Biochar and Soil Health

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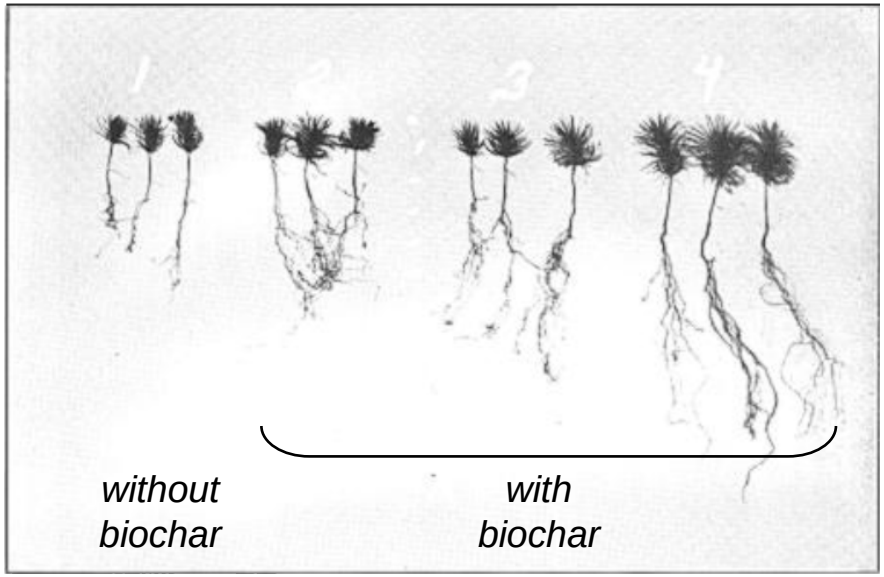
Biochar Interest

Early reports:

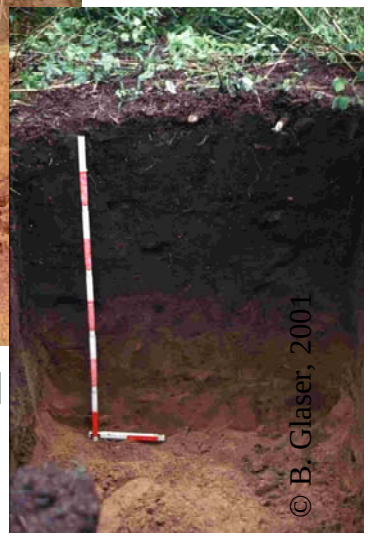
- Encyclopedia of Agriculture (Miyazaki, 1697)
- Terra Preta (Orton, 1870; Hartt, 1880; Sombroek, 1966)
- Charcoal use in soil (Allan, 1846; Trimble, 1851; Liebig, 1878)



Retan 1915 *Forestry Quarterly*

The Terra Preta - Biochar Story

'normal' soil



Terra Preta

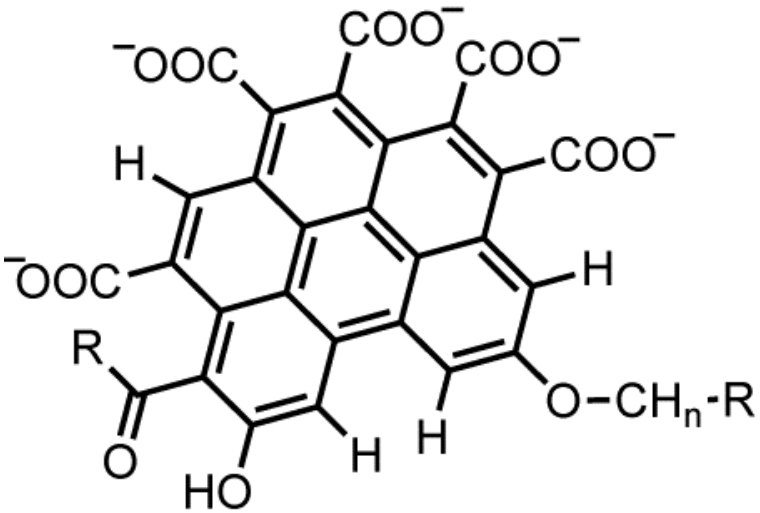
'normal' soil

"Terra Preta"

(Central Amazon, Brazil)

