Pyrolysis, Biochar and Sustainably Bioenergy Feedstock Production

David A. Laird

USDA, ARS, National, Soil Tilth Laboratory

Collaborators: Natalia Rogovska, Dedrick Davis, Rick Cruse, Robert Horton, Baiqun Wang, Doug Karlen

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 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
Decrease in water holding capacity of soil
Degradation of soil structure
- Soil will need more tillage
- Soil will need more fertilizer (N, P, & K)

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.

Fast Pyrolysis is an efficient means of turning biomass in to usable energy products.

1 kg ground
corn stover

17,300 BTU

0.75 kg
bio-oil

15,700 BTU

0.2 kg
bio-char

4,000 BTU

0.05 kg
gas

300 BTU

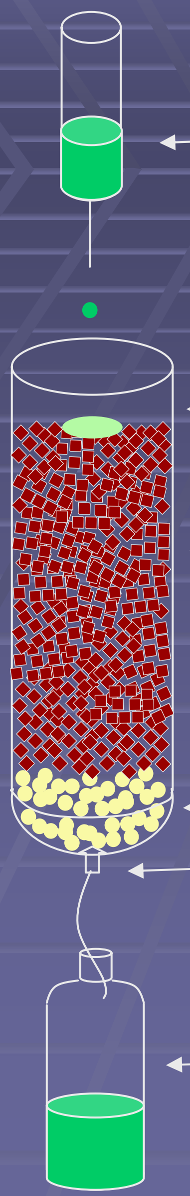
Modern Fast Pyrolyzer
Dynamotive Energy Systems Co.
200 dry ton/Day plant
West Loren Ontario CA

Terra Preta **Oxisol**

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

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

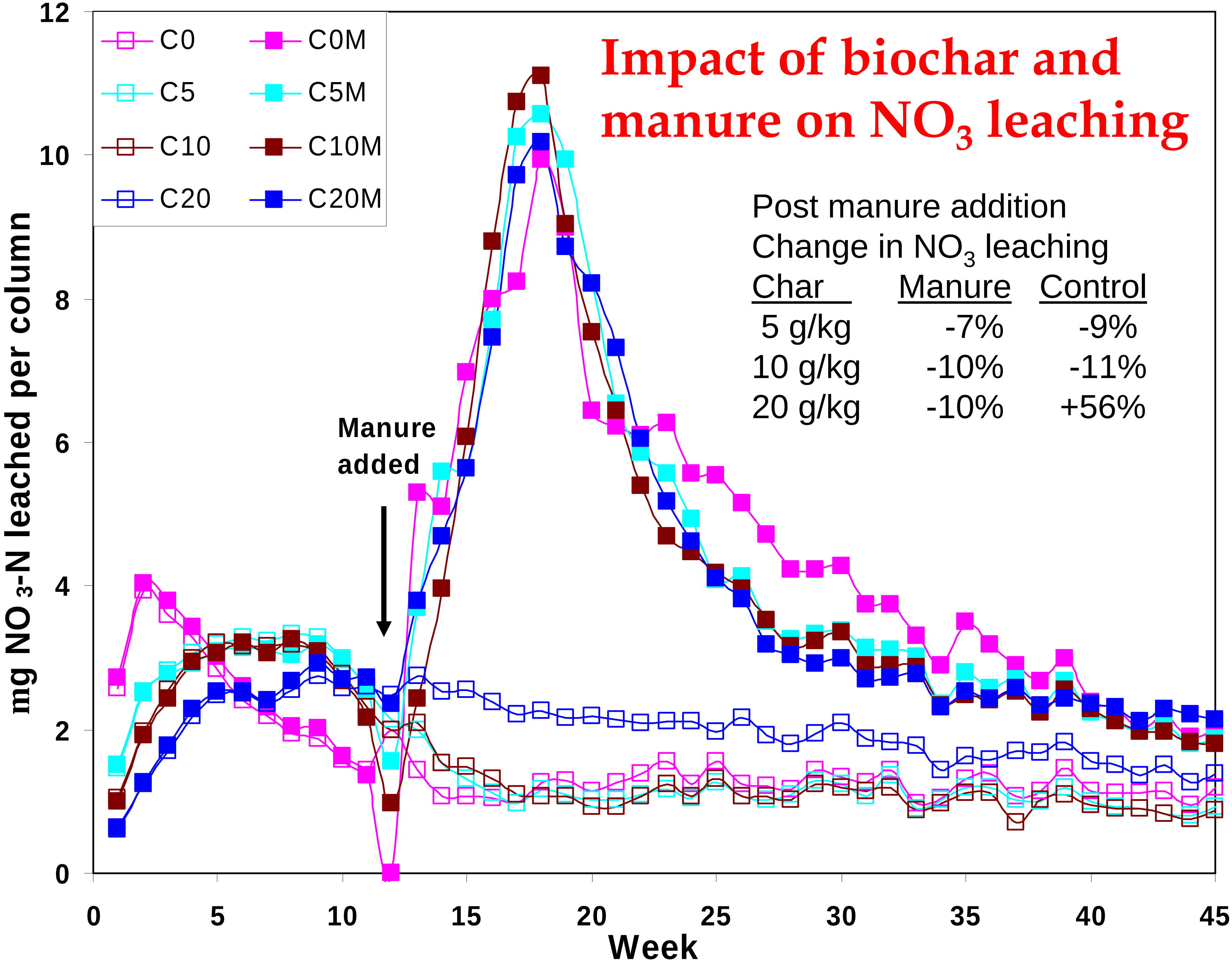
Impact of biochar on manure mineralization



