USDA

Agricultural
Research
Service

The Charcoal Vision

David A. Laird

USDA, ARS, National Soil
Tilth Laboratory

Natural Resources and Sustainable Agricultural Systems

NP #201: Water Resource Management

NP #202: Soil Resource Management

NP #203: Air Quality

NP #204: Global Change

NP #205: Rangeland, Pasture, and Forages

NP #206: Manure and Byproduct Utilization

NP #207: Integrated Agricultural Systems

NP #211: Water Availability and Watershed Management

NP #215: Pasture, Forage, Turf and Rangeland Systems

NP #216: Agricultural System Competiveness and Sustainability

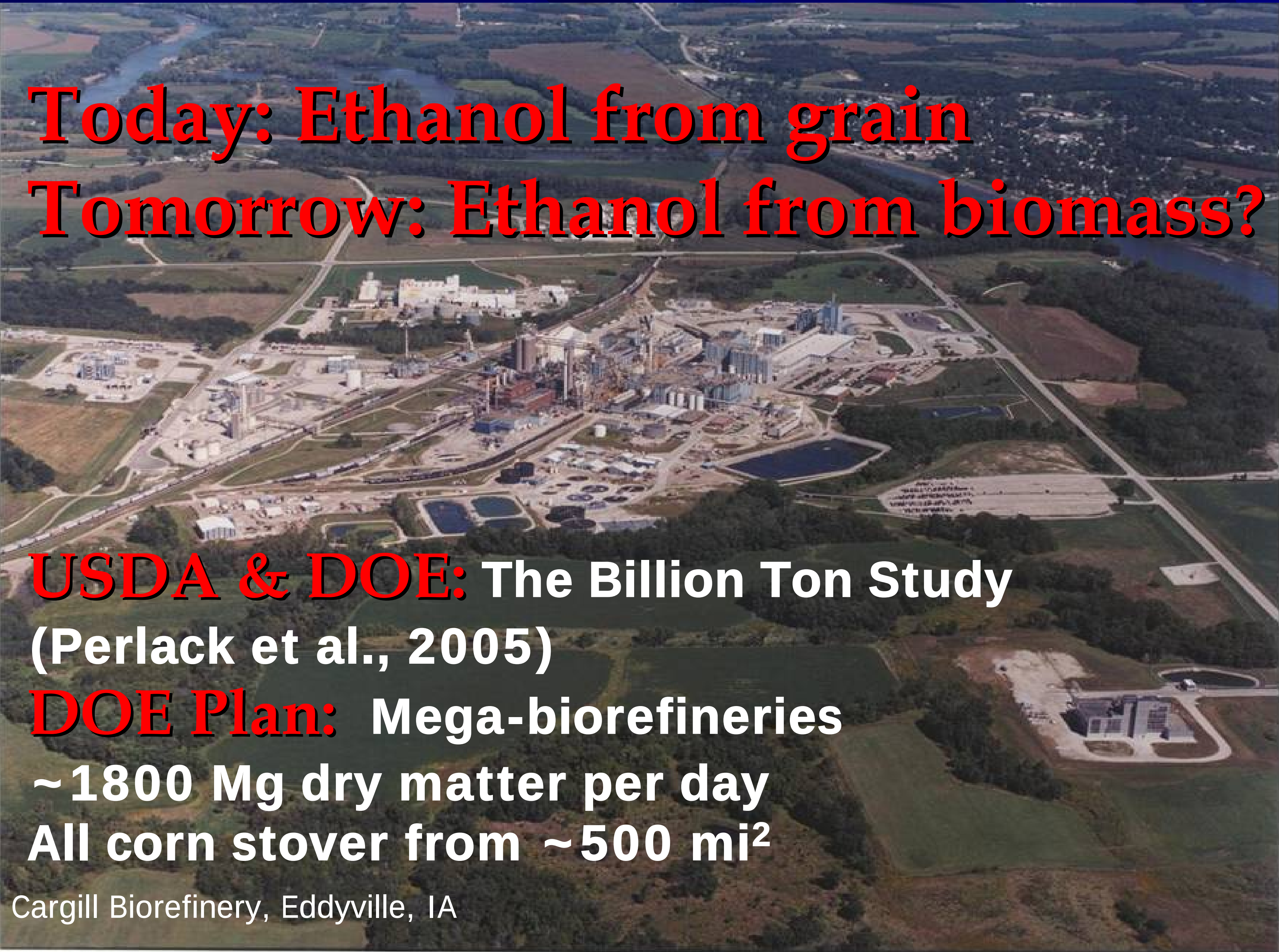
NP #307: Bioenergy & Energy Alternatives

Pierce Fleming

Renewable Energy Assessment Project (REAP)

National ARS effort: IA, IN, AL, NE, CO, OR, MN, ND, WA

Today: Ethanol from grain
Tomorrow: Ethanol from biomass?



USDA & DOE: The Billion Ton Study (Perlack et al., 2005)

