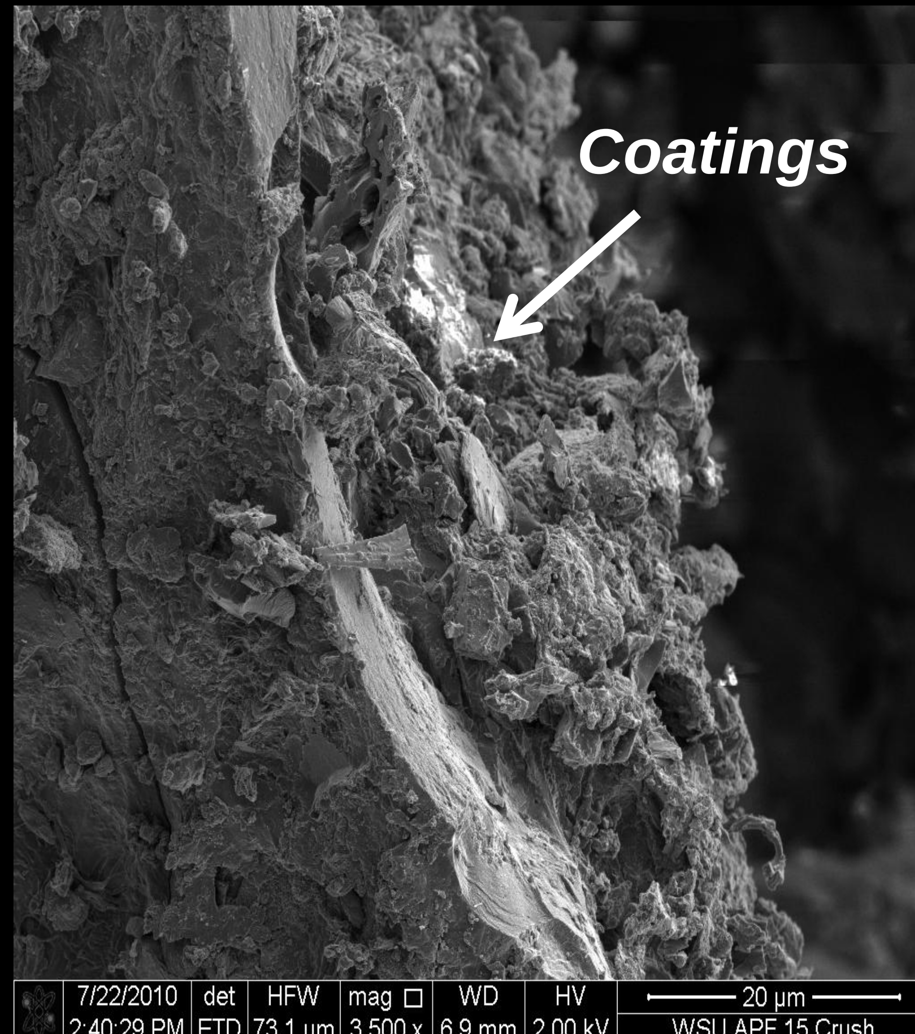
Biochar made from Manure

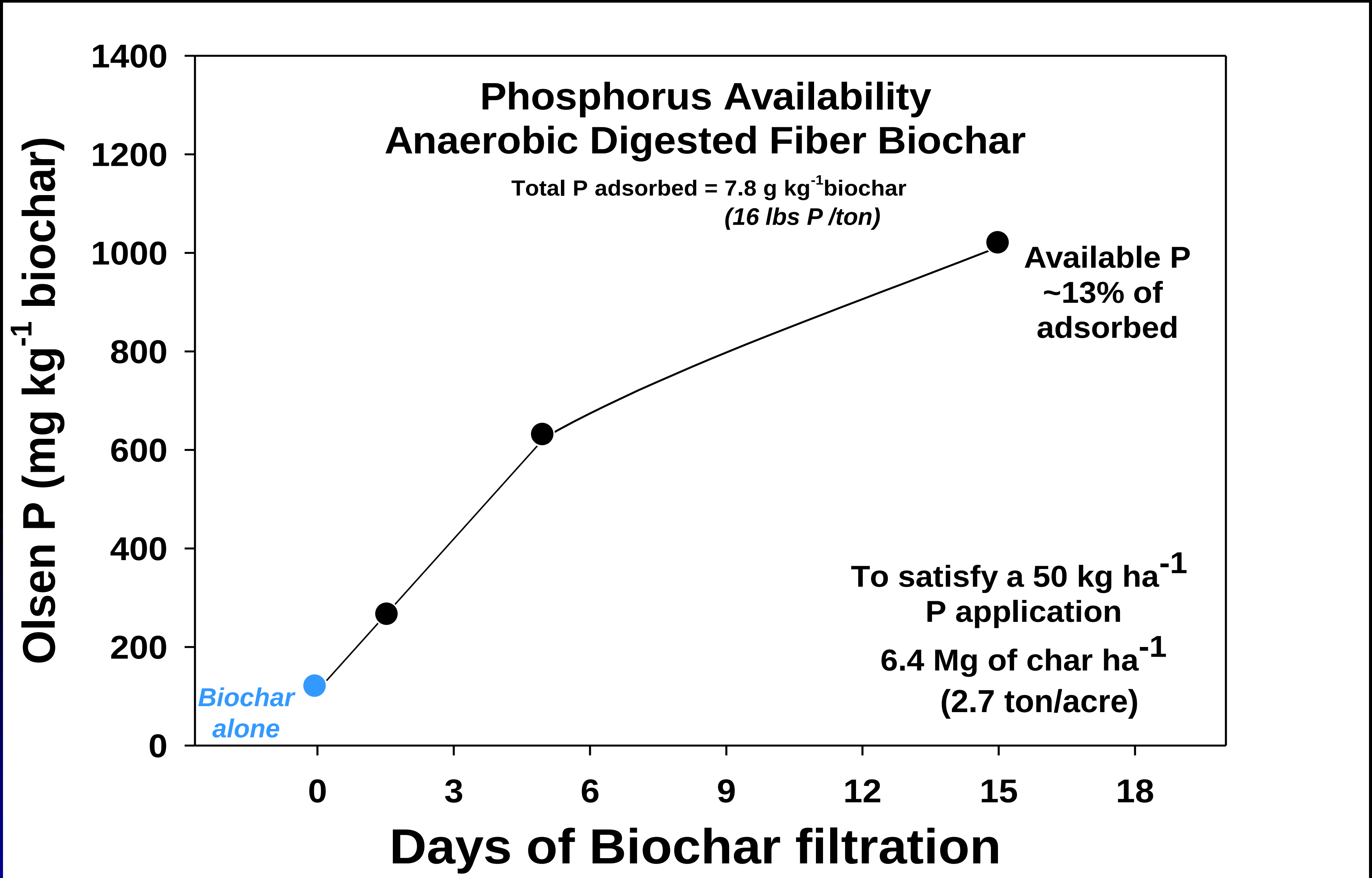


Un-amended Char



Lagoon-treated Char

P recovery of Pyrolyzed AD Manure:



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Greenhouse trial: Biochar/ Dairy Recovered P

Summary:

- ***Pyrolysis of agricultural wastes produces energy*** **and *a co-product that can be used as a soil amendment.***

  Biochar impact on soil characteristics:

  - ***increased soil pH 0.5 – 1 pH unit***
  - ***increased soil C levels*** **1.3 – 5 fold C_T and C_{AH}**
  - **up to 2.93 Mg CO2 offset per Mg of biochar**
  - ***small increase in CEC (30% sand; 3-17% SiL)***
  - ***increases in water retention dependent on char type***
    0.5 – 2.5 in ft^{-1} dependent on soil type
  - ***reduced NO_3 production 15-30%***