“Naturally” Biochar-rich and Fertile Soils

Australia

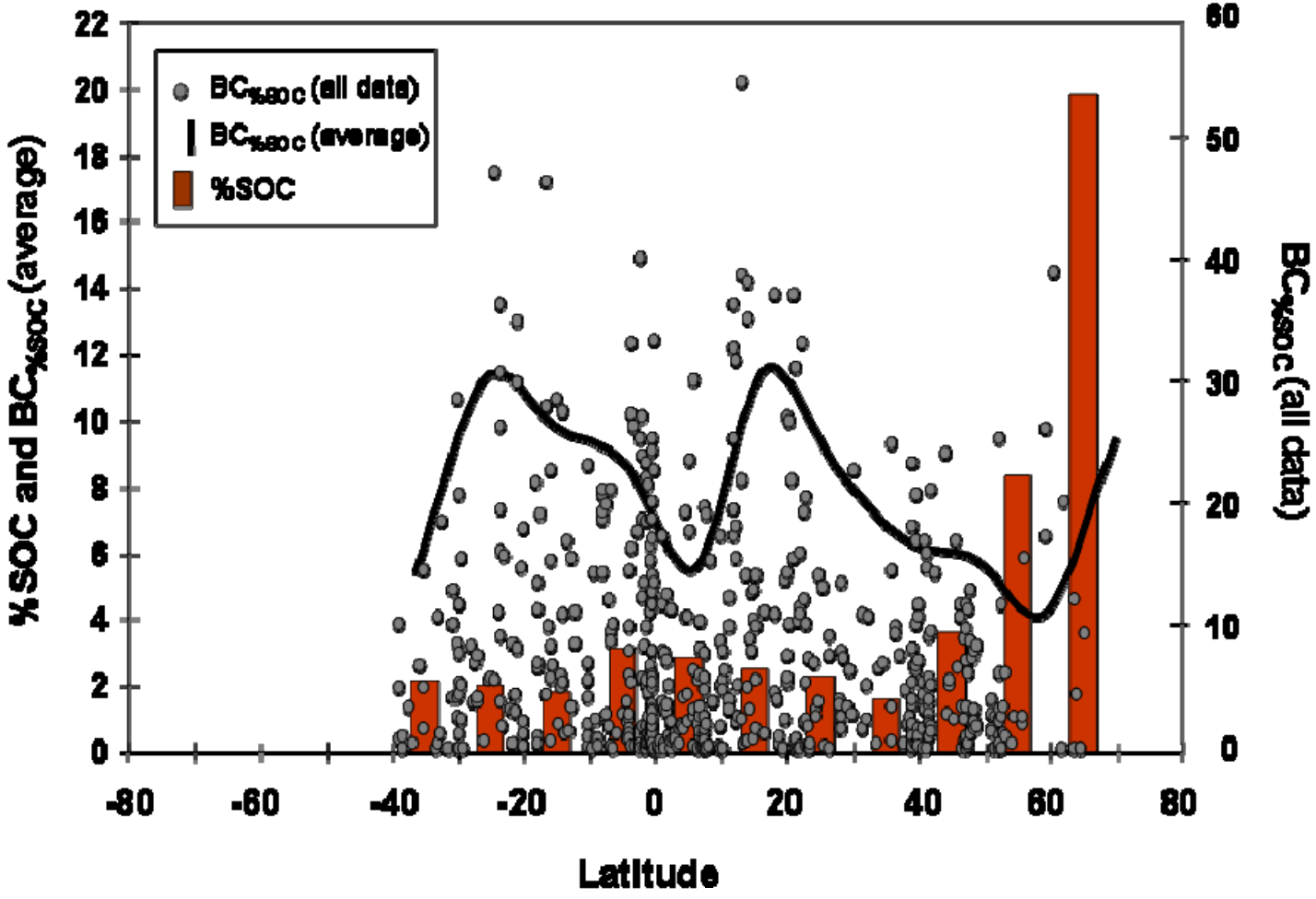


Iowa Mollisol: 50% (of OC) biochar

Downie et al 2011, AEE 140, 137-147
Mao et al., 2012, Env Sci Techn, publ online

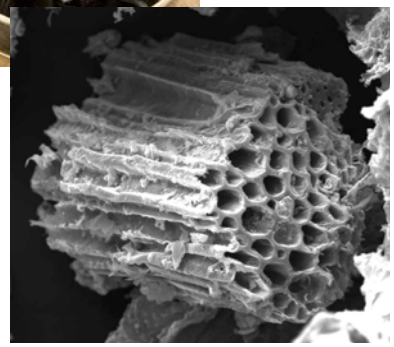
Black Carbon Rich Soils Globally

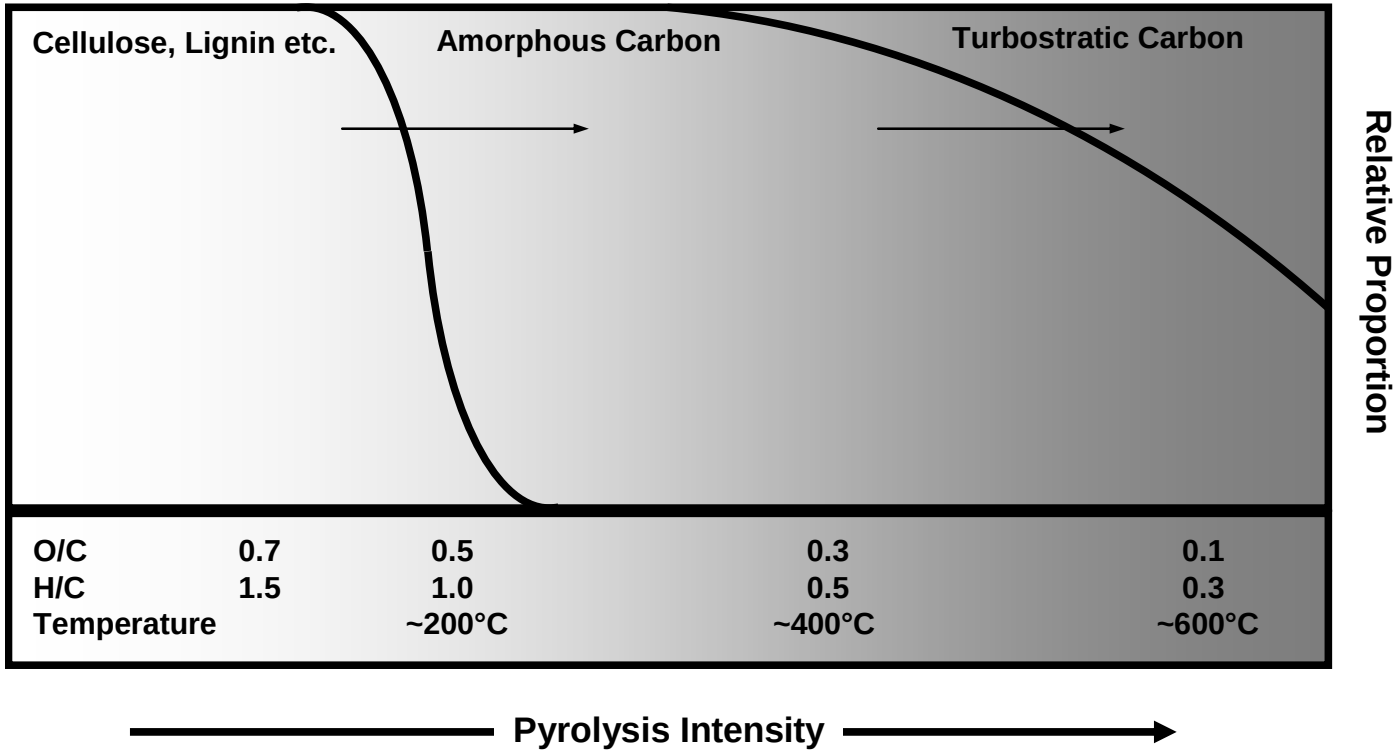
Black Carbon Rich Soils Globally



Krull et al, 2008, in: Nova Sci Publ

Biochar Conversion



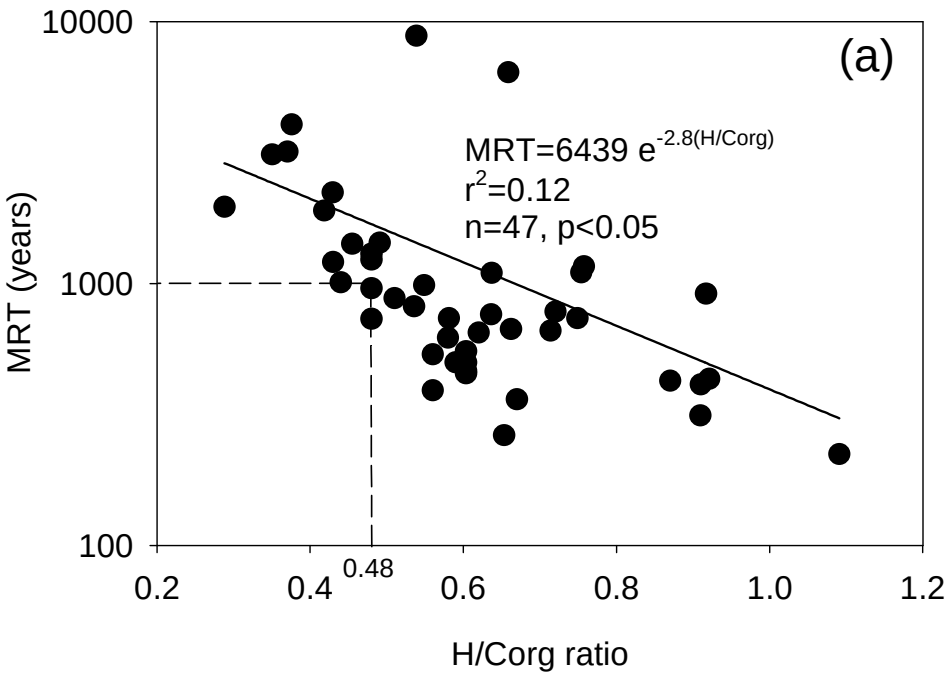


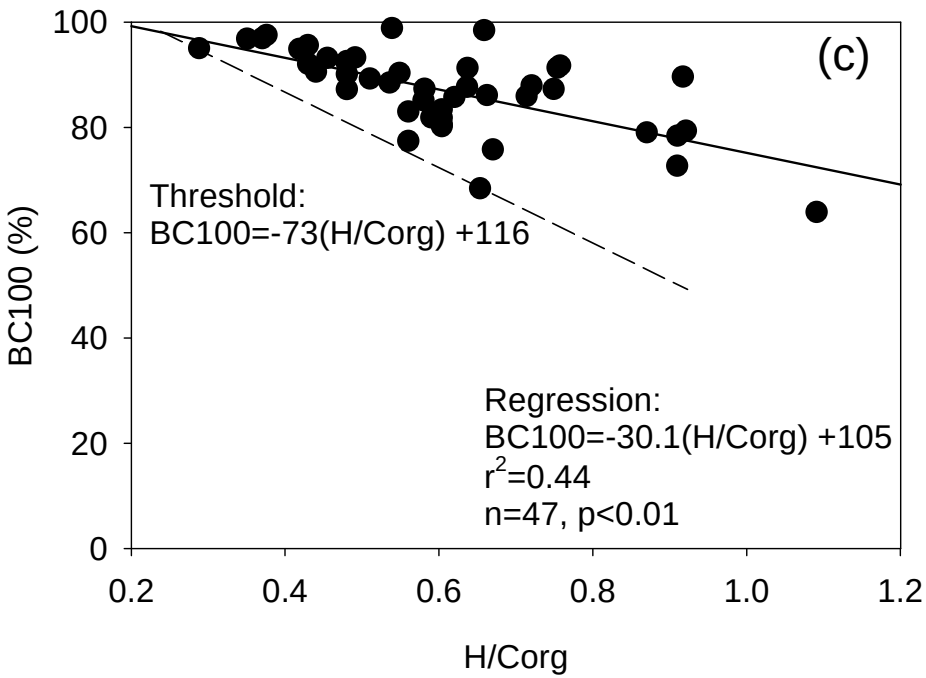
Lehmann et al., 2010, in: Imperial College Press, London

Biochar Persistence

Biochar persistence about 1-2 orders of magnitude greater than uncharred feedstock (Kuzyakov et al., 2009; Zimmerman, 2010)

Biochar Persistence in Soil





Biochars with low H/Corg ratios have high persistence
Biochars made at >500ºC from wood has H/Corg <0.48

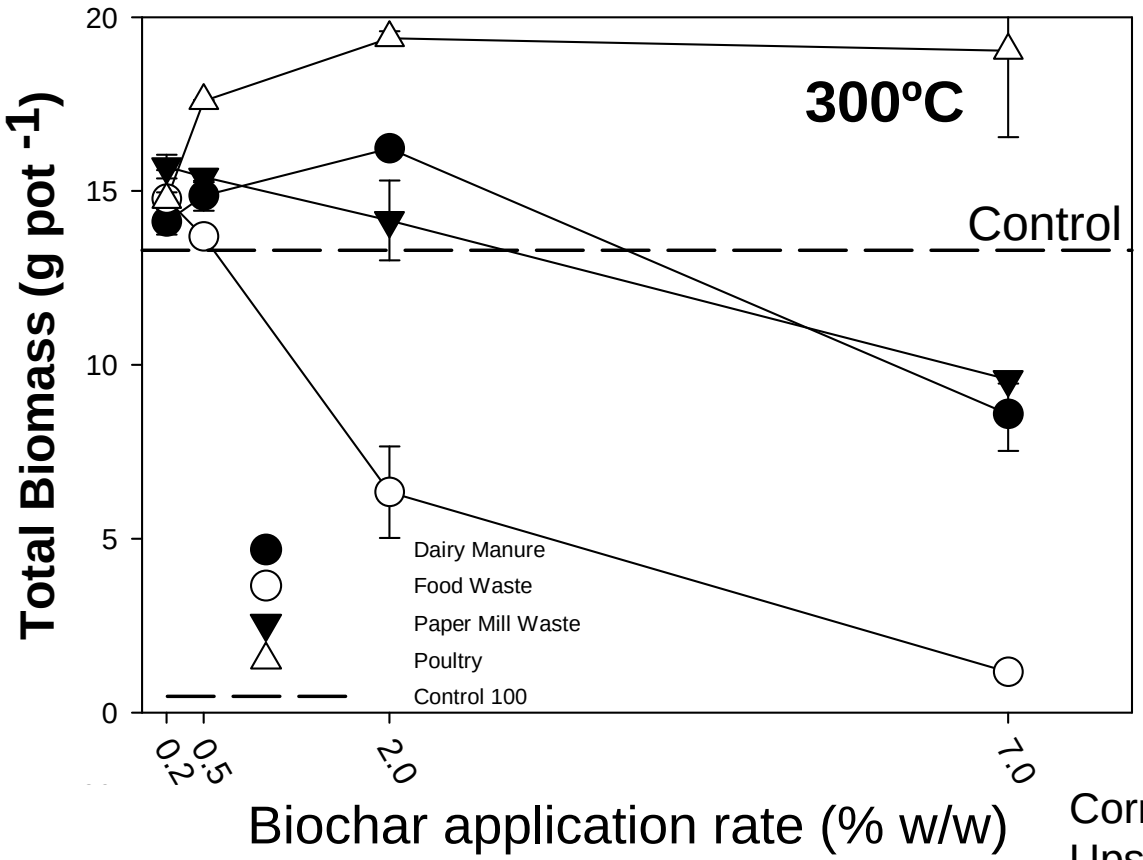
Lehmann et al, forthcoming

Biochar Properties and Agronomic Value

Corn greenhouse experiment
Upstate NY loamy soil (no significant fertility constraints)
Eight different feedstocks
Four different temperatures (300-600°C)

Rajkovich et al., 2012, BFS 48, 271–284

Dependency on Biochar Properties



Corn greenhouse trial
Upstate NY loamy soil
N=2 (mean ±SE)

Rajkovich et al., 2012, BFS 48, 271–284

Production Temperature vs Feedstock

	Mean	
Poultry manure	16.8	A
Corn stover	15.4	B
Hazelnut shells	14.3	C
Dairy manure	14.2	C
Oak	13.8	CD
Paper waste	13.7	CD
Pine	13.5	D
Food waste	10.3	E

	Mean	
500°C	14.4	A
600°C	14.	AB
400°C	13.8	BC
300°C	13.7	C

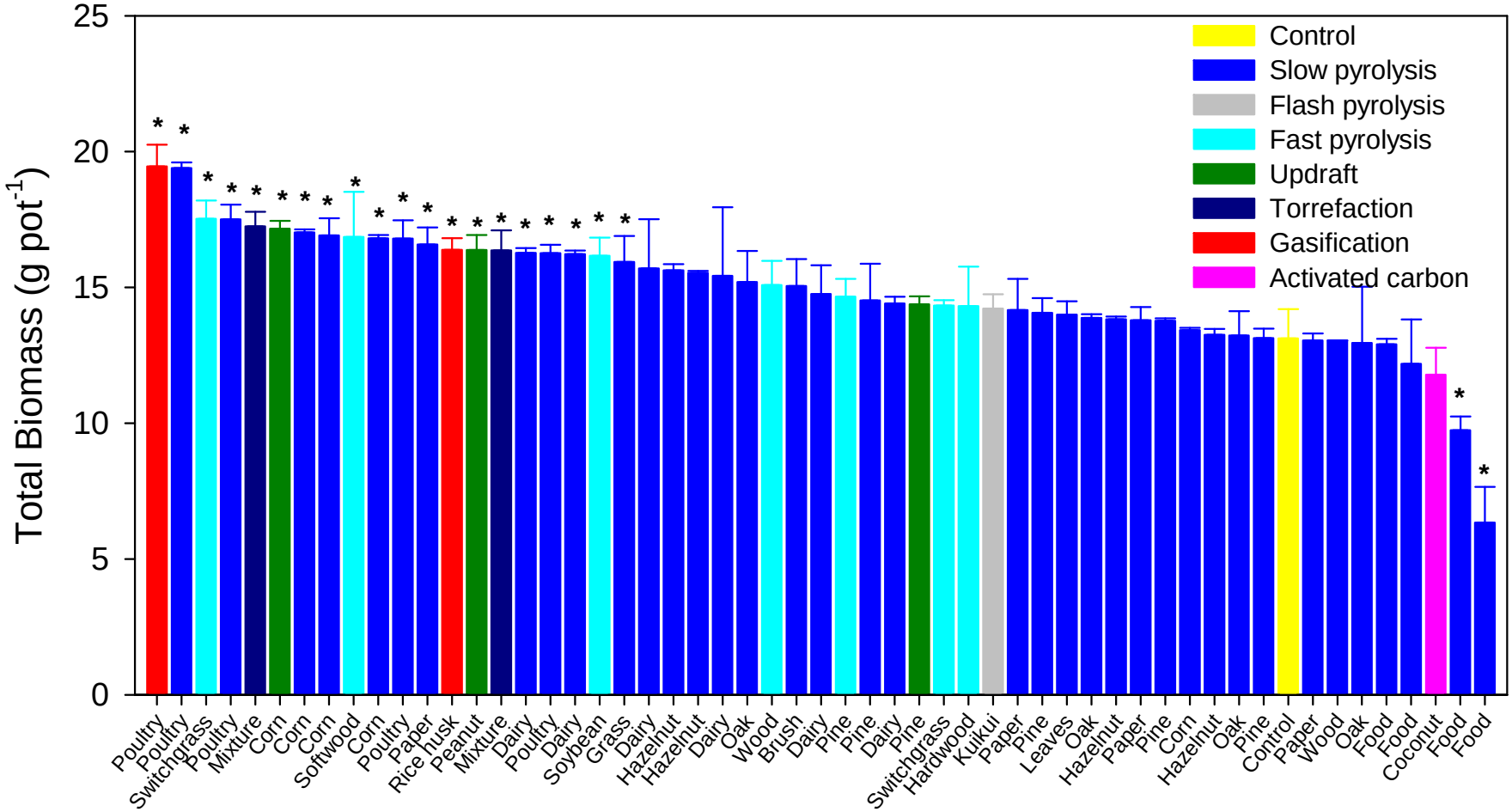
Rajkovich et al., 2012, BFS 48, 271–284

Production Temperature vs Feedstock

Effects	df Effect	MS Effect	df Error	MS Error	F value	*P*
Feedstock (F)	7	109.3	128	1.58	69.2	0.0000
Pyrolysis temperature (PT)	3	7.8	128	1.58	5.0	0.0028
Application rate (AR)	3	133.7	128	1.58	84.6	0.0000
F × PT	21	8.3	128	1.58	5.2	0.0000
F × AR	21	29.8	128	1.58	18.9	0.0000
PT × AR	9	3.5	128	1.58	2.2	0.00235
F × PT × AR	63	5.1	128	1.58	3.2	0.0000

Rajkovich et al., 2012, BFS 48, 271–284

Production Procedure vs Feedstock



Rajkovich et al., 2012, BFS 48, 271–284

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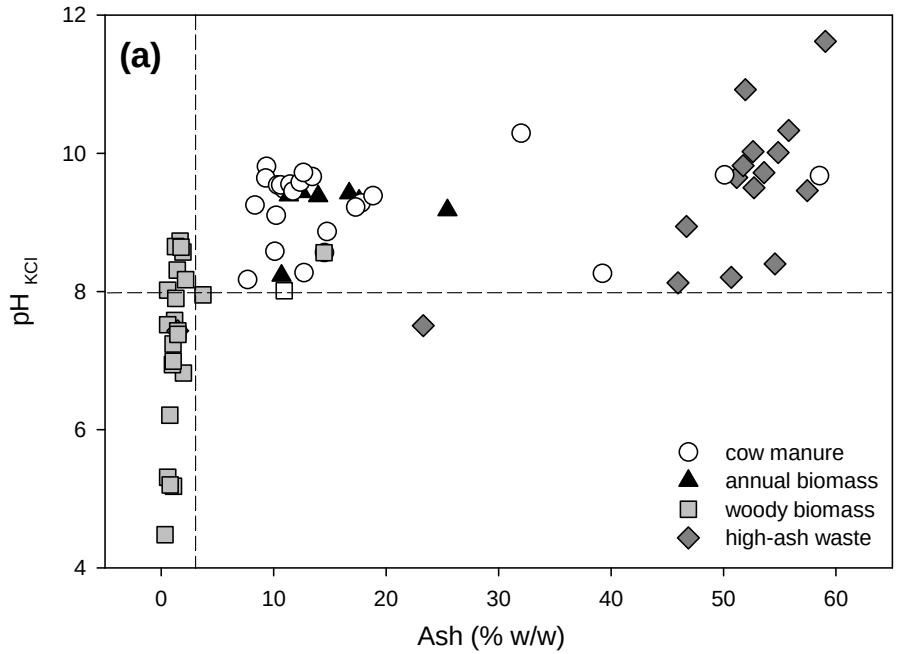
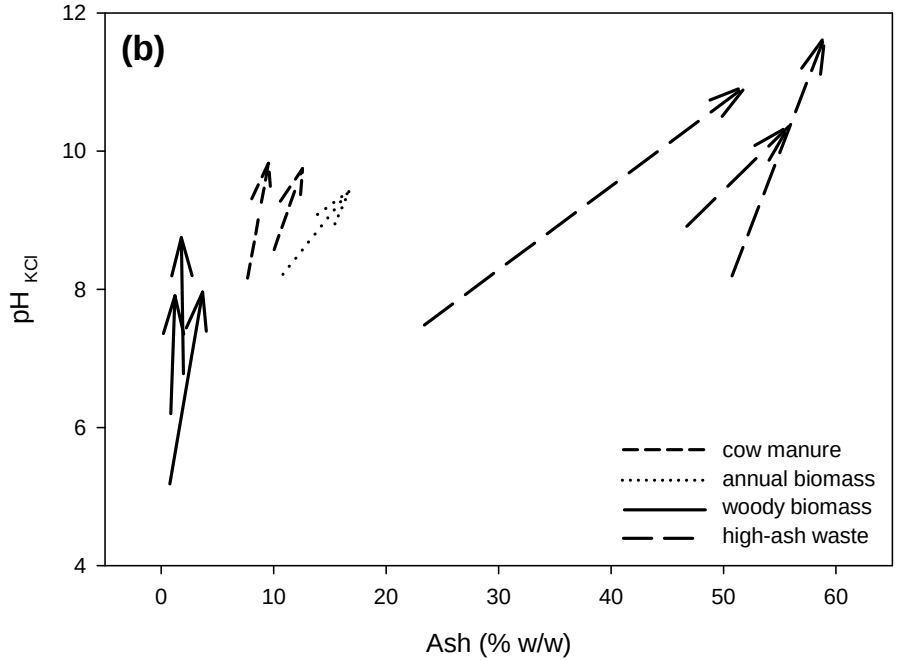
Biochar Properties and Agronomic Effects

Arrows from lowest to highest temperature within a given feedstock

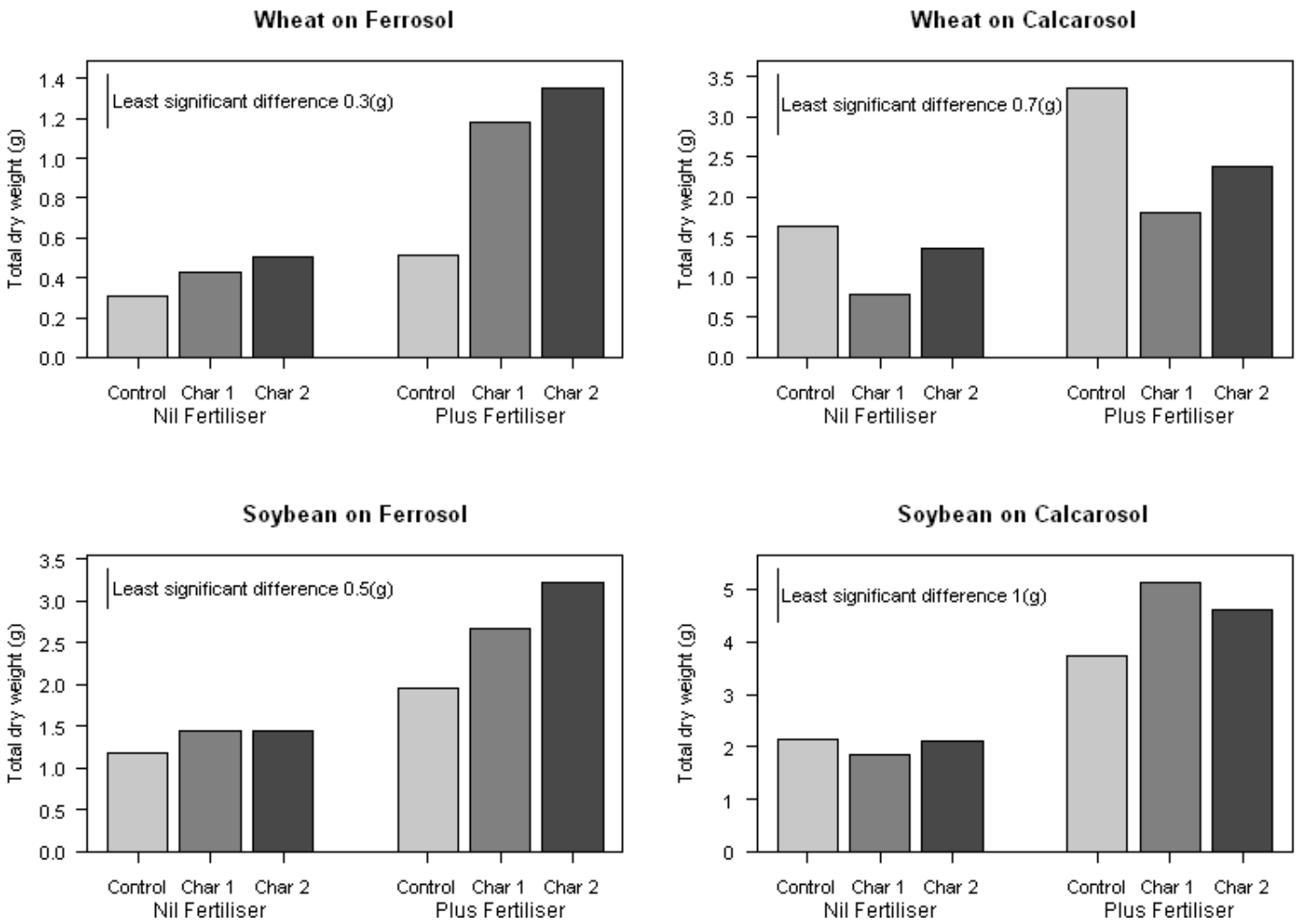




Slow pyrolysis

Enders et al.,
2012, Biores. Techn. 114, 644-653

Biochar Properties and Agronomic Effects

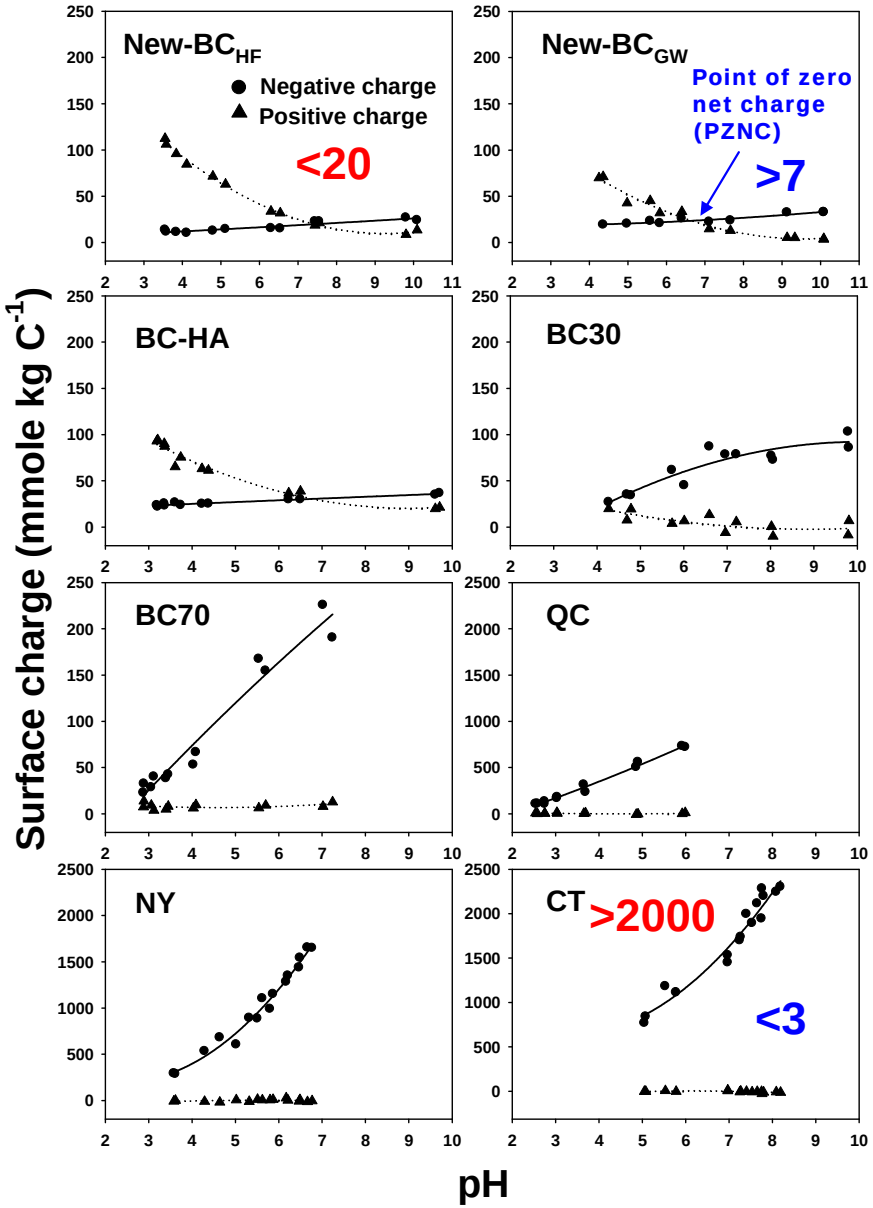


Australia
10 t/ha biochar from paper mill waste+ wood chips (550°C; pH 9.4; 8.2)

Van Zwieten et al., 2010, *Plant and Soil* 327:235–246

Biochar and Nutrient Retention

130-year-old Biochar (from pig iron production) in comparison to biochar made with traditional kilns



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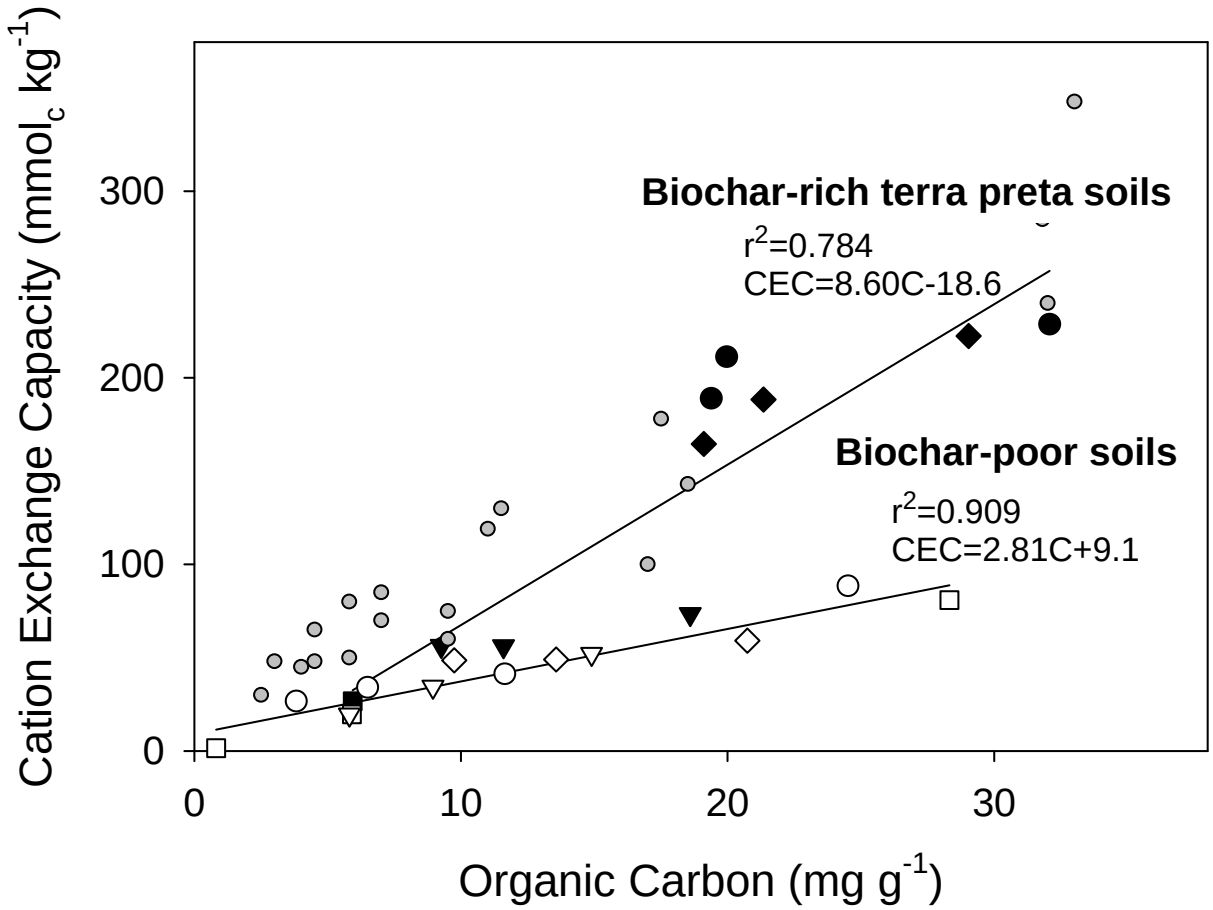
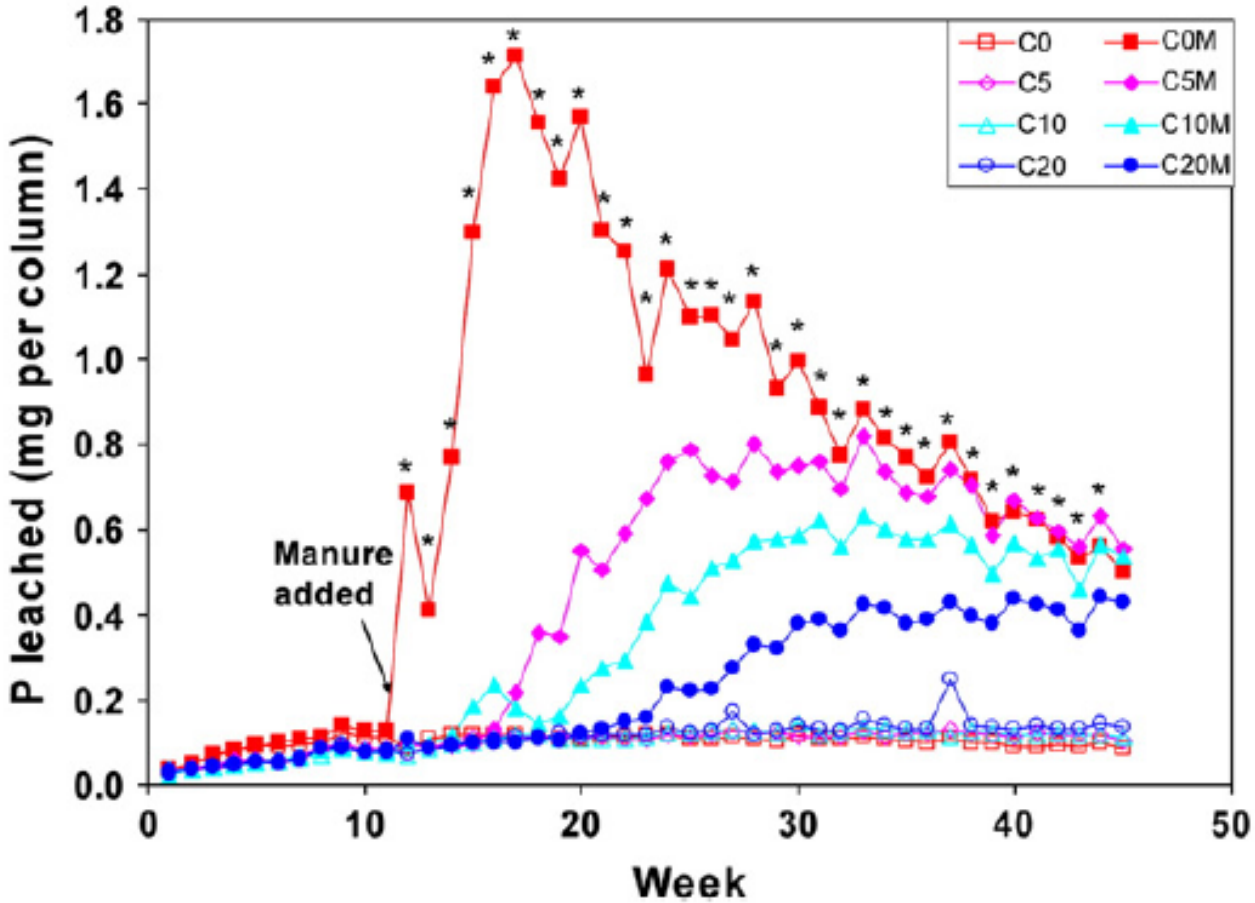
Cheng et al, 2008, *GCA*, 72, 1598-1610