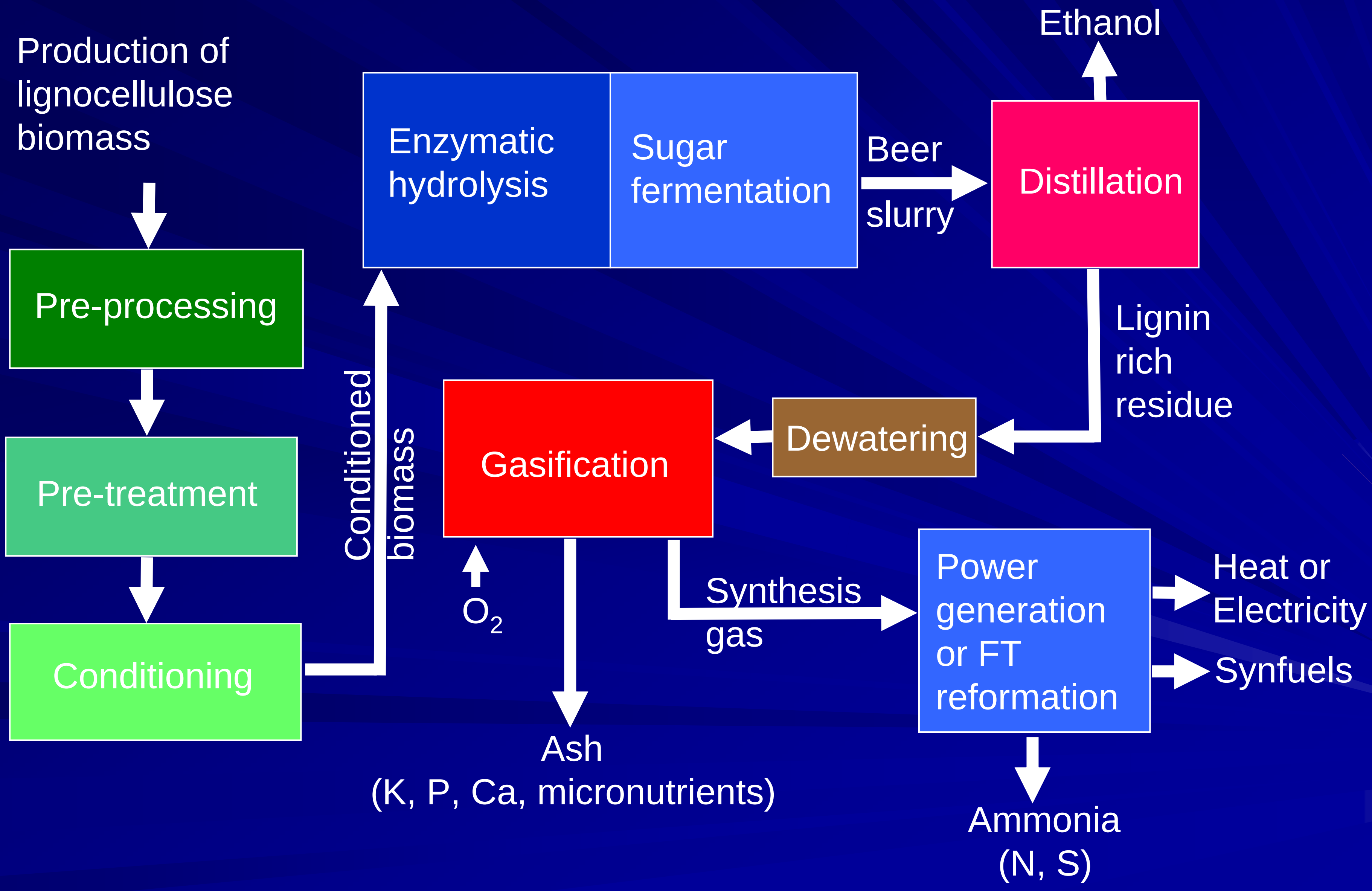
DOE Plan: Mega-biorefineries

~1800 Mg dry matter per day

All corn stover from ~500 mi^2

Cargill Biorefinery, Eddyville, IA

Integrated Cellulosic Biorefinery



Production of lignocellulose biomass

Pre-processing

Pre-treatment

Conditioning

Conditioned biomass

Enzymatic hydrolysis

Sugar fermentation

Beer slurry

Distillation

Ethanol

Lignin rich residue

Dewatering

Gasification

O_2

Ash
(K, P, Ca, micronutrients)

Synthesis gas

Power generation or FT reformation

Heat or Electricity

Synfuels

Ammonia
(N, S)

Recent literature on the impact of biomass harvesting on soils

- Wilhelm et al. 2004. Crop and Soil Productivity Response to Corn Residue Removal: A Literature Review. *Agron. J. 96:1-17.*
- Johnson et al. 2006. A matter of balance: Conservation and renewable energy. J. Soil Water Con. Soc. 61(4):120A-125A.
- Lal and Pimentel. 2007. Biofuels from crop residues. Soil & Till. Res. 93:237–238.
- Johnson et al. 2007. Biomass-Bioenergy Crops in the United States: A Changing Paradigm. *The Americas Journal of Plant Science and Biotechnology. Global Science Books (in Press).*

Nutrient content (kg/ha) of Maize grain and stover at 9.4 Mg/ha yield (L.G. Bundy)

Nutrient	Grain	Stover	Total
Nitrogen (N)	134	57	192
Phosphorous (P_2O_5)	64	16	80
Potassium (K_2O)	41	168	210
Calcium (Ca)	1	32	34
Magnesium (Mg)	9	24	32
Sulfur (S)	10	8	18
Zinc (Zn)	0.11	0.17	0.28
Boron (B)	0.03	0.11	0.15
Manganese (Mn)	0.08	0.37	0.45
Iron (Fe)	0.07	1.23	1.30
Copper (Cu)	0.02	0.10	0.12

Impact of residue removal on CEC (cmol/kg-soil)

	Depth (cm)	Not Removed	Removed	% change
Chisel	0-5	22.4	19.5	-12.9****
	5-15	22.4	20.9	-7.0****
	15-30	20.3	19.2	-5.3****
Plow	0-5	21.7	20.3	-6.2***
	5-15	22.4	20.9	-6.8****
	15-30	20.0	19.9	-0.6
No-till	0-5	21.9	20.1	-8.0**
	5-15	23.0	22.3	-3.1
	15-30	19.5	20.7	6.4****

NTRM plots Rosemont MN after 19 years.
Thanks to ARS team in St. Paul.

7 % loss

Impact of residue removal on aggregation (mass aggregates > 0.25 mm/mass soil)

	Depth (cm)	Not Removed	Removed	% change
Chisel	0-5	0.38	0.36	-5.9
	5-15	0.77	0.67	-11.9**
	15-30	0.61	0.55	-9.1
Plow	0-5	0.34	0.44	31.0***
	5-15	0.67	0.64	-4.4
	15-30	0.58	0.56	-2.6
No-till	0-5	0.76	0.38	-50.3****
	5-15	0.88	0.79	-10.3****
	15-30	0.66	0.66	-0.9

NTRM plots Rosemont MN after 19 years.
Thanks to ARS team in St. Paul.

7 % decrease

Impact of residue removal on % organic C

	Depth (cm)	Not Removed	Removed	% change
Chisel	0-5	2.95	2.47	-16.5****
	5-15	2.78	2.47	-11.1****
	15-30	2.03	2.03	0.2
Plow	0-5	2.71	2.45	-9.4***
	5-15	2.72	2.32	-14.8****
	15-30	2.32	2.26	-2.5
No-till	0-5	3.17	2.58	-18.5*
	5-15	2.67	2.60	-2.5
	15-30	1.96	2.05	4.7

NTRM plots Rosemont MN after 19 years.
Thanks to ARS team in St. Paul.

>7800 kg-C/Ha

Impact of residue removal on % total N

	Depth (cm)	Not Removed	Removed	% change
Chisel	0-5	0.255	0.212	-16.9****
	5-15	0.248	0.216	-12.7****
	15-30	0.173	0.174	0.9
Plow	0-5	0.228	0.210	-7.7***
	5-15	0.233	0.206	-11.4****
	15-30	0.198	0.198	0.3
No-till	0-5	0.280	0.226	-19.3*
	5-15	0.238	0.220	-7.6**
	15-30	0.168	0.170	1.2

NTRM plots Rosemont MN after 19 years.
Thanks to ARS team in St. Paul.

>780 kg-N/Ha

Impact of residue removal on N mineralization potential (mg-N/kg-soil)

	Depth (cm)	Not Removed	Removed	% change
Chisel	0-5	73.2	53.8	-26.6**
	5-15	49.6	36.3	-26.8***
	15-30	22.8	15.5	-32.2***
Plow	0-5	47.3	33.8	-28.7***
	5-15	40.6	32.4	-20.1**
	15-30	28.2	21.0	-25.5**
No-till	0-5	75.4	37.8	-49.9**
	5-15	44.8	38.3	-14.4
	15-30	21.3	15.7	-26.3***