- ***Effects on plant growth are variable.***

- ***How to incorporate biochar? (broadcast vs. banding)***

- ***Availability of feedstocks will compete with other energy technologies.***

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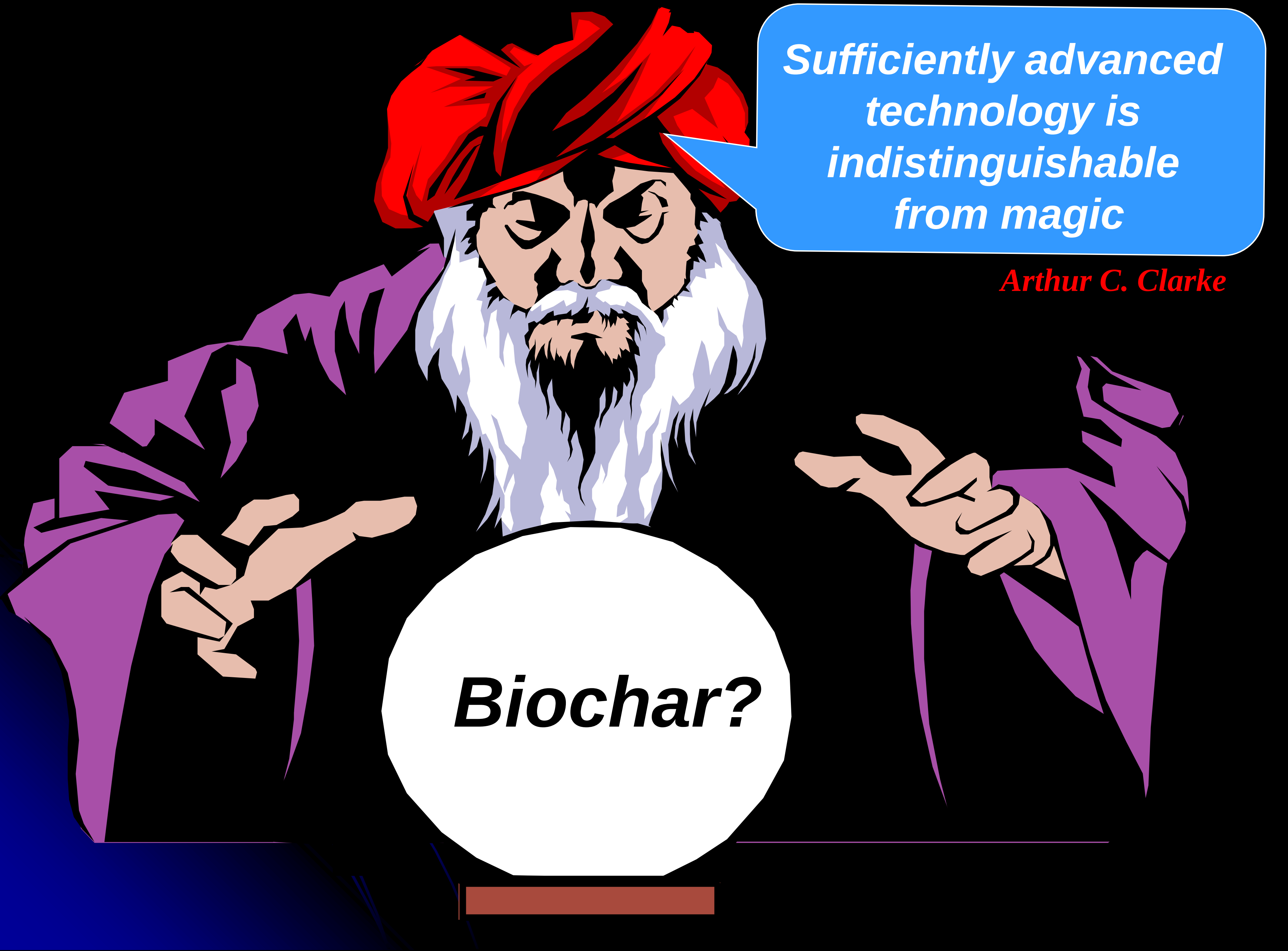

Sufficiently advanced technology is indistinguishable from magic
Arthur C. Clarke
Biochar?

Long-term Supply of feedstocks: Biochar?