Biochar and Nutrient Retention



Liang et al., 2006, *Soil Sci. Soc. Am. J. 70: 1719-1730*

Biochar Properties and Nutrient Leaching



Typic Hapludoll, Iowa
Hardwood charcoal
Column experiment, n=6

Laird et al, 2010, Geoderma 158, 436-442

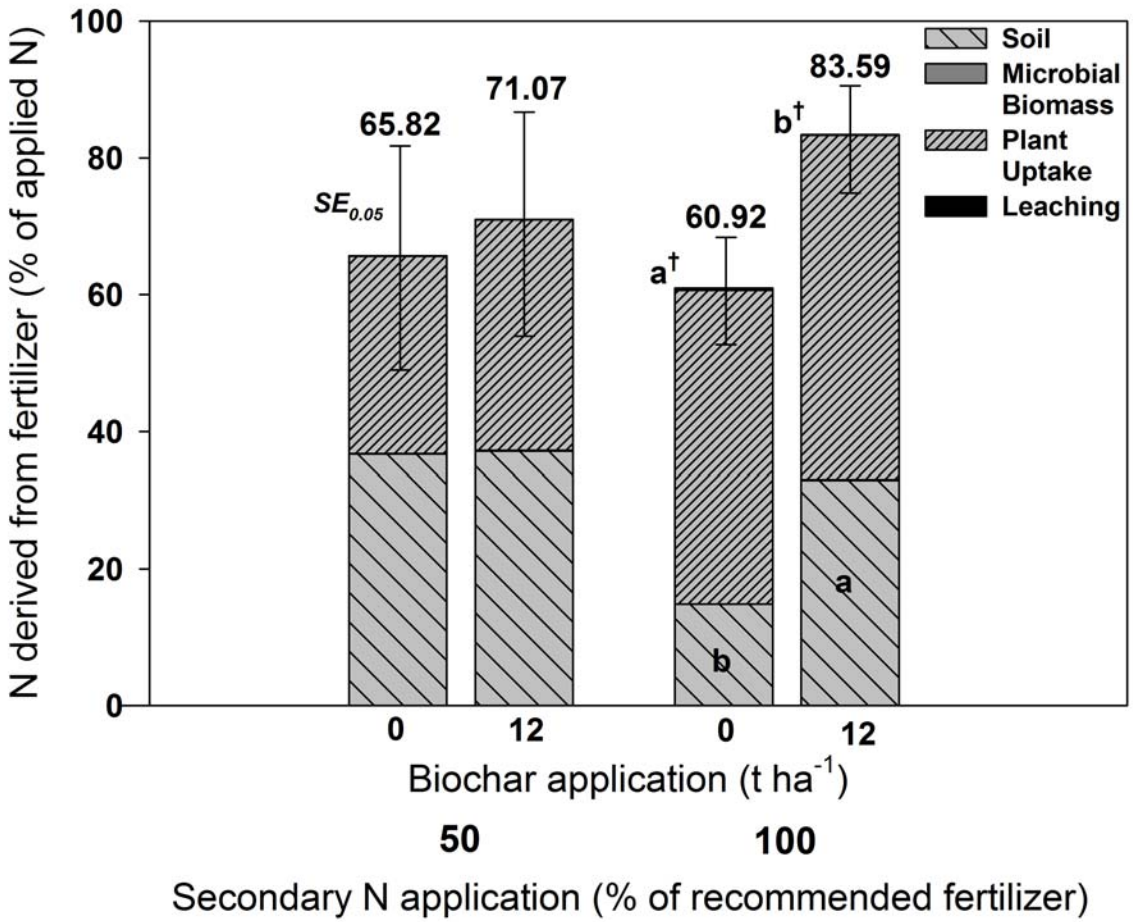
Biochar Effects on N Use Efficiency

Year	Secondary N fertilizer (% of recommended fertilizer application)	Total N uptake (kg total N ha^{-1}) 0 t ha^{-1}	12 t ha^{-1}	*p* (biochar effect)
2007	50	55.69	46.61	0.5996
	100	68.77	58.68	0.2596
2008	50	78.26	80.44	0.8683
	100	116.22	116.28	0.9958
2009	50	72.88	69.55	0.7416
	100	112.28	121.58	0.4565
2010	50	97.50	87.82	0.7899
	100	113.01	116.23	0.7294
p (N effect)		0.0117	0.0048	

Corn field experiment
Biochar application in 2007
Corn stover biochar (550°C)
Nitrogen study in 2009
N-15 labeled NH_4 (10 atom%)
N=3

Guerena et al., 2013, Plant Soil

Biochar Effects on N Use Efficiency



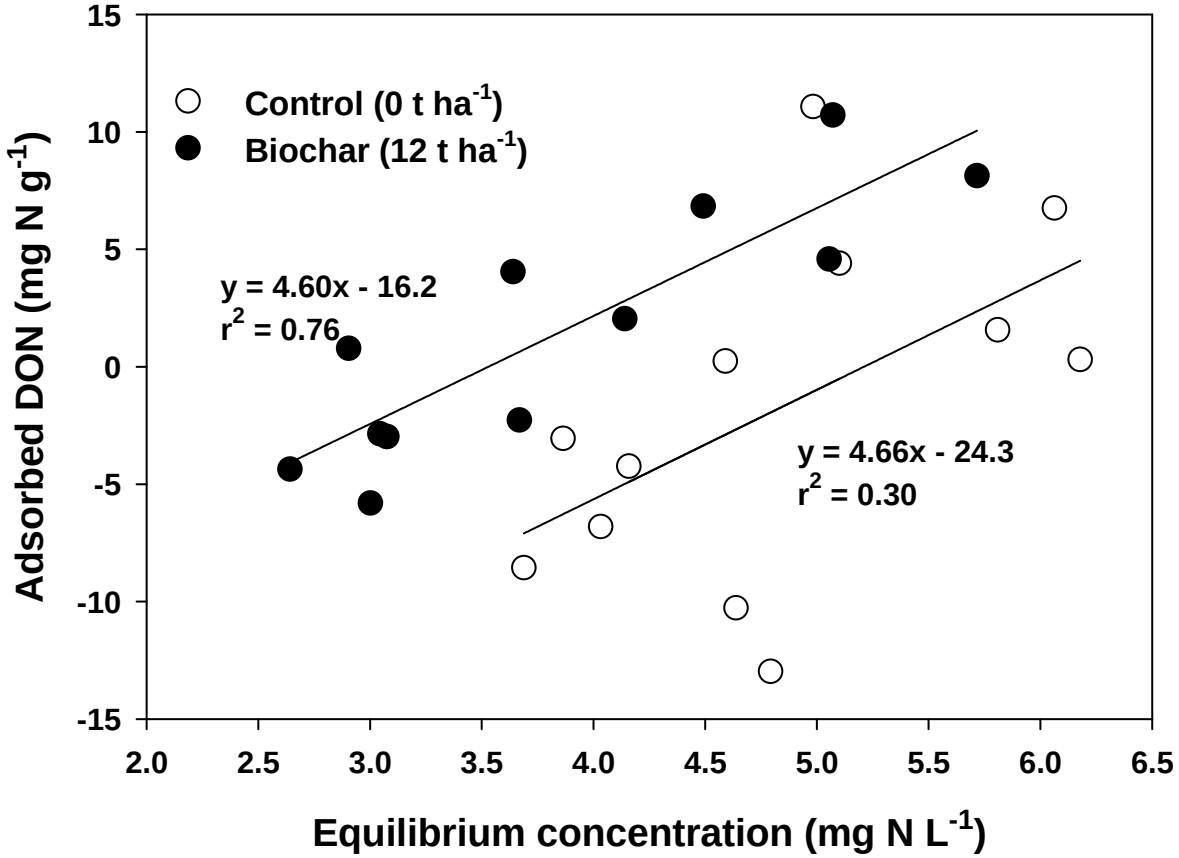
One order of magnitude greater NO_3 than NH_4 leaching

More organic N leaching than NH4 leaching

Guerena et al., 2013, Plant Soil

Biochar Effects on N Use Efficiency

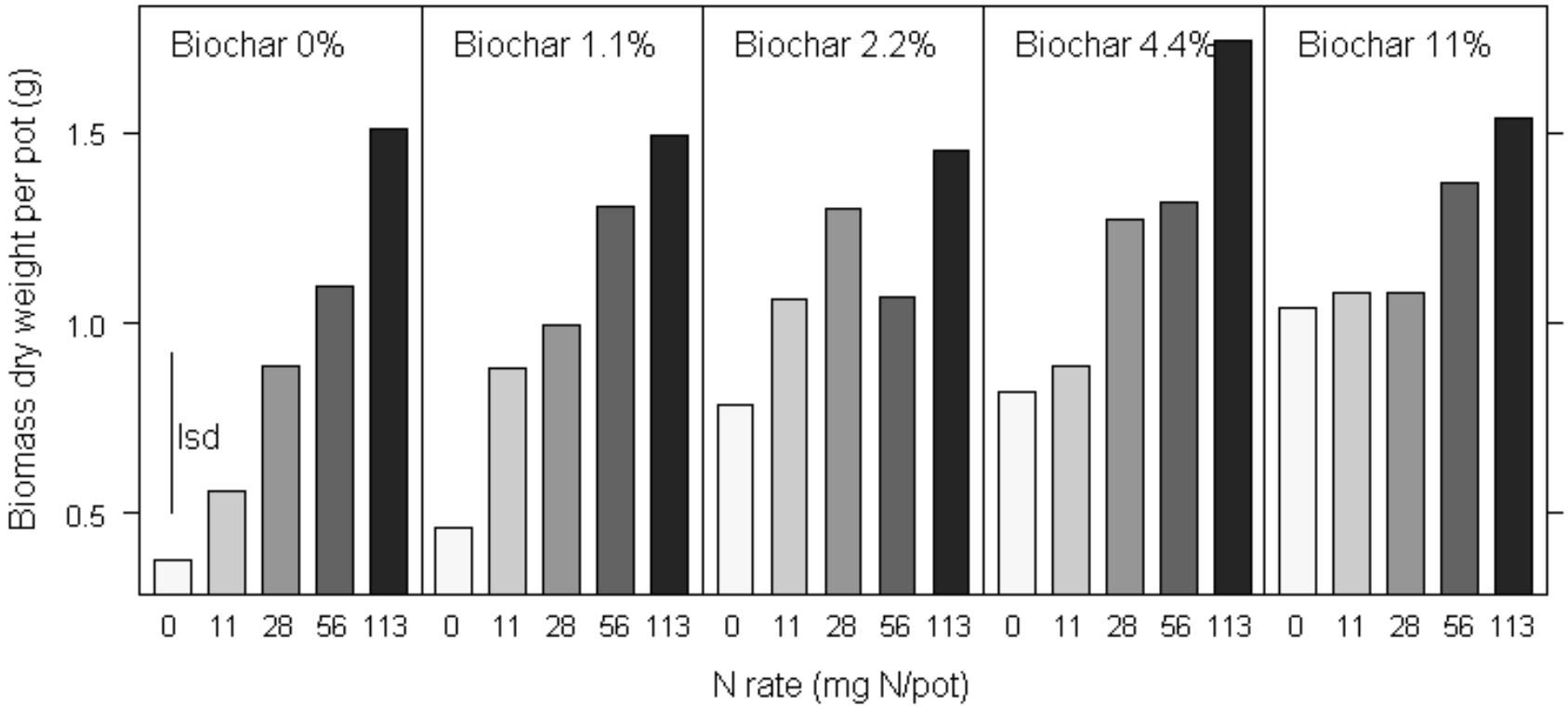
Organic Nitrogen Retention in Soil?



Guerena et al., 2012, Plant Soil

Biochar Effects on N Use Efficiency

Similar plant growth at lower N application



Van Zwieten et al., 2010, AJSR

Biochar Effects on Denitrification

Soil	Fluxes of N_2 and N_2O when the difference between biochar and control N_2O fluxes was maximum**					
	N_2 ($\mu mol\ kg^{-1}\ soil\ h^{-1}$)		N_2O ($\mu mol\ kg^{-1}\ soil\ h^{-1}$)		$N_2O/(N_2 + N_2O)$	
	Control	Biochar	Control	Biochar	Control	Biochar
Elba	2.75	3.03	17.39	17.99	0.864	0.856
Lins	0.06	0.06	2.26	0.44	0.972	0.850
Arkport	15.77	4.82	0.54	0.09	0.053	0.038
Lentiscosa	3.41	23.73	4.45	2.34	0.550	0.159
Tioga	0.12	0.14	1.43	0.38	0.820	0.651
Howard	1.23	2.08	7.46	9.39	0.793	0.766
Secanos	5.23	0.76	3.64	0.61	0.443	0.394
Cabezo	10.95	4.29	1.74	0.67	0.295	0.142
Hudson A	0.22	0.22	0.36	0.48	0.607	0.291
Madalin	0.58	0.97	3.64	0.17	0.795	0.130
Niagara	0.41	1.06	18.53	9.10	0.971	0.854
Hudson B	3.59	4.04	7.28	4.61	0.643	0.511
Costa	7.79	14.25	5.67	2.36	0.458	0.179
Coronela	14.49	2.26	9.99	1.47	0.468	0.244
Guarapuava	0.17	0.09	1.63	0.14	0.782	0.447

Values are the mean of 4 replicates.

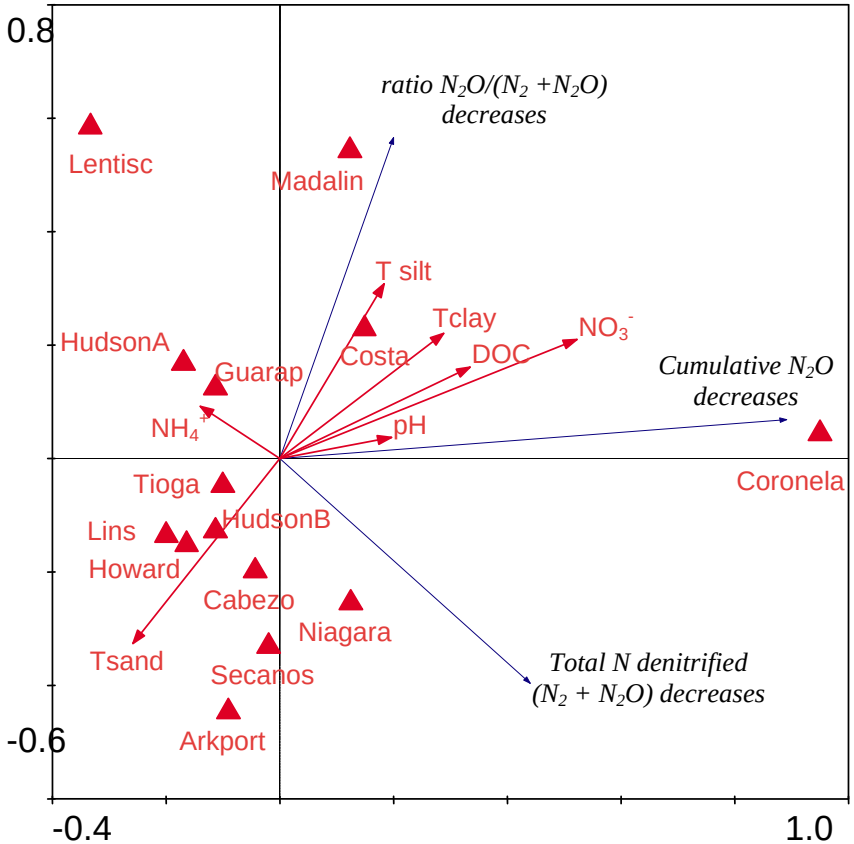
N_2O emission decrease by 10-90% in 14 different agricultural soils

In 10 out of the 15 measured soils, also the total N denitrified between 4 and 232%

Cayuela et al., 2013, sumitted

Biochar Effects on Denitrification

Reason for decreases in denitrification



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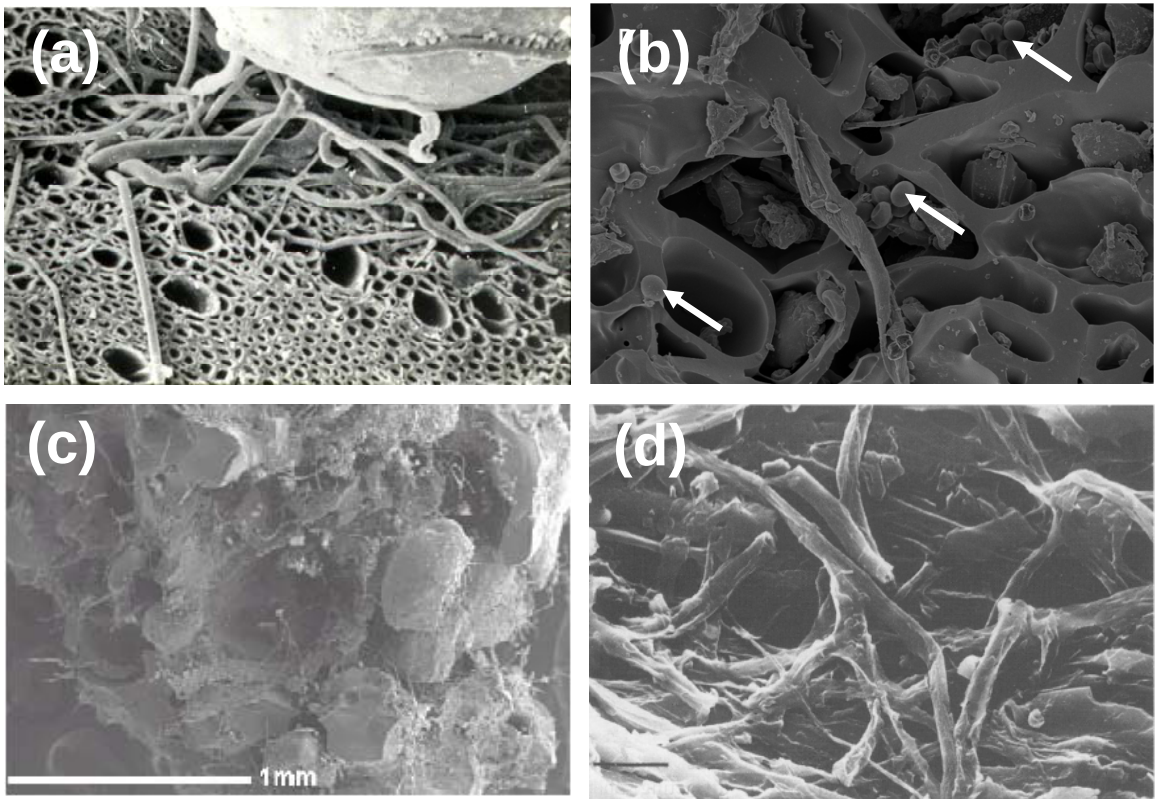
Cayuela et al., 2013, sumitted