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

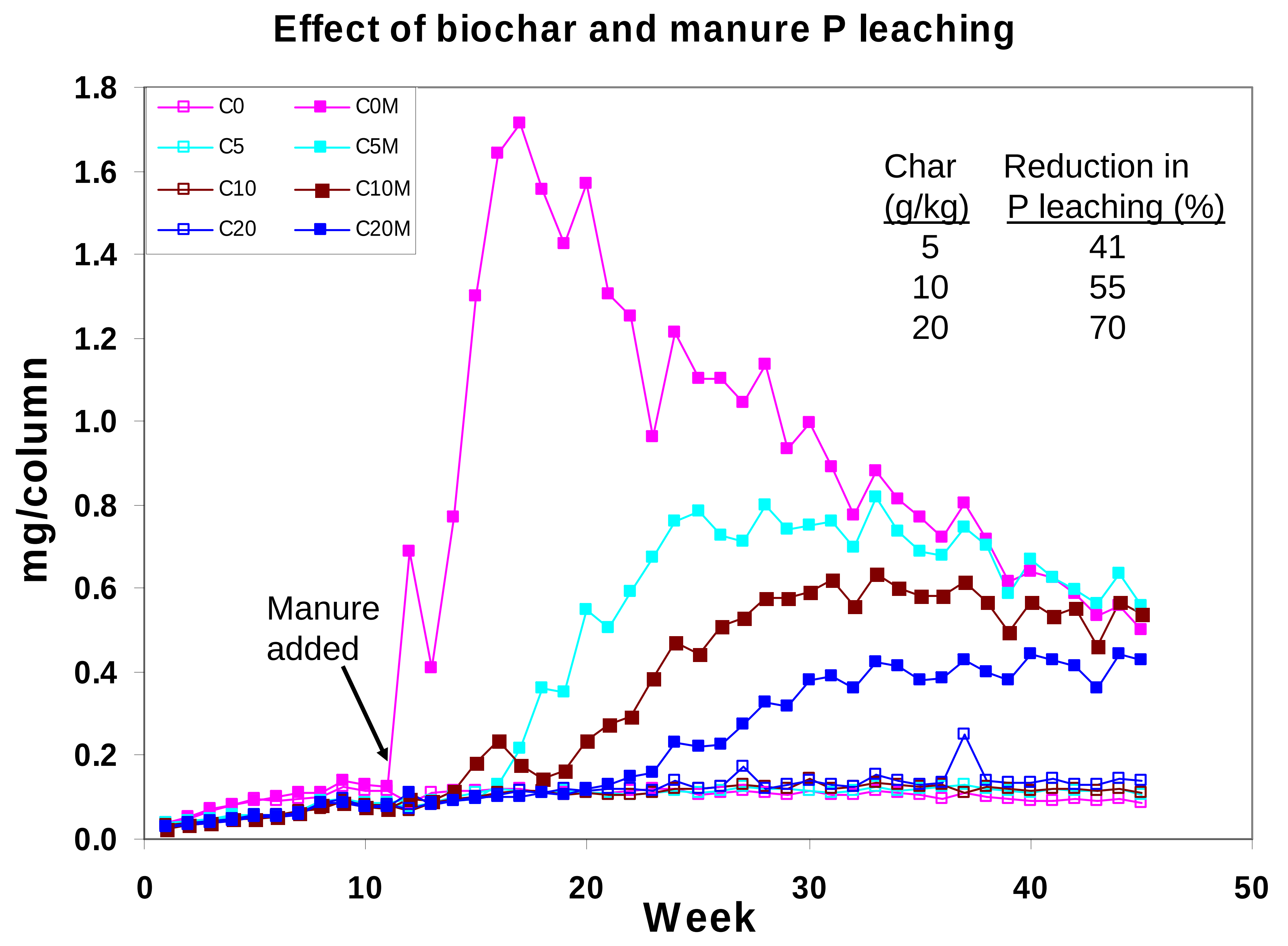
Measure
NO_3, BD, CO_2, Na, K, Ca, and P in leachate
And total C, N, pH, moisture retention at end

Impact of biochar and manure on NO_3 leaching

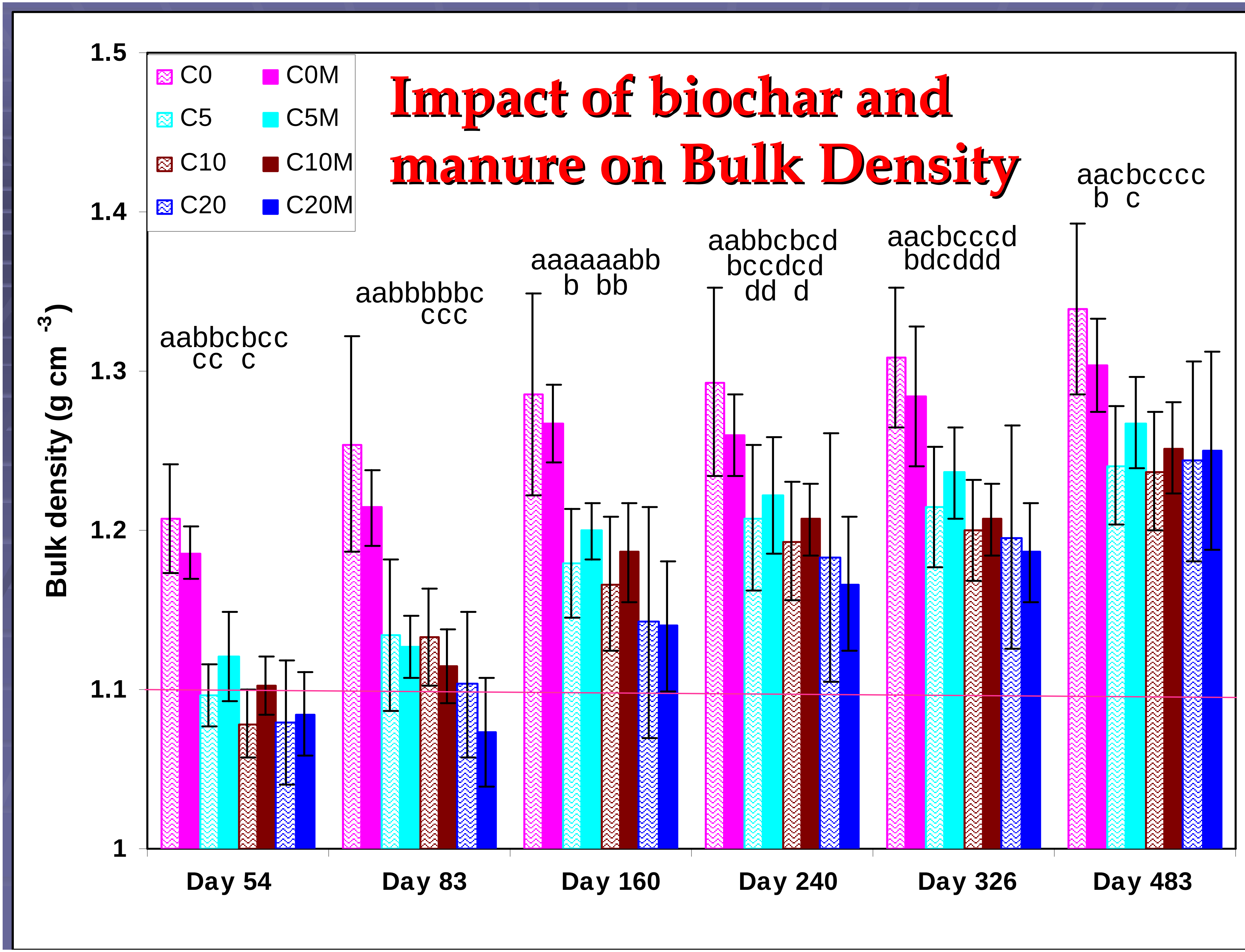


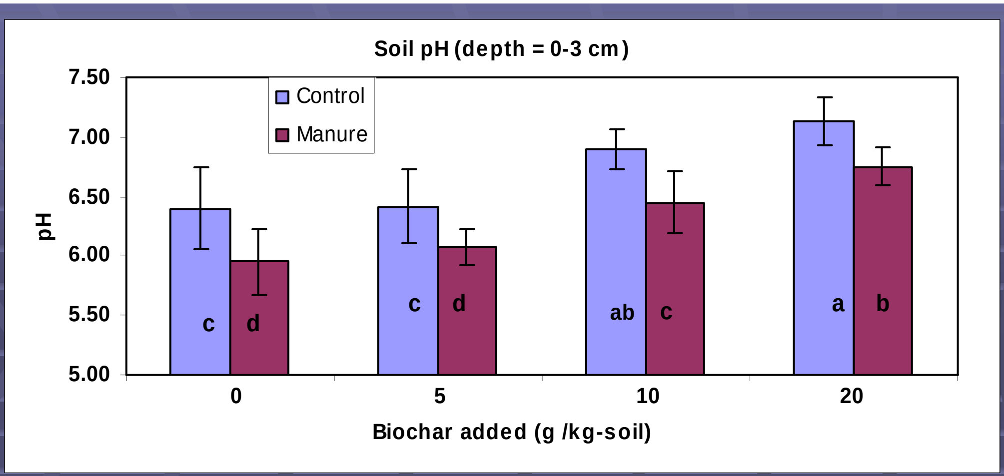
Post manure addition
Change in NO_3 leaching

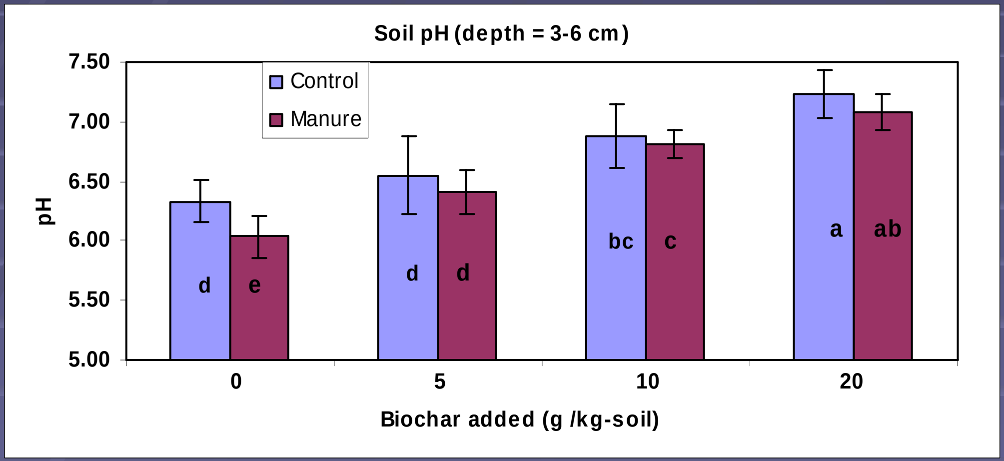
Char	Manure	Control
5 g/kg	-7%	-9%
10 g/kg	-10%	-11%
20 g/kg	-10%	+56%

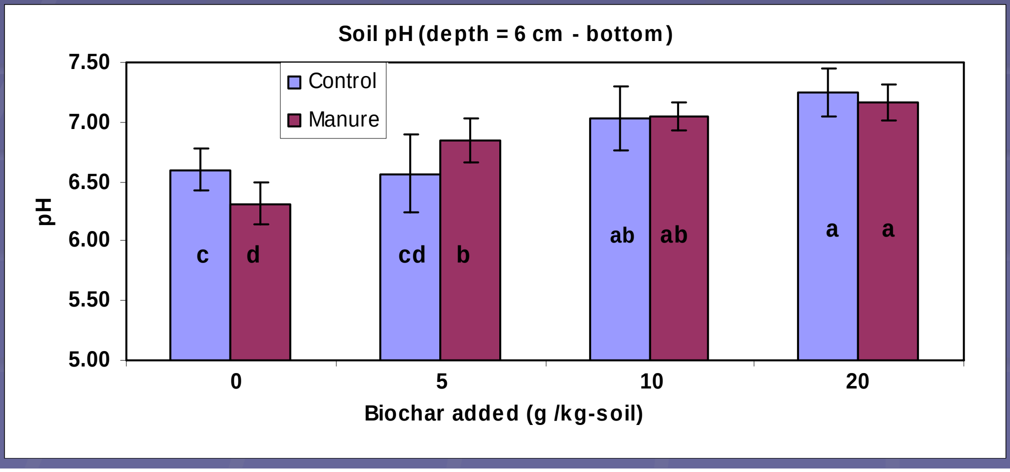


Effect of biochar and manure P leaching
mg/column
Week
C0
C0M
C5
C5M
C10
C10M
C20
C20M
Char (g/kg)
Reduction in P leaching (%)
5
41
10
55
20
70
Manure added
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
0
10
20
30
40
50


Impact of biochar and manure on Bulk Density
Bulk density (g cm -3)
1.5
1.4
1.3
1.2
1.1
1
C0
C0M
C5
C5M
C10
C10M
C20
C20M
aabbcbcc
cc c
aabbbbbc
ccc
aaaaaabb
b bb
aabbcbcd
bccdcd
dd d
aacbcccd
bdcddd
aacbcccc
b c
Day 54
Day 83
Day 160
Day 240
Day 326
Day 483





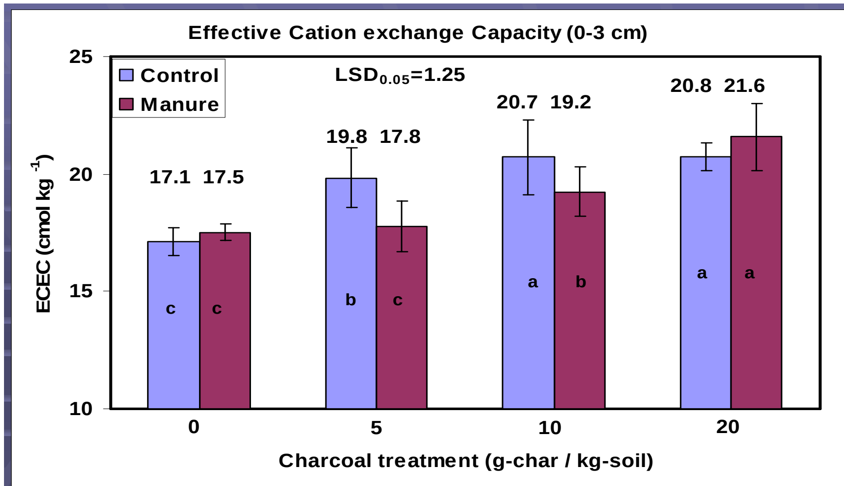


Impact of Biochar on Soil pH

Ash content of biochar = 7.5%

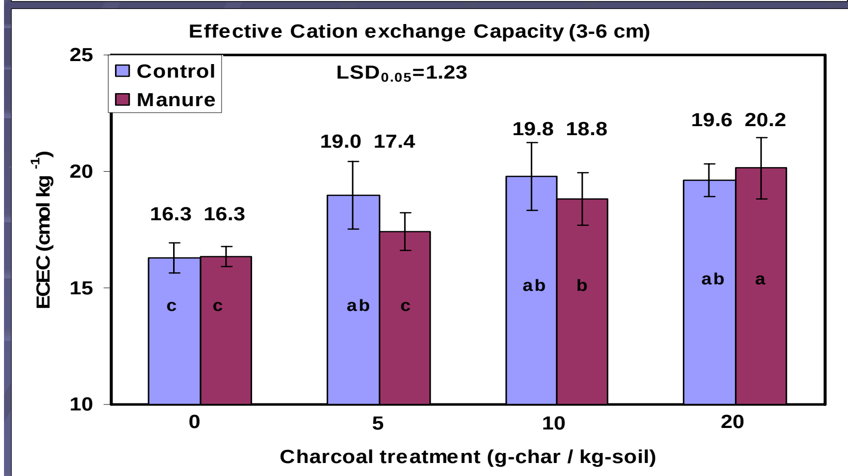
Assuming the ash is CaO then:

CCE = 12.5



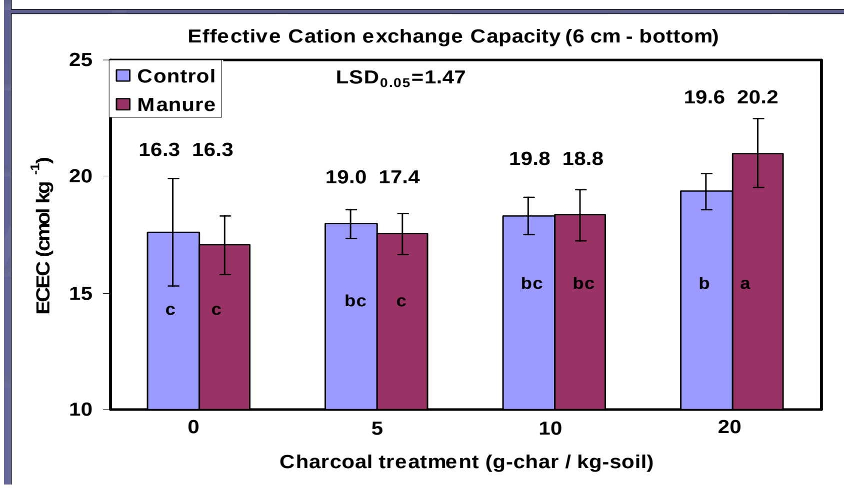
Percent change in ECEC (0-3 cm)