- ***Forest Resources***

  - logging debris – 67 M dry T y^{-1}
  60% recovery
  Converted to biochar = 10 M T Carbon

  - forest thinning – 60 M dry T y^{-1}
  at most 30% collected 18 MT
  Converted to biochar = 4.5 M T Carbon

  - Primary wood processing mills – 91 M dry T y^{-1}
  bark, saw mill slabs, edgings, sawdust, etc.
  < 2 million dry tons available
  Converted to biochar = 0.4 M T Carbon

  - Secondary wood processing mills – 16 M dry T y-1
  millwork, containers, pallets, etc.
  recovered from urban MSW

DOE Billion Ton Report, 2005

Long-term Supply:

- ***Available Urban Wood residues 63 M dry T y^{-1}***

Material	Generated	Recovered/ Un-useable	Available
Construction	11.6	3.0	8.6
Demolition	27.7	16.1	11.7
Woody yard	9.8	8.0	1.7
Wood (MSW)	13.2	7.3	6.0
Total	62.3	34.4	28.0

Expected to increase 30%. ***(McKeever, 2004)***

Converted to biochar = 7 M T Carbon

- ***Total Forest resources available for biochar production ~ 88 M dry T y^{-1} of 296 M dry T y^{-1} inventoried. (30%)***

Total biochar produced = 22 M T Carbon y^{-1}

Land Application @ 10 T $acre^{-1}$ = 2.2 million acres

Long-term Supply:

- ***Crop residues*** ***(corn stover, small grain residues)***

  - DOE estimated 428 M dry T of residues. (2006)

  - 28% (120 M dry T) will be available for conversion

  - ignore ethanol industry, convert by pyrolysis

Converted to biochar = 27 M T Carbon

- ***Dedicated crops*** ***(perennial, switchgrass, poplars, etc.)***

  - DOE reports potential production for 377 M dry T

  - Yields range from 5-10 T acre^{-1}

  - Acreage needed: 38 - 75 M acres

  - ignore ethanol industry, convert by pyrolysis

Converted to biochar = 85 M T Carbon

Total biochar produced = 112 M T Carbon y^{-1}

Land Application @ 10 T acre^{-1} = 11.2 million acres

Washington State

Forest Resources

logging debris – 1.9 M T y^{-1}

forest thinning – 0.5 M T y^{-1}

mill residues - 5.2 M T y^{-1} @10% = 0.5 M T y^{-1}

urban wood – 0.8 M T y^{-1}

3.7 *M T y^{-1}*

Converted to biochar = 0.8 M T Carbon

Crop Residues - 2.2 *M T y^{-1}* @ 20% = 0.4 *M T y^{-1}*

Converted to biochar = 0.1 M T Carbon

Total biochar produced = 0.9 M T Carbon y^{-1}

Land Application @ 10 T $acre^{-1}$ = 90,000 acres

WA State, Biomass Inventory and Bioenergy Assessment, 2005

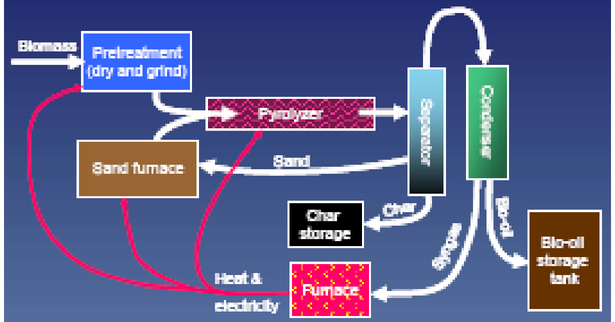
Potential Impact on Energy Security, Food Security, Global Climate Change, and Water Quality

If the U.S. were to harvest and pyrolyze 1.3 billion tons of biomass per year: We could displace 1.9 billion barrels of imported oil with domestically-produced and renewable bio-oil (about 25% of U.S. annual oil consumption). We could also sequester 153 million tons of carbon per year by amending soils with the biochar co-product. The total carbon credit (400 million tons of C per year) would reduce U.S. greenhouse gas emissions by about 10%.

Adding biochar to soils has been shown to increase crop yields for tropical soils and is anticipated to do the same for temperate region soils. Amending soils with biochar improves soil quality, because biochar acts as a liming agent, reduces soil bulk density, and increases nutrient cycling. In addition, amending soils with biochar returns to the soil most of the plant nutrients that are removed from the soil when biomass is harvested.

Biochar strongly adsorbs excess plant nutrients, pesticides and many other pollutants. Therefore amending soils with biochar reduces leaching of pollutants and thereby improves the quality of water in lakes and streams.