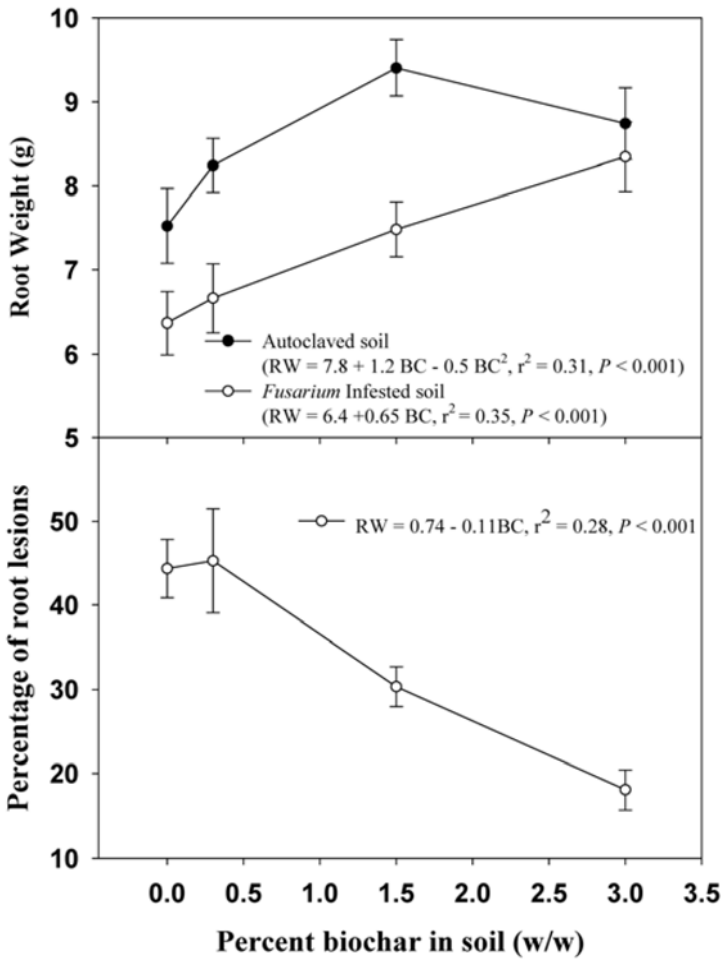
Biochar Effects on Soil Biota



- Microorganisms observed on biochar surfaces
- Total microbial biomass increases in most studies
- Effects largely unexplored

Lehmann et al, 2011, Soil Biol Biochem 43, 1812–1836

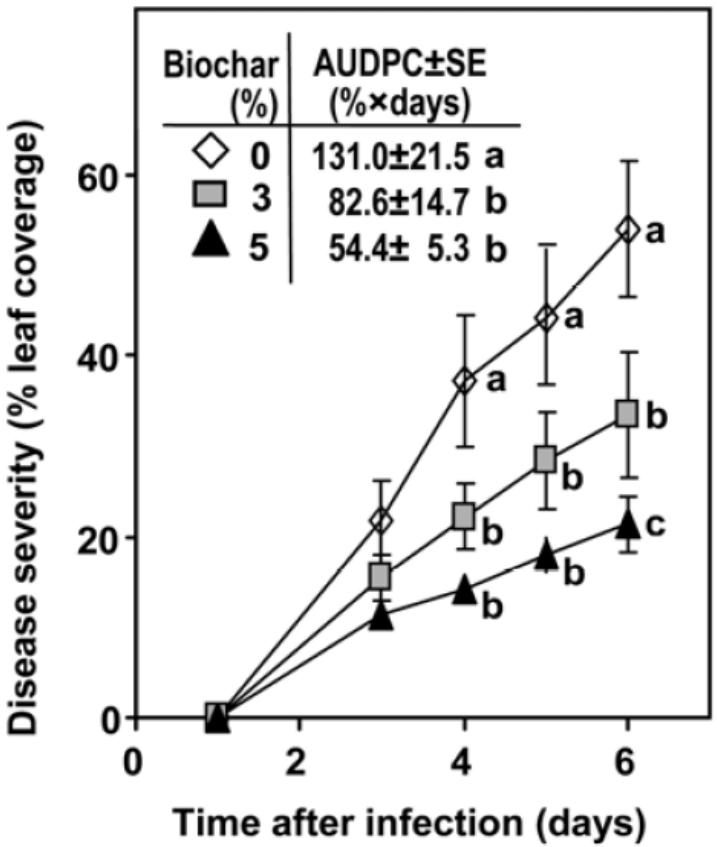
Biochar Effects on Plant Disease



Fusarium on asparagus

Elmer and Pignatello, 2011, *Plant Disease 91*, 960-966

Biochar Effects on Plant Disease



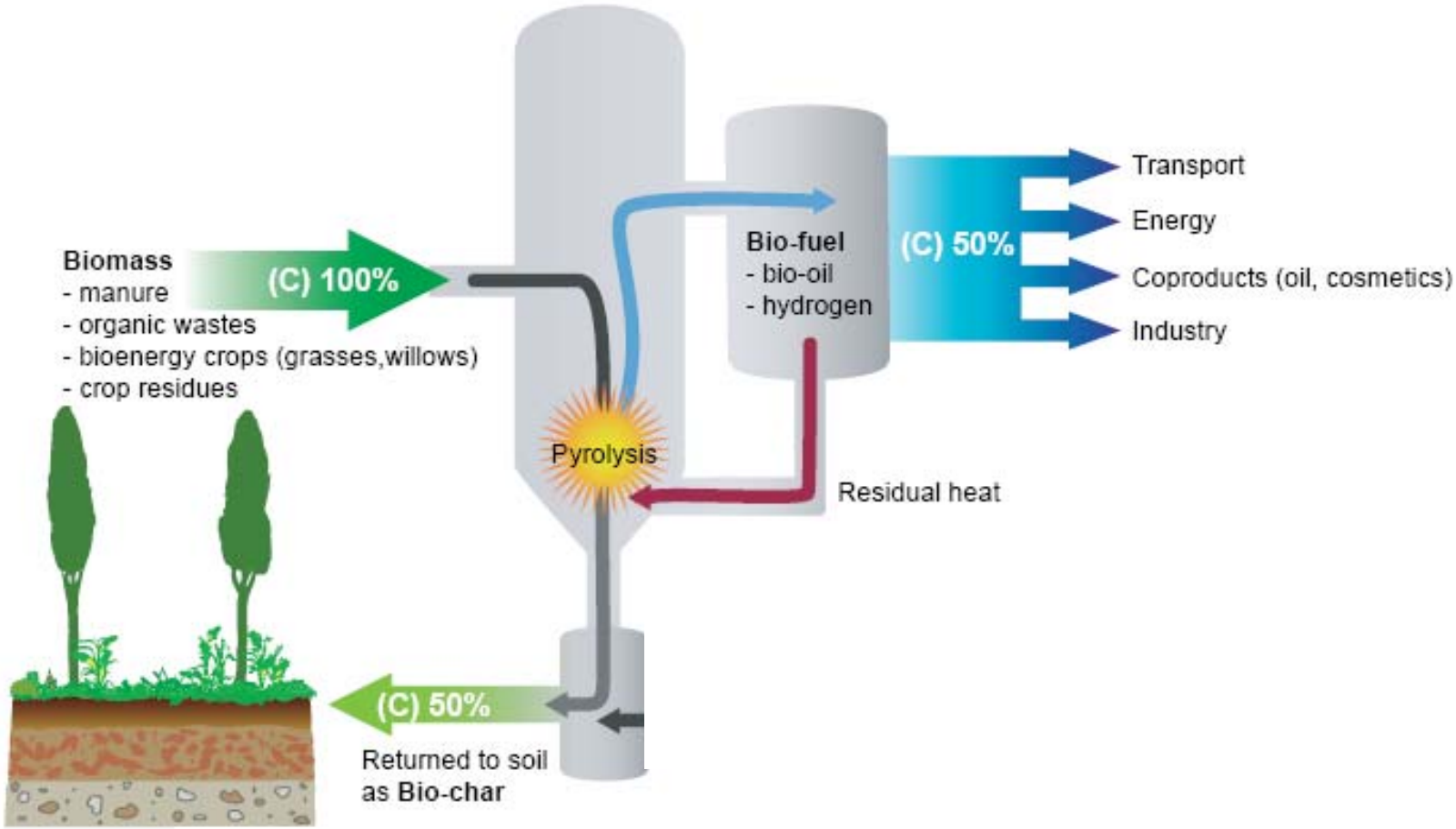
Grey mold on tomato
Area under disease progression

Several studies have shown disease reductions with biochar additions.
Mechanisms unclear, longevity of effect unquantified

Elad et al, 2010, *Phytopathology* 100, 913

Biochar Products

Biochar as a System



Biochar Systems – Beyond Material