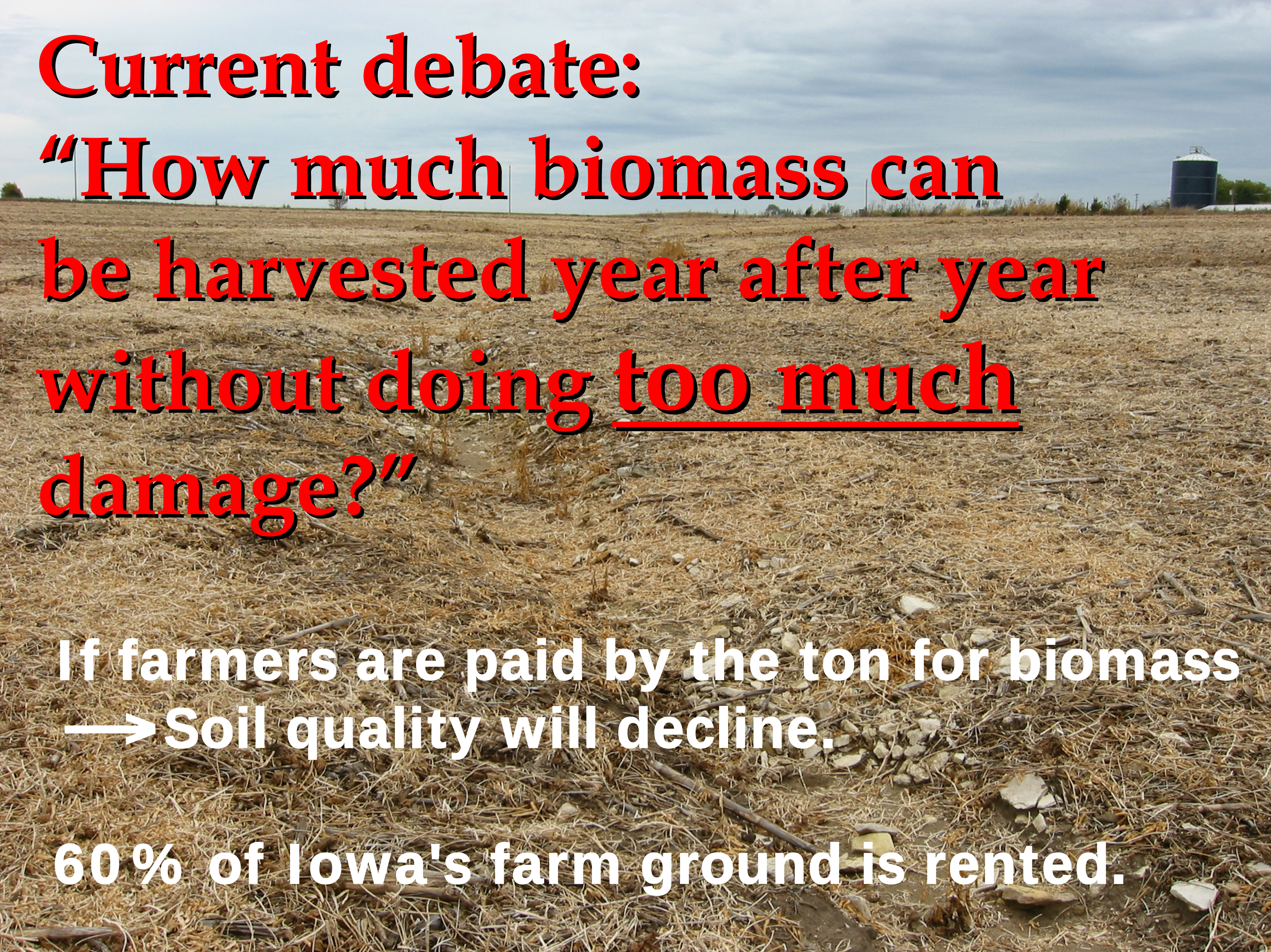
NTRM plots Rosemont MN after 19 years.
Thanks to ARS team in St. Paul.

>56 kg-N/Ha

Removing residue for bioenergy will adversely impact soil and environmental quality

Decline in soils ability to supply nutrients
    Soil will need more fertilizer (N, P, & K)
Decrease in water holding capacity of soil
    More vulnerable to drought
Degradation of soil structure
    More erosion, soil will need more tillage
Increased leaching of N and P
    Degradation of water quality

Greenhouse gas reductions from use of bioenergy will be significantly discounted due to the loss of SOC and increased energy demand for fertilizer production and increased tillage.



Current debate:
"How much biomass can be harvested year after year without doing too much damage?"

If farmers are paid by the ton for biomass
⟶Soil quality will decline.

60% of Iowa's farm ground is rented.

Paradigm shift

We need integrated systems that build soil quality and increase productivity so that both food and biomass crops can be harvested.

The Charcoal Vision

A distributed network of small pyrolyzers to process biomass

Pyrolysis

Biomass + heat → Bio-oil + Syngas + Charcoal

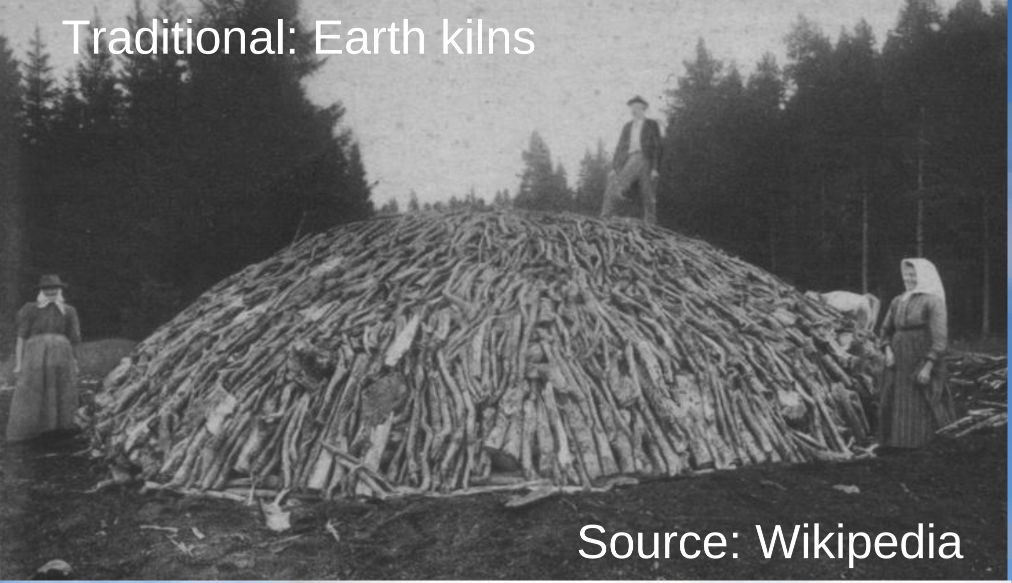
Bio-oil energy product (heating value ~19 vs ~43 MJ/kg for fuel oil). Bio-oil can be refined to make transportation fuels & co-products.

Syngas powers the pyrolyser

Charcoal returned to the soil

Red Arrow Products Co.
70 ton per day RPT^{TM} reactor
Operated by Ensyn, Inc.

http://www.ensyn.com/what/rtp.htm



Traditional: Earth kilns

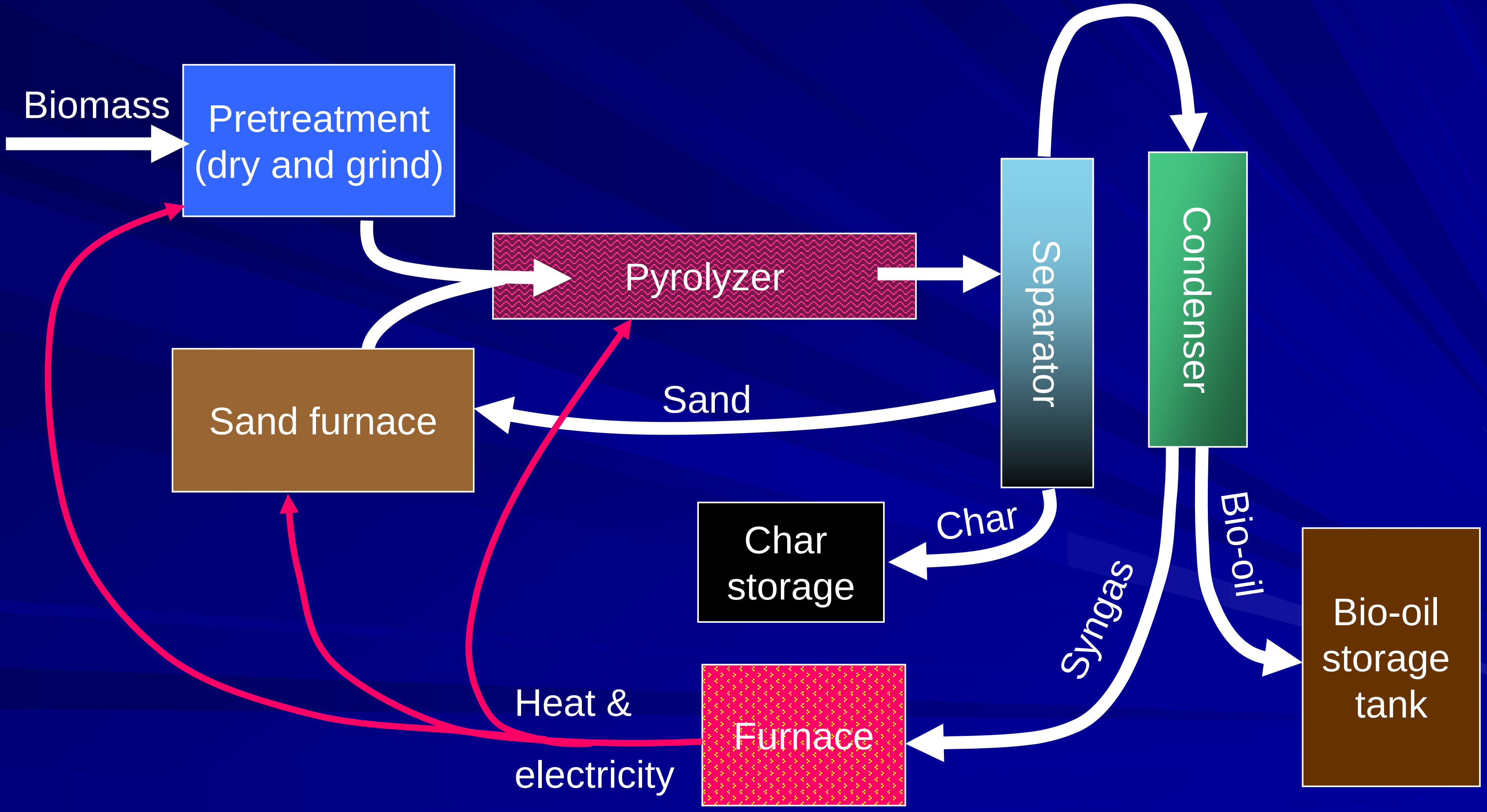
Source: Wikipedia

Steel kilns

Photo by Jorg Behmann

Modern Fast Pyrolyzer
Dynamotive Energy Systems Co.

Fast Pyrolysis



Biomass

Pretreatment
(dry and grind)

Pyrolyzer

Separator

Condenser

Sand

Sand furnace

Char

Char storage

Syngas

Bio-oil

Bio-oil storage tank

Heat &

electricity

Furnace

Terra Preta **Oxisol**

Glaser et al. 2001. Naturwissenschaften (2001) 88:37–41

Interest in soil charcoal amendments is growing rapidly

- Seifritz, W.: 1993, ‘Should we store carbon in charcoal?', International Journal of Hydrogen Energy **18** : 405-407.
- Glaser, B., J. Lehmann, W. Zech (2002) Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal – a review. Biol. Fertil. Soils. 35:219–230.
- Okimori, Y. et al. 2003. ‘Potential of CO2 emission reductions by carbonizing biomass waste from industrial tree plantation in south Sumatra , Indonesia ', *Mitigation and Adaptation Straegies for Global Change* **8** , 261-280.
- Laird, D.A. 2005. Use of Charcoal to Enhance Soil Quality in a Future Powered by Bioenergy. 2005. *Growing the Bioeconomy; Biobased Industry Outlook Conference*. (http://www.valuechains.org/bewg/Conf2005/Sessions/conservation.htm)
- Lehmann et al. 2006. Bio-char sequestration in terrestrial ecosystems – A Review. Mitigation and Adaptation Strategies for Global Change. 11: 403–427 C Springer 2006
- Fowles M. 2007. Black carbon sequestration as an alternative to bioenergy. Biomass and Bioenergy (in press).
- **Day, D. EPRIDA. http://www.eprida.com/home/index.php4**
- **International Agrichar Initiative 2007 Conference. April 29 - May 2, 2007. Terrigal, New South Wales, Australia**

Estimates of soil char range from <5 to 55% of total organic C

Soil Series	TOC	Char	Char
	----g C kg^{-1} soil----		%
Brennyville (sl)	18.6	1.8	10
Elliott (sl)	28.7	6.6	23
Houston Black (c)	36.9	7.6	21
Vallers (scl)	41.3	13.6	33
Walla Walla (sl)	10.3	3.6	35

Skjemstad et al. (2002) Soil Sci. Soc. Am. J. 66:1249–1255.

Photo by James S. and Susan W. Aber
http://www.geospectra.net/kite/ross/fire.htm

Charcoal amendments enhance plant available water in sandy soils and aeration in clay soils

	-----------% Charcoal (V/V)-----------			
Soil	0%	15%	30%	45%
	-------% available water (V/V)--------			
Sand	6.7	7.1	7.5	7.9
Loam	10.6	10.6	10.6	10.6
Clay	17.8	16.6	15.4	14.2

Data presented by **Glaser et al. (2002)** Biol Fertil Soils 35:219–230. Based on work of Tryon (1948).

Charcoal amendments enhance soil fertility

- Cation Exchange Capacity

  100 to 1000 cmol kg^{-1}

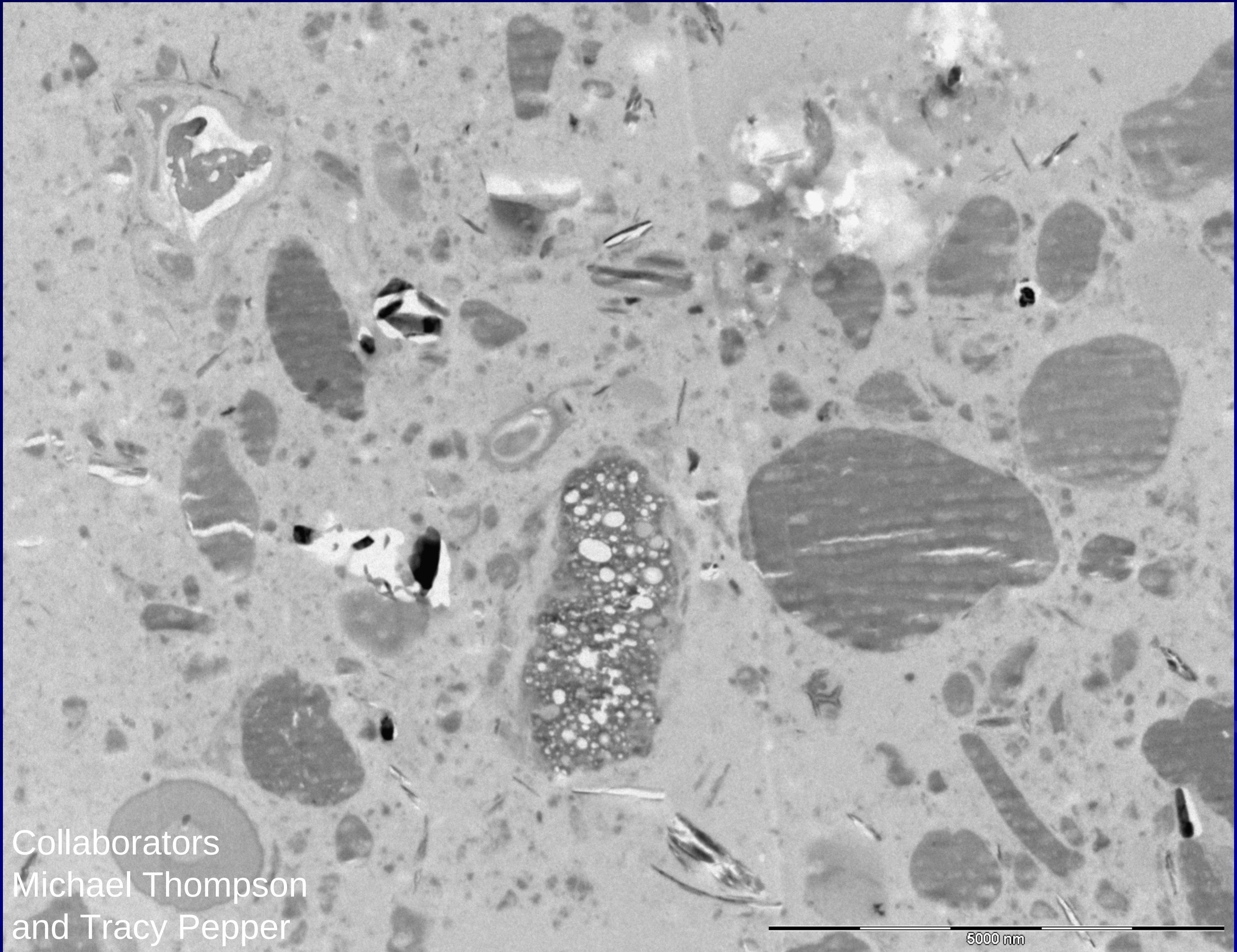
Charcoal (% V/V)	ECEC (cmolc kg^{-1})	BS (%)	Available K (cmolc kg^{-1})	Available Ca (cmolc kg^{-1})	Available P (mg kg^{-1})
0	3.4	35	0.03	1.00	7.0
15	4.2	155	0.22	6.01	23.0
30	5.1	281	0.46	13.46	37.4
45	5.9	336	0.57	18.56	37.7