Fast Pyrolysis

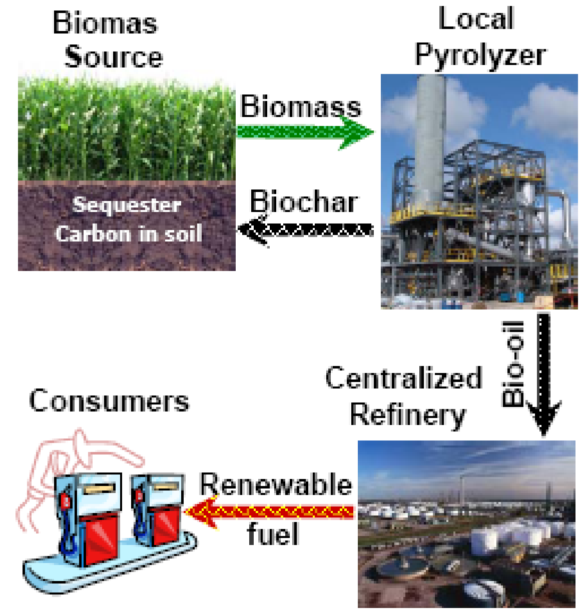


When biomass is heated in the absence of oxygen it thermally decomposes into syngas, bio-oil, and biochar. Syngas is a combustible gas that can be used to provide the energy needed to run the pyrolyzer. Bio-oil is an energy raw material with about half the heating value of fuel oil. Biochar can also be used as a renewable fuel (displacing coal) or as a soil amendment. Modern fast pyrolyzers are designed to maximize the production of bio-oil by heating the biomass to >400°C in less than one second.

Agricultural Research Service

USDA

ARS Biochar and Pyrolysis Initiative



The Biochar Vision

We envision using a distributed network of fast pyrolyzers to turn biomass (crop residue, switchgrass, yard waste, etc.) into bio-oil, a renewable energy product, and biochar, a soil amendment that builds soil quality, increases crop yields, and sequesters carbon in soils for millennia.

Biochar Report

FINAL REPORT

Use of Biochar from the Pyrolysis of Waste Organic Material as a Soil Amendment

Submitted by
Center for Sustaining Agriculture and Natural Resources
Washington State University
July 2009

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http://csanr.wsu.edu

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Key Findings: Economics

Chapter 5.

- Pyrolysis temperature influences the trade-off between production of bio-oil and biochar. Higher temperatures lead to more bio-oil and less biochar, as does fast pyrolysis versus slow pyrolysis.
- Above about 525°C, bio-oil production declines; thus this represents an economic threshold to stay below.
- Based solely on energy content, biochar is worth about $114/metric ton and bio-oil about $1.06/gallon.

Chapter 6.

- Forest thinning represents a major potential feedstock source for pyrolysis in Washington in terms of quantity of under-utilized biomass.
- Only a larger stationary facility has returns over total costs ($4/ton dry feedstock) for biochar and bio-oil production at prices based on energy content.
- The break-even selling price for biochar from a stationary facility is $87/metric ton without transportation to the end user.
- The break-even selling price for bio-oil from a stationary facility is $1.03/gallon without transportation to the end user.
- If bio-oil can be sold for $1.15/gallon, then the break-even price for biochar from a stationary facility drops to $7/metric ton.
- Labor costs are the major factor in driving up costs for a smaller mobile pyrolysis unit.
- For a stationary facility to be profitable under the assumed prices and costs, feedstock cost should not be higher than $22/ton.
- Siting pyrolysis with existing collected feedstocks, use for waste heat, and other synergies is important for its economic viability.

Key Findings: Carbon Offsets

Chapter 7.

- Biochar represents an offset of about 2.93 MT* CO_2/MT biochar.
- Biochar production via pyrolysis still provides a large C sequestration potential even after emissions from process energy are subtracted.
- Biochar can substitute for agricultural lime for raising soil pH, but is much more expensive.
- With carbon offsets, biochar production can become profitable when trading prices per metric ton CO2 are $16.44, $3.39, and $1.04 for the smaller mobile, transportable, and relocatable facilities, respectively. A stationary facility is profitable without a carbon credit.

Competing Uses: