Recycling nutrients and carbon from waste-to-fertilizers

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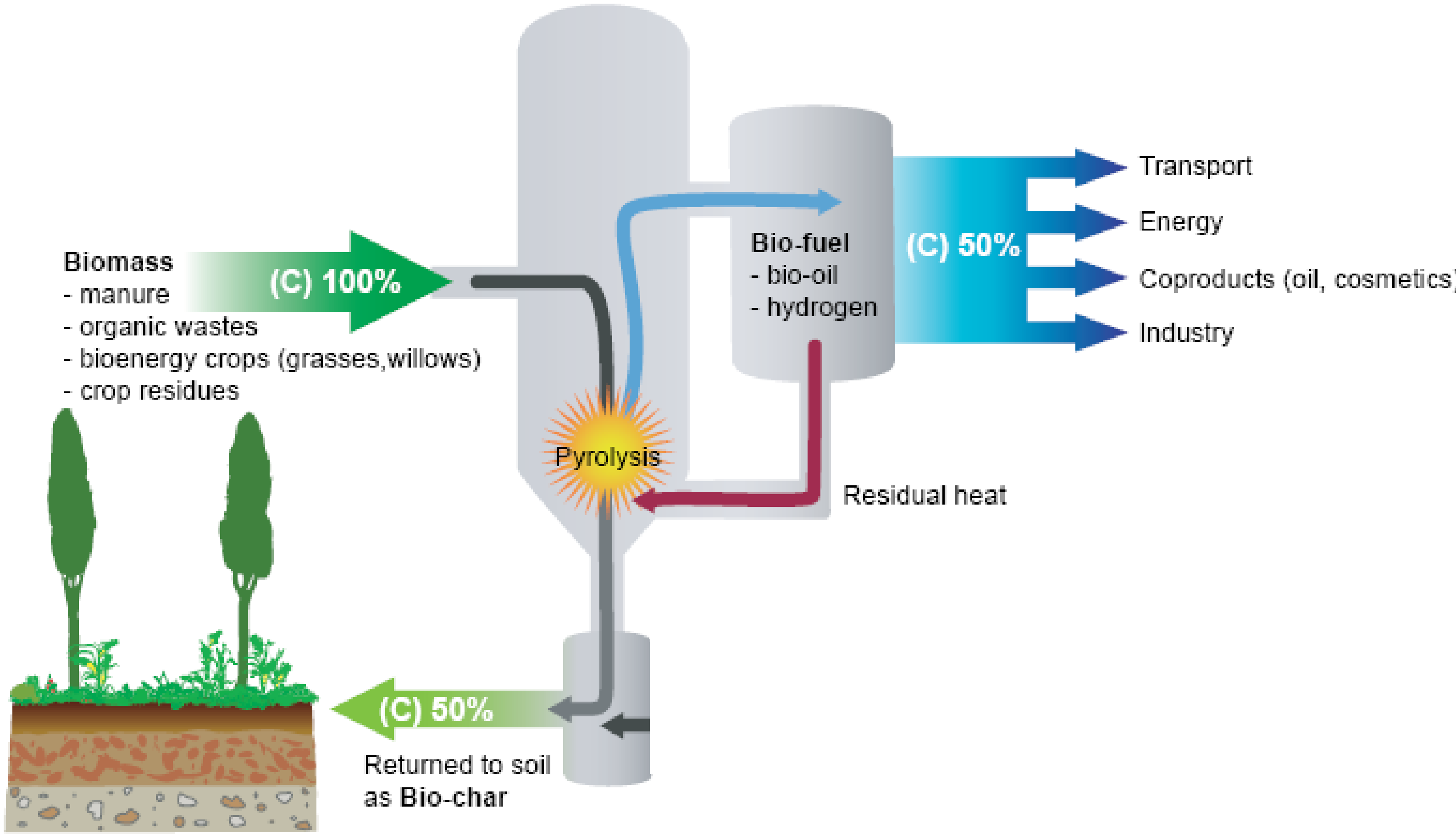
Pyrolysis-Biochar System



Lehmann, 2007, Frontiers in Ecol Env

Chapter 1: Biochar as a Soil Amendment

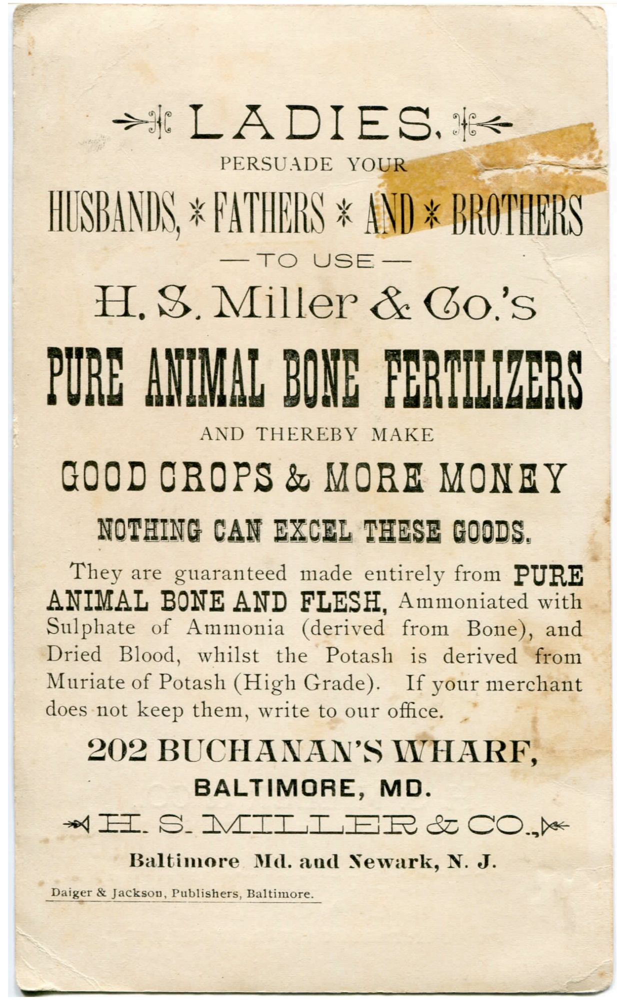
Carbon Product
Carbon persistence
Surface area and functional groups
Electron shuttle and fused arom.

Soil Health
GHG reduction + C sequestration
Pollution reduction by leaching and gas emissions
Soil remediation
Inoculant carriers
Signaling (plant-plant; plant-MO)

Nutrient Product
Nutrient enrichment
Nutrient availability
Sterilization
Denaturing of pollutants

Fertilization
Pollution avoidance

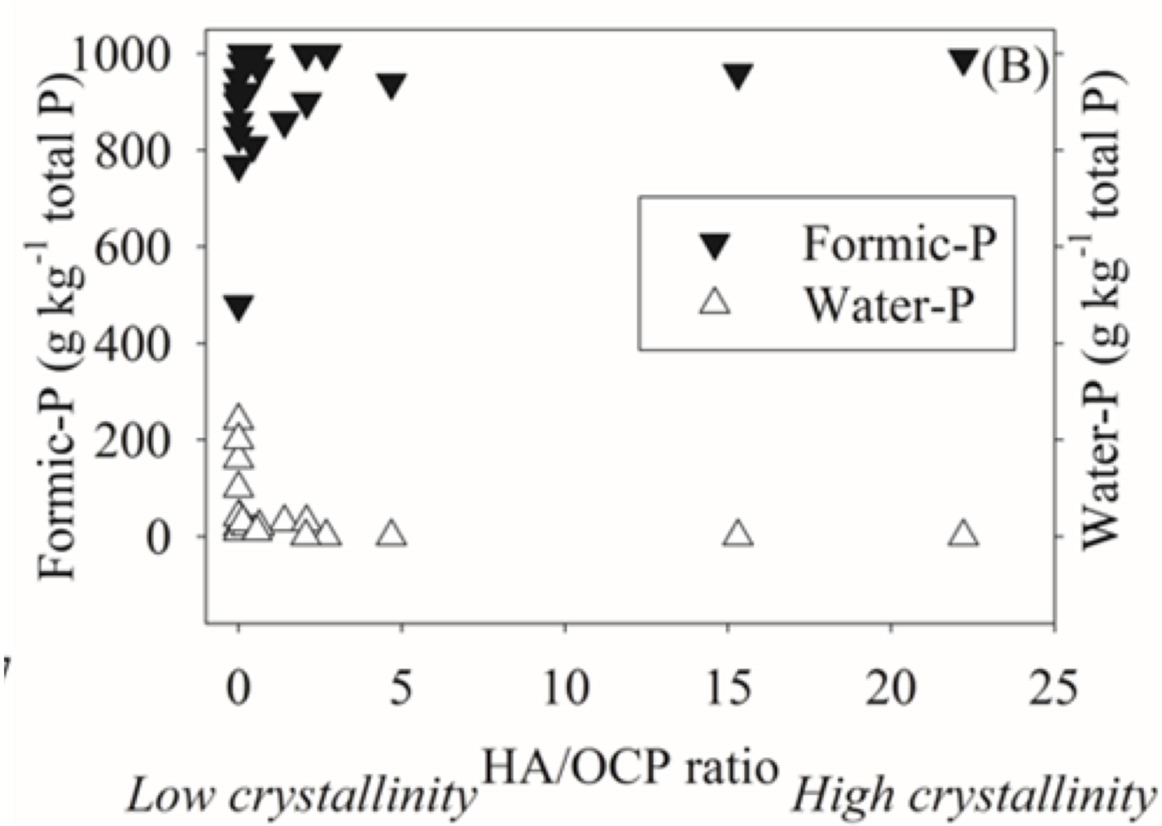
Fertilizers from animal residues is NOT New

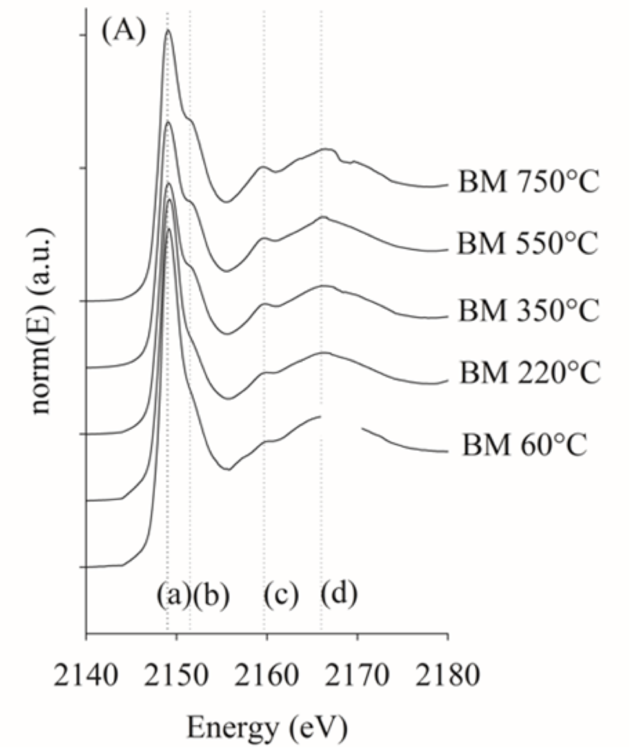


Pyrolysis Fertilizers are NOT New

Pyrolysis of Slaughterhouse Wastes

P: 8% to 15% (Rock P: 8%; TSP 20%)

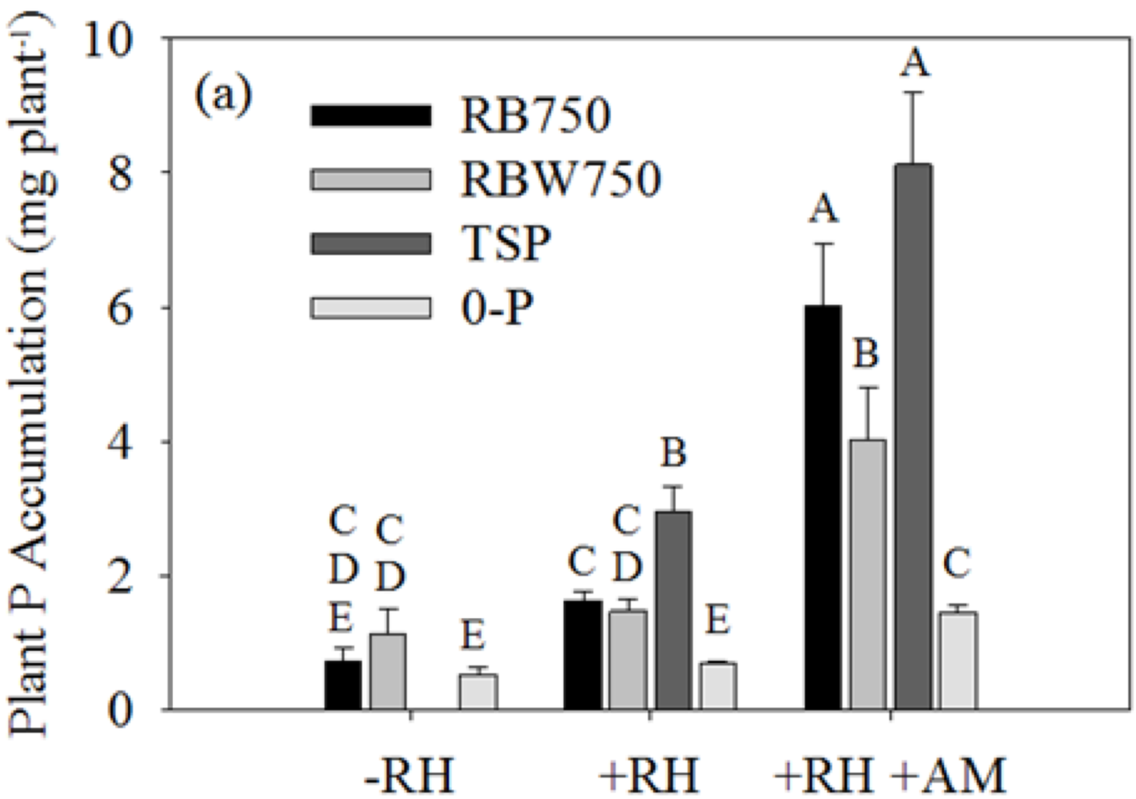




Zwetsloot et al, 2015, *J Sci Food Agriculture* 95, 281-288

Pyrolysis of Slaughterhouse Wastes

No significant different plant P uptake between bone char (RB750) and TSP

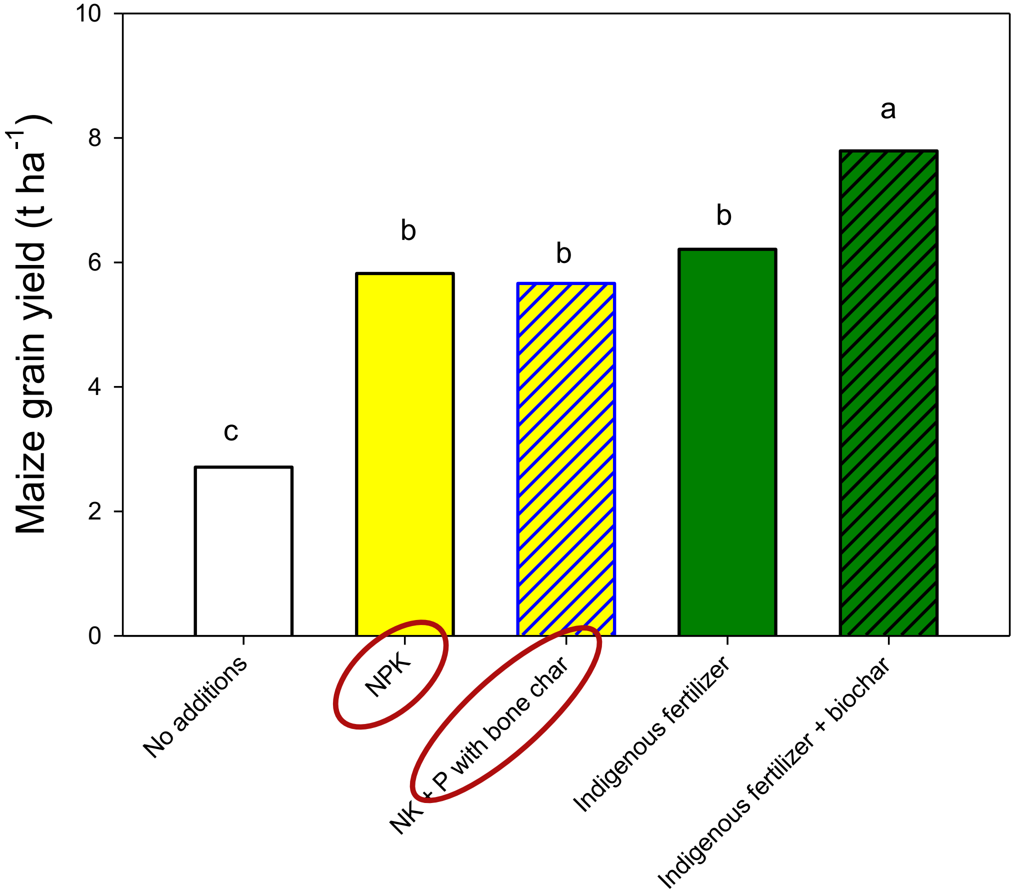


Greenhouse trial
Z. mays after five weeks (n=5)
(-RH) without root hairs
(+RH) with root hairs
(+RH +AM) with root hairs and AM inoculants

Zwetsloot et al, 2016, *Plant and Soil* 408, 95–105

Bone Char as a Fertilizer

Char P has similar effectiveness as commercial P fertilizer



(n=10)

Recycling of Dairy Manure using Pyrolysis

No contaminants (heavy metal, PAH, PCB, dioxin/furans, etc.)
No pollutants from manure (pathogens, hormones, antibiotic)

Value as ingredient of potting mix: appr. \$1,900 ton^{-1}
83% from non-nutrient value (as potting mix)

www.pyrolysis.cals.cornell.edu

INNOVATION CENTER FOR U.S. DAIRY
HEALTHY PEOPLE • HEALTHY PRODUCTS • HEALTHY PLANET

Enders et al., 2019, Soil Sci Soc Am. Ann. Meeting

Recycling from Urban to Agriculture

STANFORD UNIVERSITY & THE CLIMATE FOUNDATION
A Sanitation System That Converts Human Waste into Biological Charcoal
Reinvent the Toilet Challenge

BILL & MELINDA GATES foundation

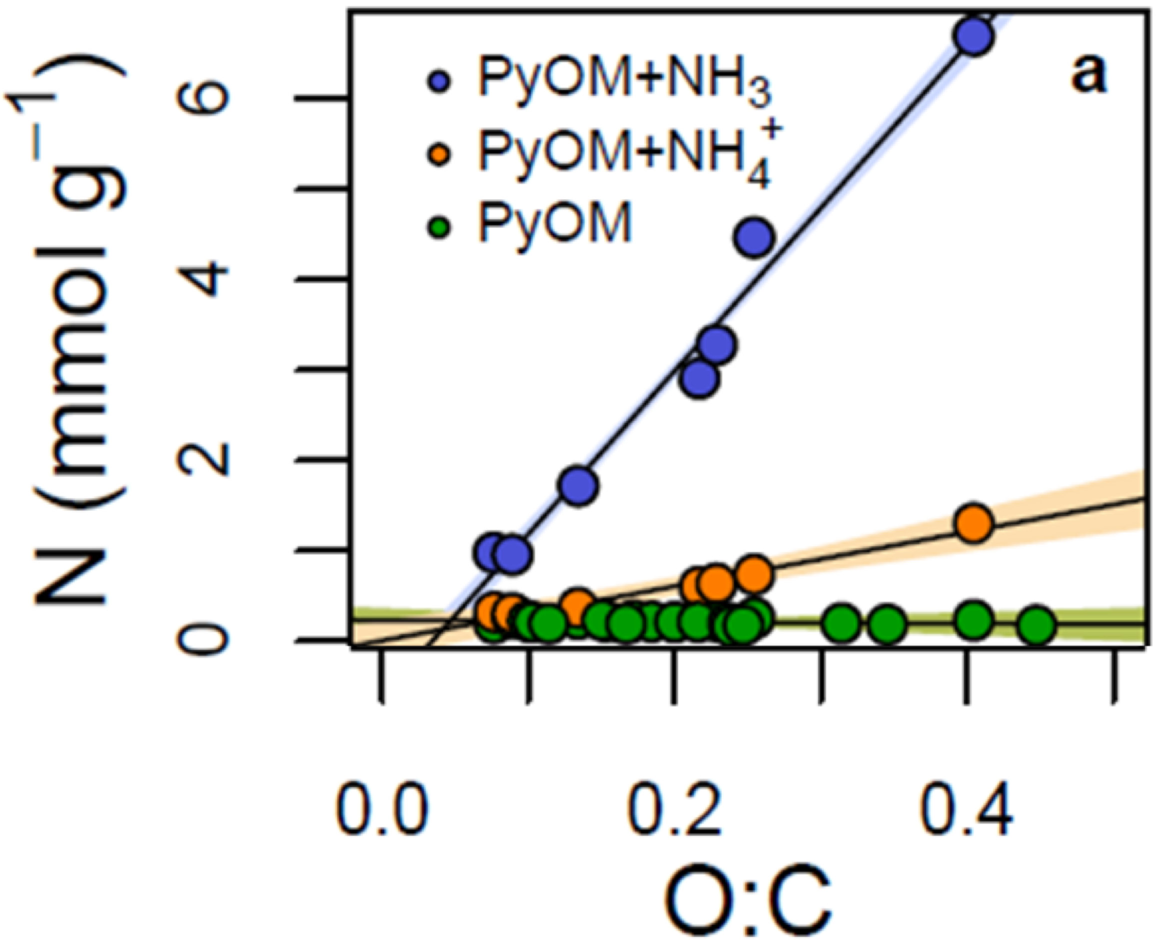
Biochar as Adsorber

Biochar	Solution	Total N before urine (%w/w)	Total N after urine (%w/w)	**ΔN after urine (%w/w)**
500°C HSW	**Fresh urine + HCl**	3.33 ± 0.08	4.47 ± 0.17	**1.14 ± 0.19**
	Fresh urine		3.59 ± 0.05	0.26 ± 0.09
	Deionized water		3.71 ± 0.02	0.38 ± 0.08

- **N retention primarily NH_4^+ at pH <7**
- **Greater than predicted by CEC, 1.14% vs. 0.31% (w/w)**

Kroumbi, prelim. data

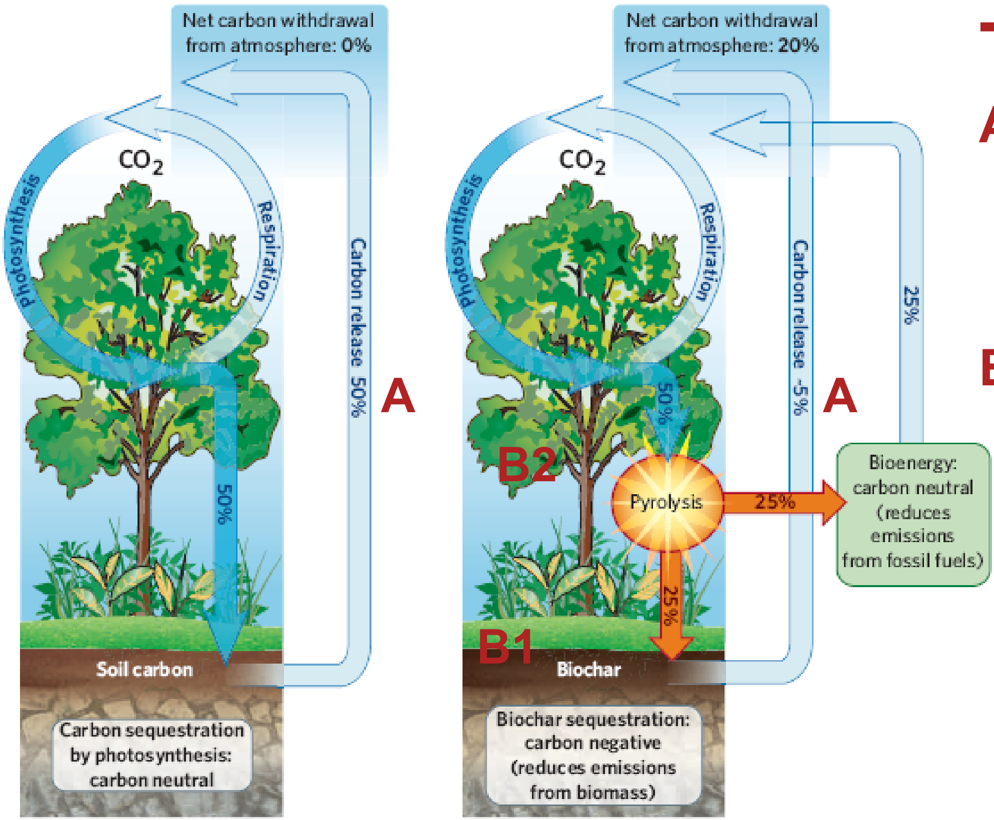
Biochar Oxidation and NH_3 Retention



Up to 18% N

Hestrin et al, 2019, *Nature Communications* 10, 664

Biochar Climate Mitigation



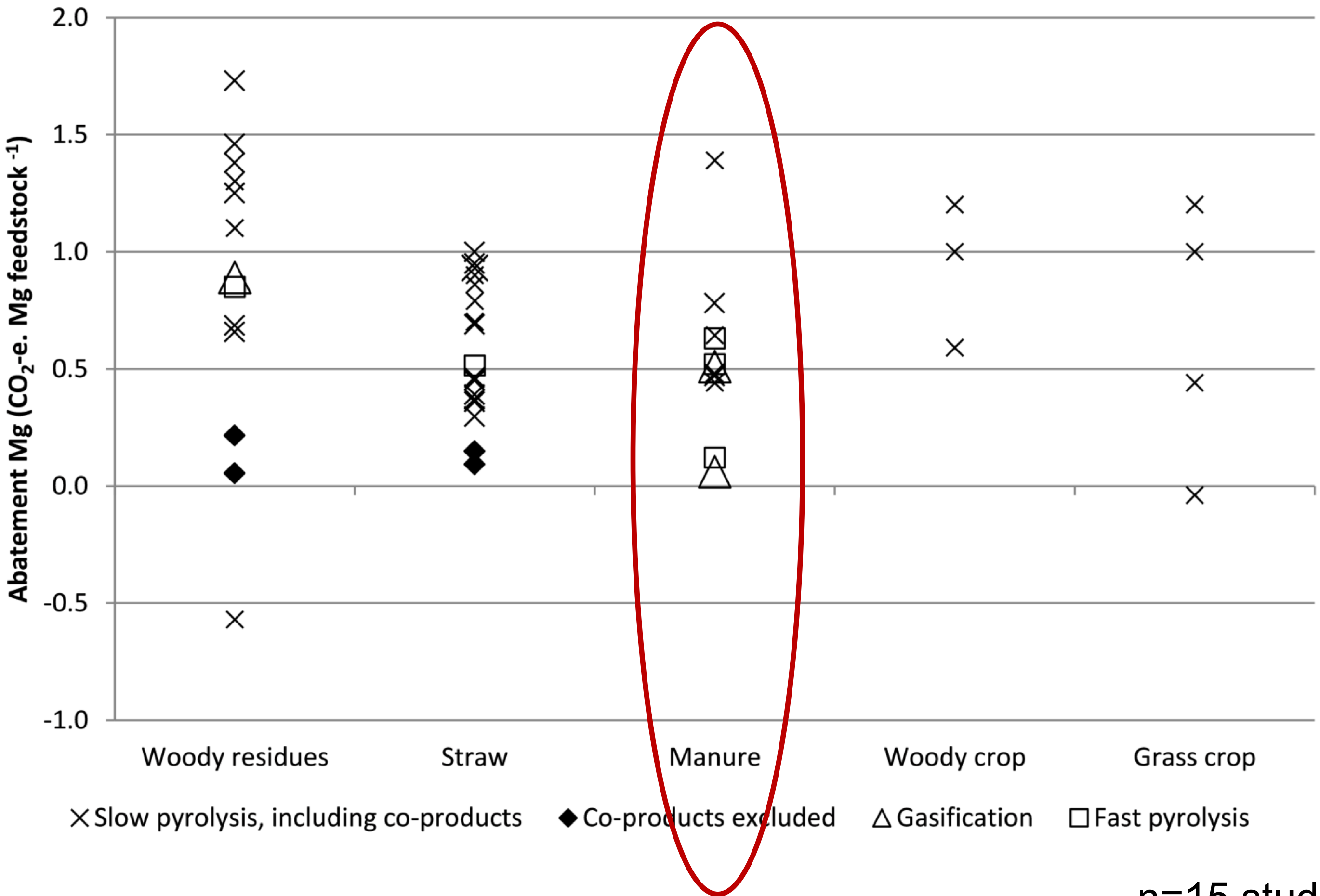
Two Entry Points:

A: Soil CDR and emission reduction through pyrolysis: reduce $CO_2/N_2O/CH_4$ return of the charred OM

B: Soil CDR and emission reduction through soil application:
B1: reduce soil GHG emissions ($CO_2/N_2O/CH_4$)
B2: increase CO_2 capture by plants through photosynthesis

Lehmann, 2007

Biochar Systems Effects on GHG



n=15 studies with 48 scenarios

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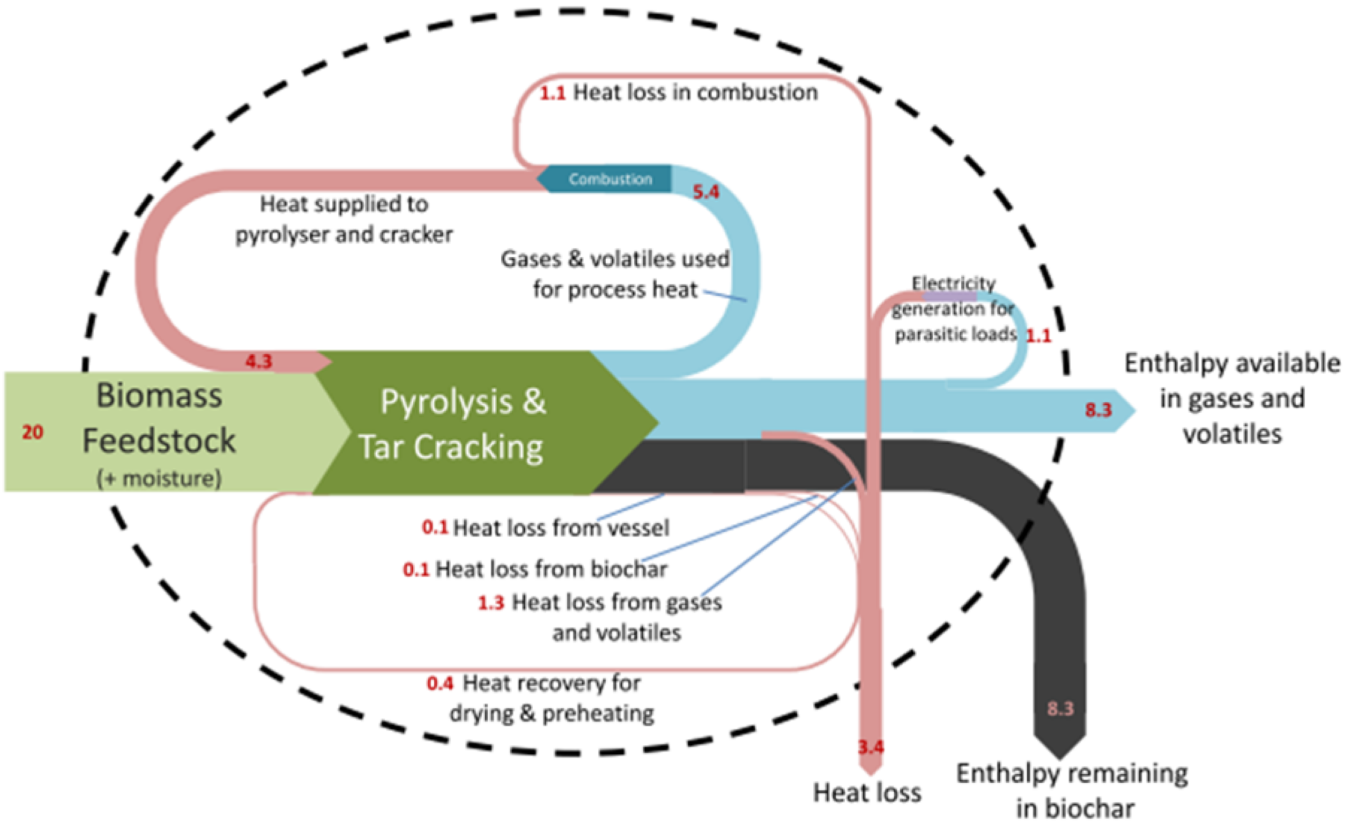
Cowie et al., 2015, *Earthscan*

Chapter 3: Bioenergy Production



GJ per Mg of dry, ash-free feedstock
example system based on slow pyrolysis at
450° C followed by tar-cracking at 800° C

Woolf et al. 2014 *ES&T* 48, 6492-6499

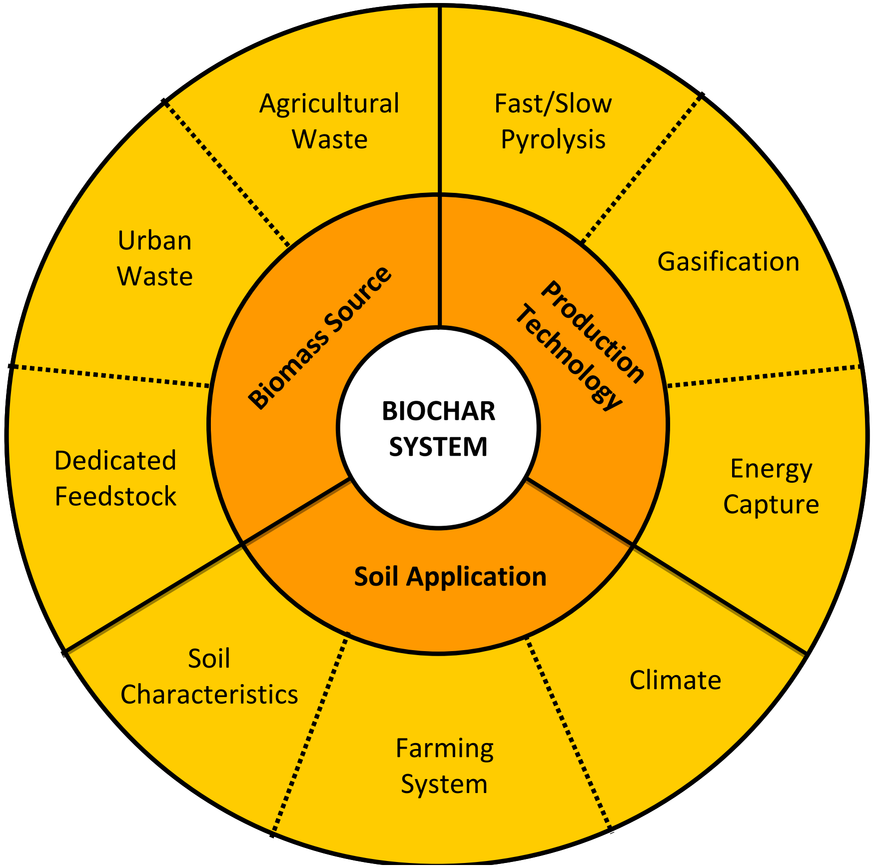
Animal Manure and Energy Generation

125-600 t/yr of poultry litter

Fuel offsets of US$66,000/yr

$480/t biochar at farm gate

Chapter 4: Waste Recycling Systems



New York Phosphate

Dairy Manure:
9,000 tons phosphate per year

Fertilizer sales (2009):
8121 tons phosphate per year

Recycling of Slaughterhouse Waste

Table 1 | Total phosphorus in annual bone residues from slaughtered animals in Ethiopia.

	Total no. of animals[5]	Bone mass[6] (kg per animal)	% of animals slaughtered (per year)	Bone residues (tonnes per year)	Total phosphorus (tonnes per year)
Cattle	50,283,000	20–30	16–17	160,908–256,447	-
Sheep	23,642,000	4–5	19–34	17,968–40,192	-
Goats	22,070,000	4–5	15–30	13,242–33,106	-
TOTAL	95,995,000	-	-		

Simons et al., 2014, *Nature Geoscience* 7, 3

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Recycling of Slaughterhouse Waste

Collection

1.25 ETB/kg
Average payout 3x daily wage
Amount exceeded capacity

Recycling of Slaughterhouse Waste

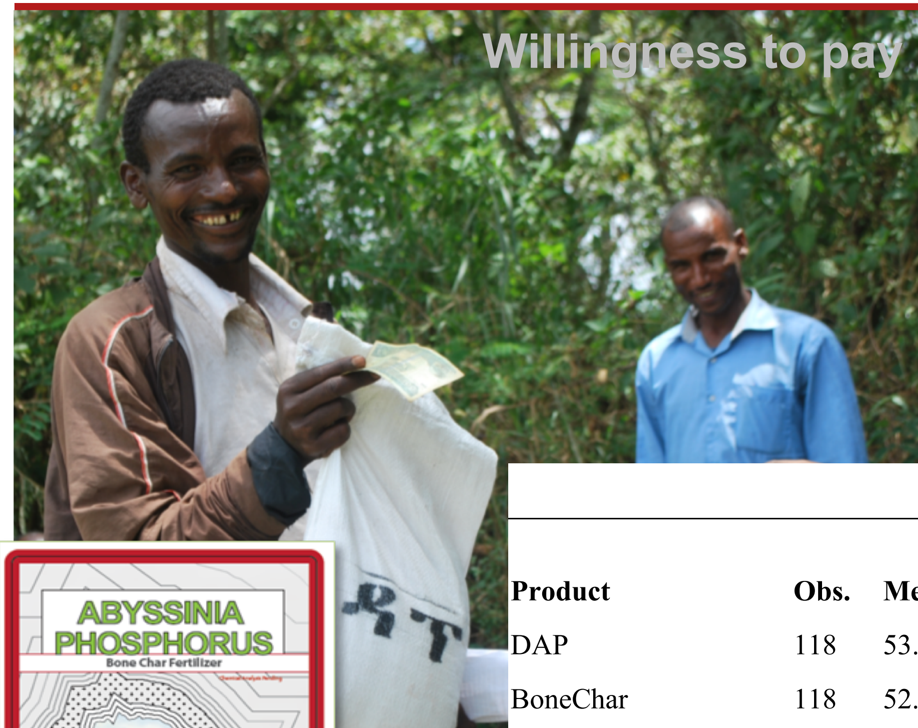
Price Comparison of Bone Char Fertilizer with Imported P Fertilizers

Bone Char P Fertilizer is less expensive!

Cost scenario	Bone char fertilizer cost	Cost imported equivalent	BC % diff. to imported equivalent
TSP Equivalent			
low-cost	ETB 5.33	ETB 12.65	-57.89%
high-cost	ETB 8.42	ETB 12.65	-33.48%
intermediate	ETB 6.87	ETB 12.65	-45.69%
DAP Equivalent			
low-cost	ETB 8.96	ETB 15.08	-40.56%
high-cost	ETB 12.13	ETB 15.08	-19.59%
intermediate	ETB 10.54	ETB 15.08	-30.08%

Nesin, 2017, MSc Cornell
Group of Garrick Blalock

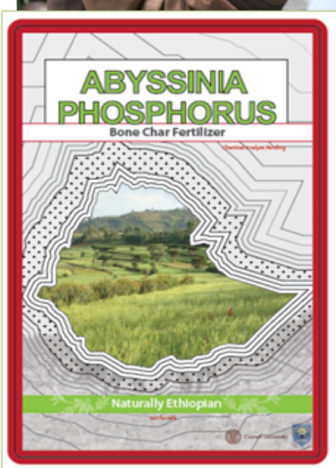
Recycling of Slaughterhouse Waste



Bone Char valued as imported DAP

Product	Obs.	Mean Bid	Std. dev.	Median Bid	Mean Bid	Mean price paid
DAP	118	53.04*	31.53	50.00	153.3	122.5
BoneChar	118	52.02*	30.54	45.00	127.5	107.5
BoneChar+Urea	118	53.91*	25.44	50.00	111.3	100.0

*Average bid price is significantly greater than zero at $p < 0.01$ level



Nesin, 2017, MSc Cornell
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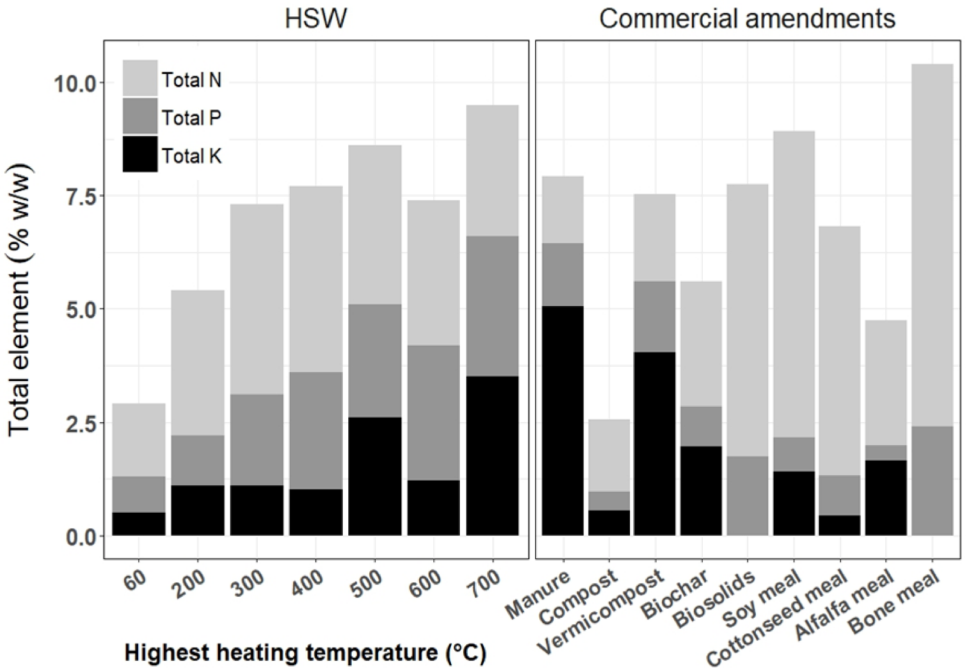
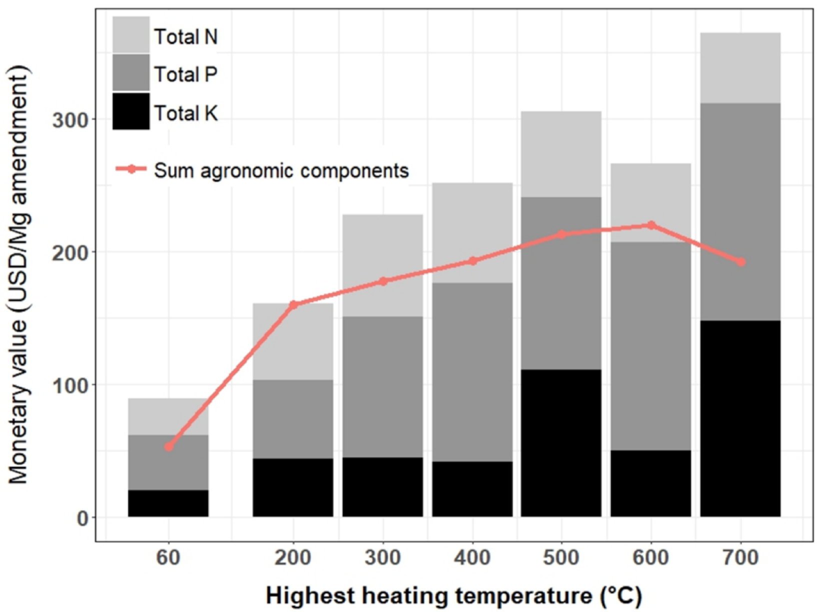
Recycling of Humanure using Pyrolysis





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Krounbi et al., 2019, *Waste Management* 89, 366–378

Take home

1. Recycling options exist for nutrients from wastes
2. Nutrient use efficiency and production costs can be as high as for commercial mineral fertilizers
3. Perceived value to farmers can be as high as for commercial mineral fertilizers
4. Very active field of basic and applied research as well as commercial development

Bedding