Data presented by **Glaser et al. (2002)** Biol Fertil Soils 35:219–230. Based on work of Tryon (1948).

Charcoal increases crop yields

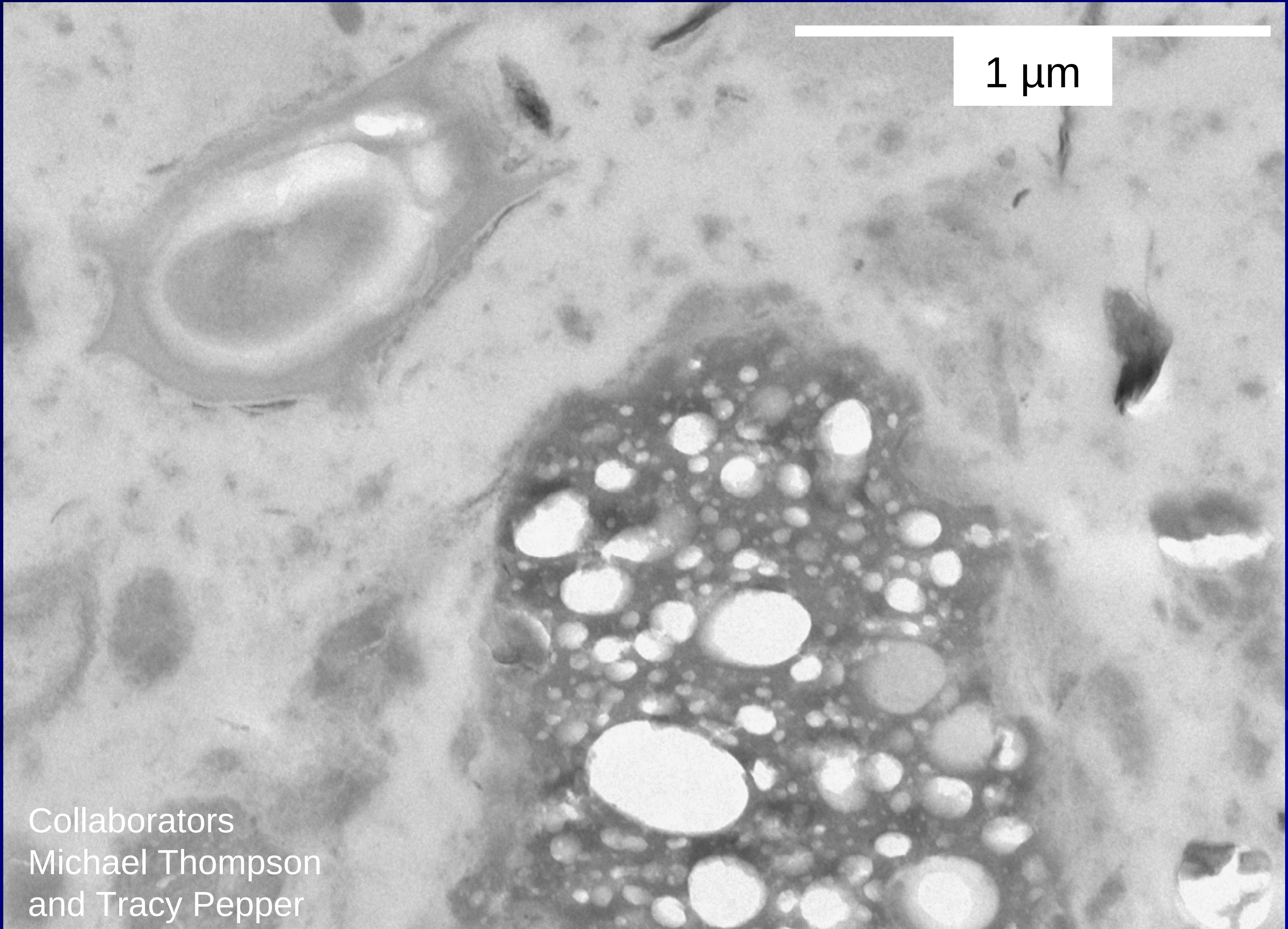
Char (Mg ha^{-1})	Biomass	Crop	Soil type	Reference
0	100	Maize	Alfisol	Mbagwu & Piccolo (1997)
0.2	118	Maize	Alfisol	
2.0	176	Maize	Alfisol	
20.0	132	Maize	Alfisol	
0	100	Pea	Dehli soil	Iswaran et al. (1980)
0.5	160	Pea	Dehli soil	
0	100	Moong	Dehli soil	
0.5	122	Moong	Dehli soil	
0	100	Soybean	Volcanic ash loam	Kishimoto & Sugiura (1985)
0.5	151	Soybean	Volcanic ash loam	
5.0	63	Soybean	Volcanic ash loam	
15.0	29	Soybean	Volcanic ash loam	

HRTEM soil charcoal



Collaborators
Michael Thompson
and Tracy Pepper

HRTEM soil charcoal



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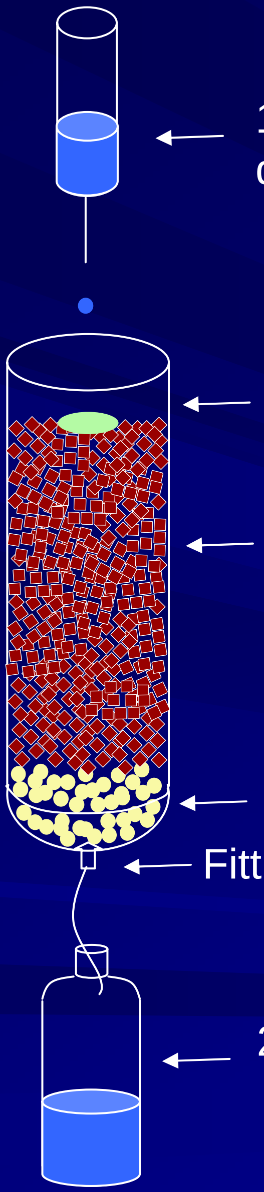
Impact of bio-char on manure mineralization



125 mL syringe to control drip rate of leachate

Fiberglass filter

Column holding 1 kg soil

80 mL sand

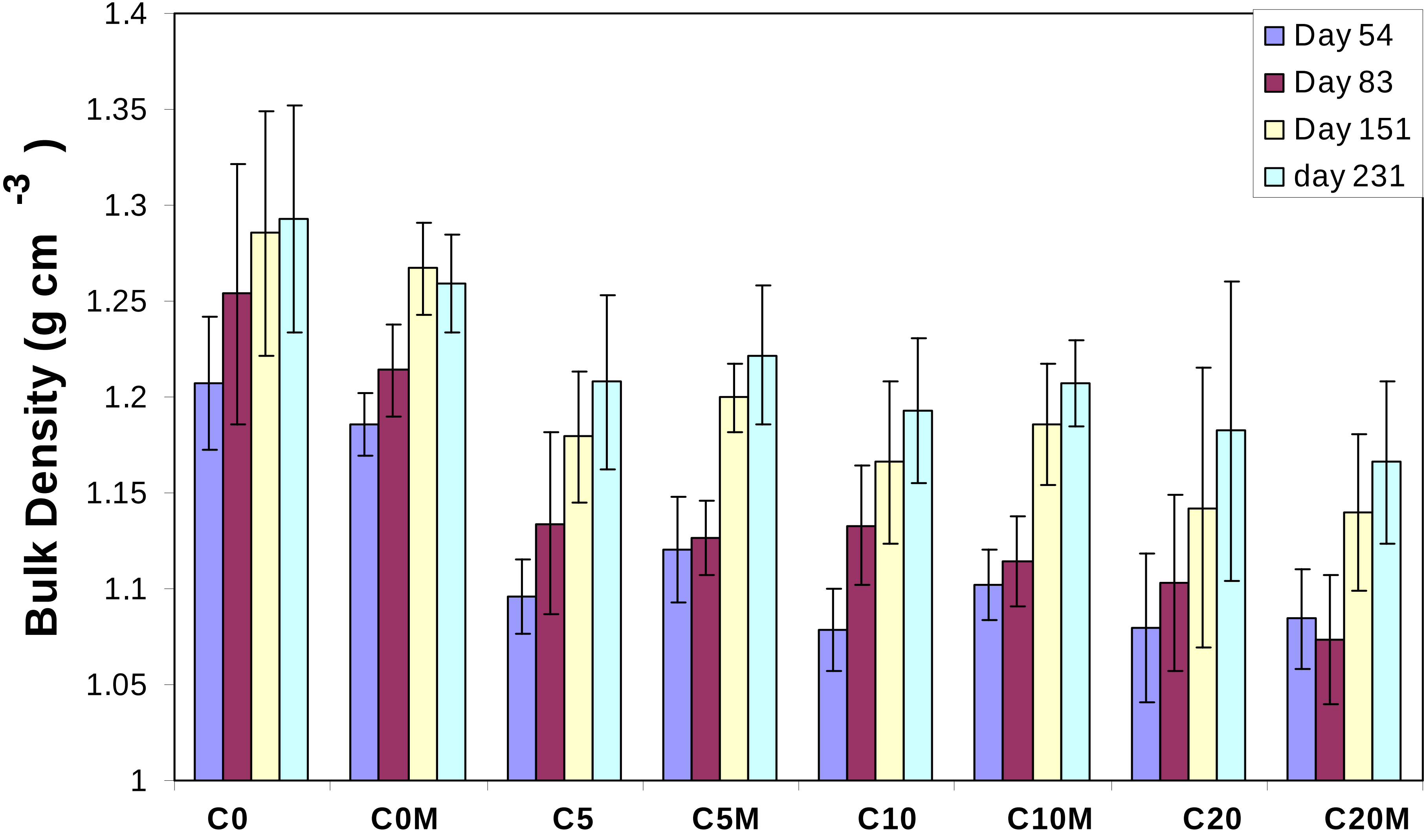
Fitting with fiber glass plug

250 mL bottle to catch lechate

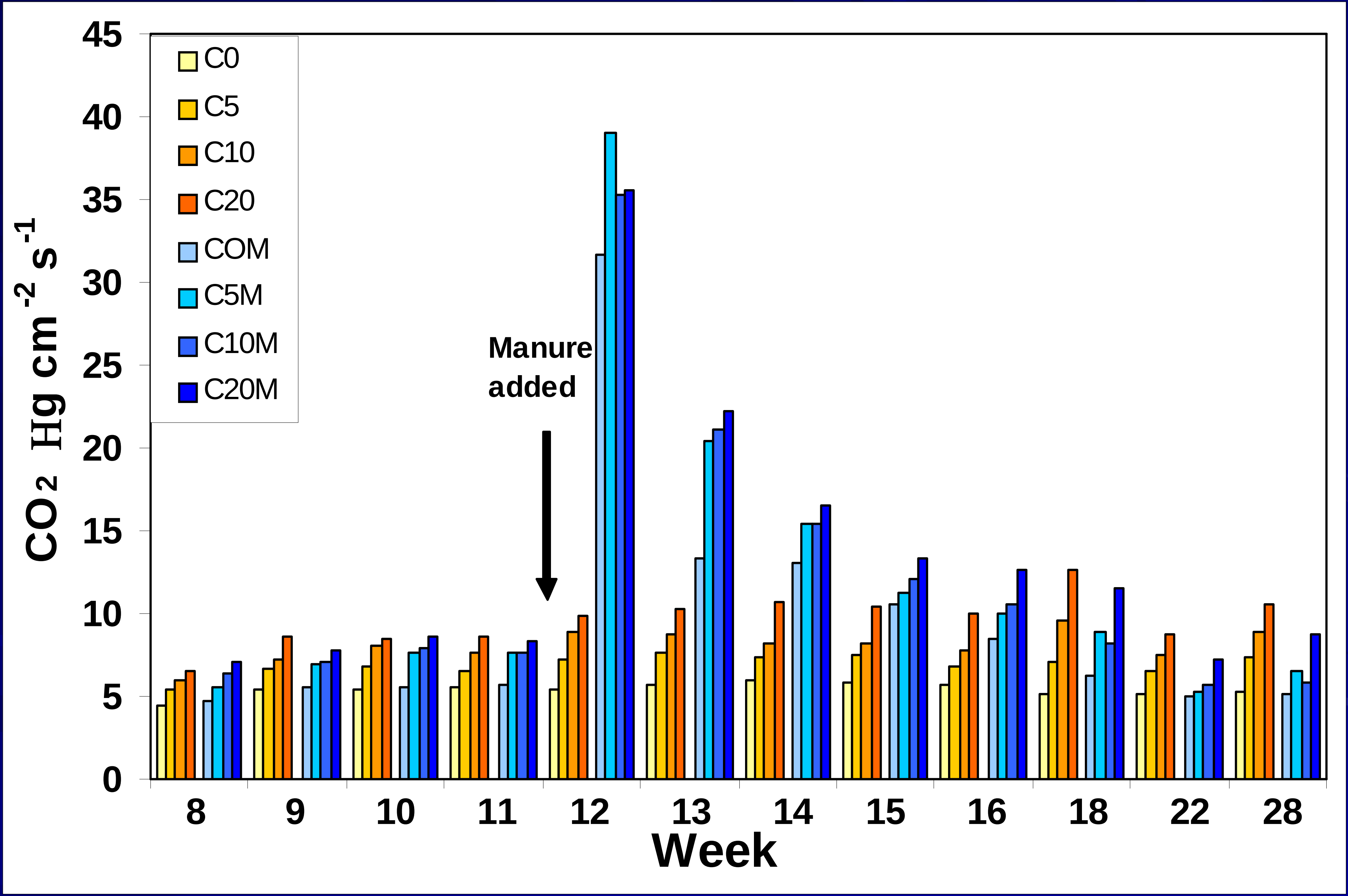
Charcoal: 0, 5, 10, and 20 g kg^{-1}
Initial bulk density ~1.1 g cm^{-3}
Leached weekly with 200 mL 0.005 M $CaCl_2$
5 g dry swine manure (3.9% N) added week 12

Measure NO_3, DOC, BD, CO_2, Si and total P

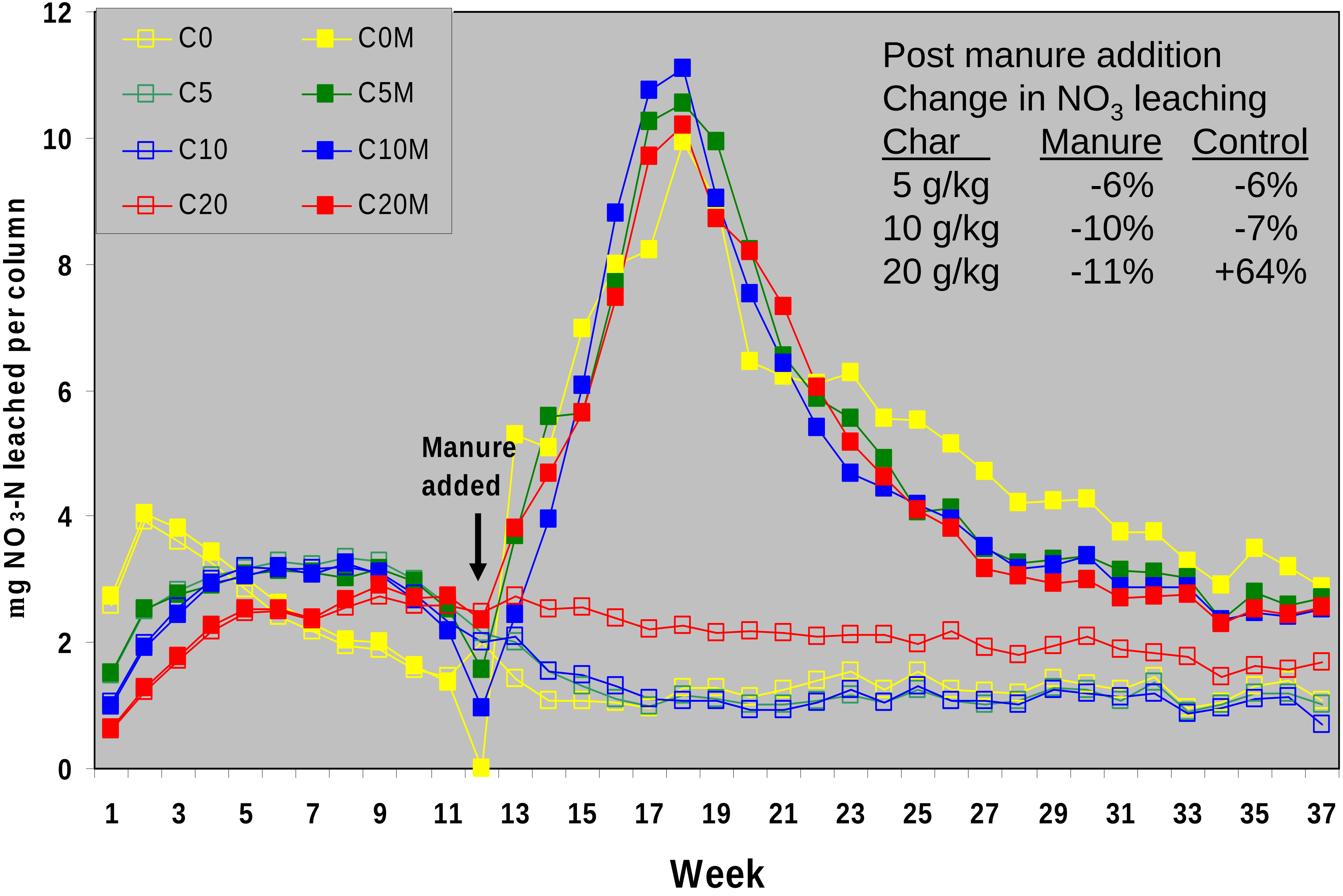
Impact of bio-char and manure on Bulk Density



Impact of bio-char and manure on CO_2 emissions



Impact of bio-char and manure on NO_3 leaching

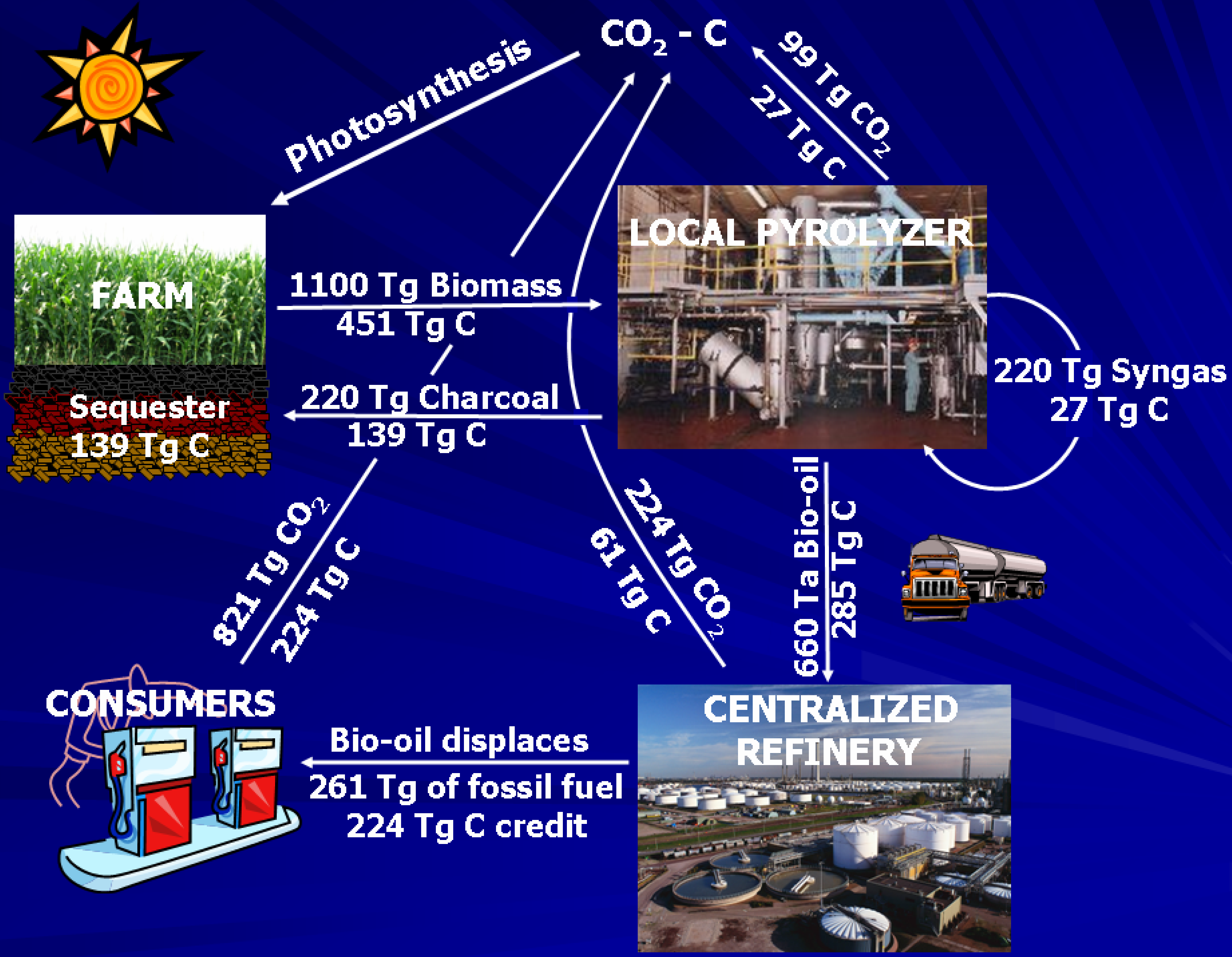


Post manure addition

Change in NO_3 leaching

Char	Manure	Control
5 g/kg	-6%	-6%
10 g/kg	-10%	-7%
20 g/kg	-11%	+64%


KNIGHT



CO_2 - C

Photosynthesis

99 Tg CO_2
27 Tg C

FARM

1100 Tg Biomass
451 Tg C

LOCAL PYROLYZER

220 Tg Syngas
27 Tg C

220 Tg Charcoal
139 Tg C

Sequester
139 Tg C

821 Tg CO_2
224 Tg C

224 Tg CO_2
61 Tg C

660 Ta Bio-oil
285 Tg C

CONSUMERS

Bio-oil displaces
261 Tg of fossil fuel
224 Tg C credit

CENTRALIZED REFINERY

Impact on Global Change

Unanswered questions:

Half life of charcoal in soils 10s to 1000s years?

Potential reduction in N_2O emissions?

Stimulate biogenic humus formation?

Conservative guess:

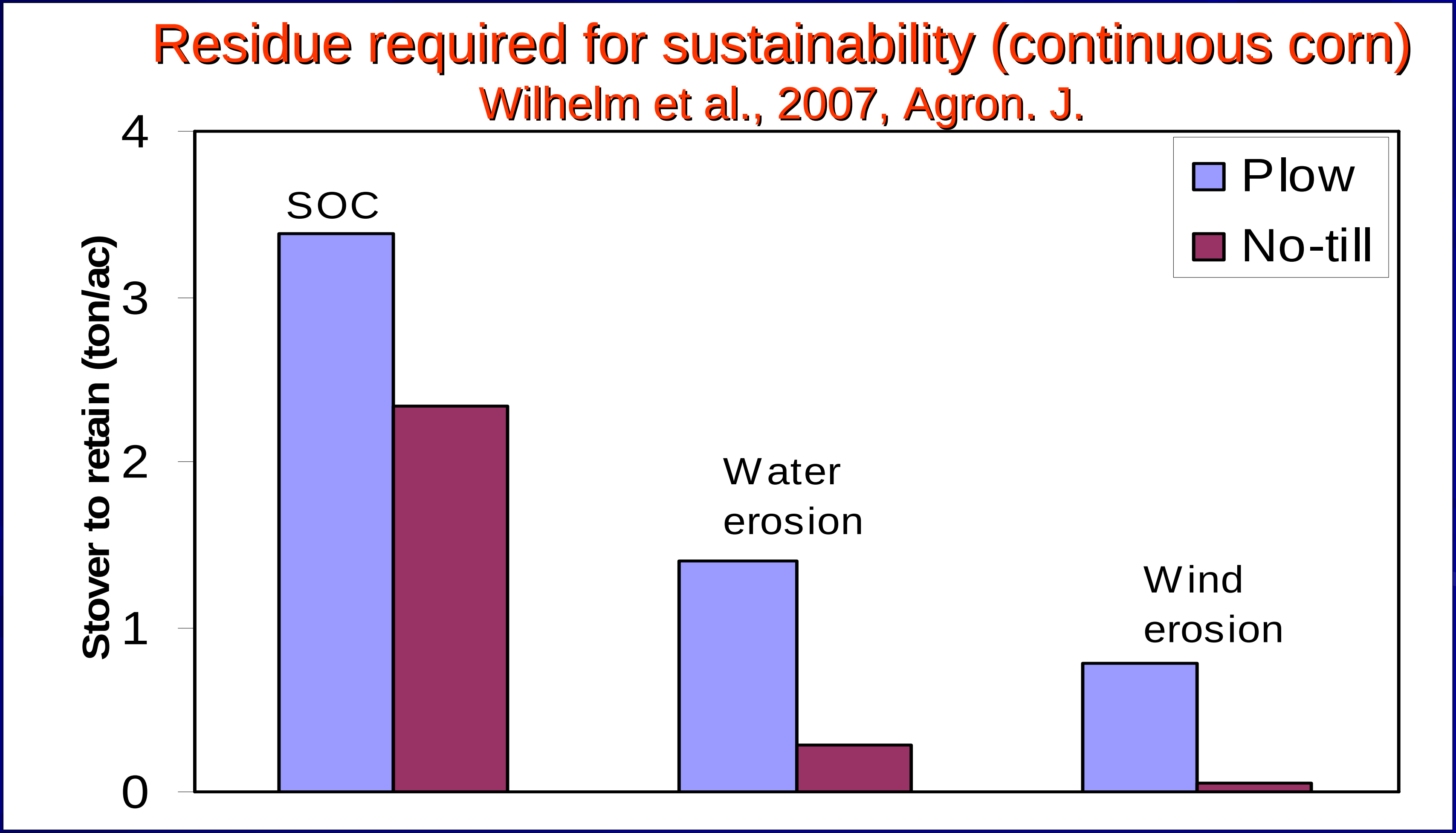
Assuming 1.1×10^9 Mg biomass:

Then permanently sequester 139 Tg of C and displace 224 Tg of fossil fuel C per year.

Total C credit = 363 Tg of C per year
(10% of annual U.S. CO_2-C emissions)

Potential Production of Bio-energy

Assuming 1.1x10^9 Mg biomass: Then the U.S. can displace 1.9 billion barrels of fossil oil with bio-oil (approximately 25% of U.S. annual oil consumption).



Residue required for sustainability (continuous corn)

Wilhelm et al., 2007, Agron. J.

Bio-char Strongly Adsorbs Organic & Inorganic Pollutants

Atrazine (Laird et al. 1994. Env. Sci. & Tech. 28:1054-1061)

Copper (Wu, et al. 1999. J. Envir. Qual. 28:334-338).

The 230th ACS National Meeting in Washington , DC,

Aug 28-Sept 1, 2005

Characterization and Properties of Environmentally Relevant Black Carbon Particles -- 25 presentations

http://oasys.acs.org/acs/230nm/techprogram/ENVR.HTM

Increasing soil charcoal will enhance water quality!

Advantages of Pyrolysis Platform

- Scale – flexible and potentially mobile
- Feedstock – any dry organic material
- Greenhouse gas negative energy – net removal CO_2 from the atmosphere.
- Farmers – use existing equipment, harvest sequentially, more biomass, biomass quality is of little concern, on-farm storage
- Build soil quality – increase crop and biomass production
- Improve water quality – bio-char in soil will reduce leaching of nutrients and pesticides.
- Enhance rural economies – LLC's or local CO-OP with local financing
- Technology – simple, relatively inexpensive, and nearly ready to implement.

The Down Side

1) Not economical, unless the value of putting charcoal in soil is considered (Carbon credit or green payment).

2) Crop production may require new management systems. Compatibility with no-till? Cover crops?

3) Technology: Optimum pyrolyzer design? Refining of bio-oil? Bio-char handling and application equipment?

4) Research: Soil and Environmental Science, Engineering, Economics, and Policy.