Char added (g/kg)	Control	+Manure
0	0	2
5	14	4
10	17	11
20	18	21



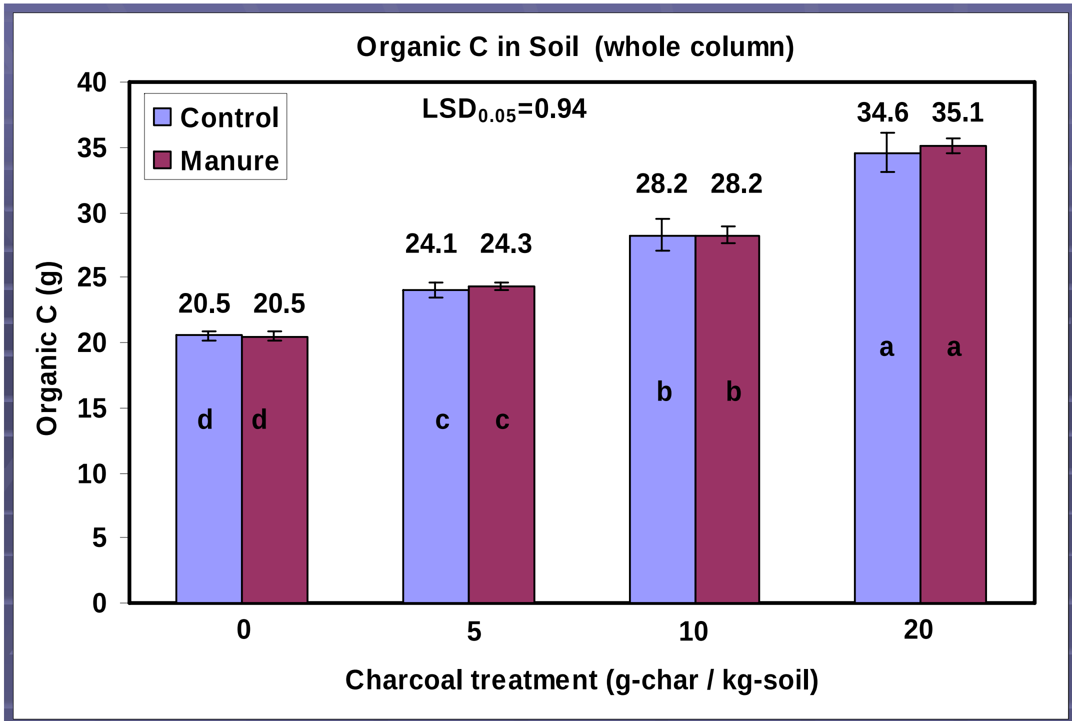
Percent change in ECEC (3-6 cm)

Char added (g/kg)	Control	+Manure
0	0	0
5	14	6
10	18	13
20	17	19



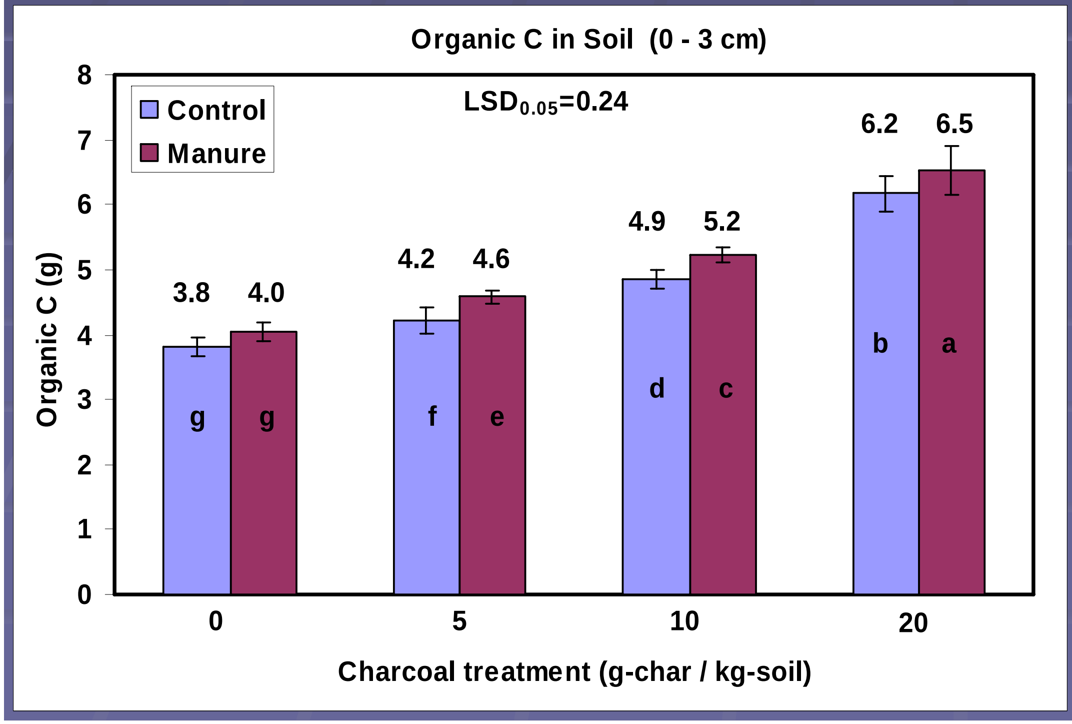
Percent change in ECEC (6 cm – bottom)

Char added (g/kg)	Control	+Manure
0	0	-3
5	2	0
10	4	4
20	9	16



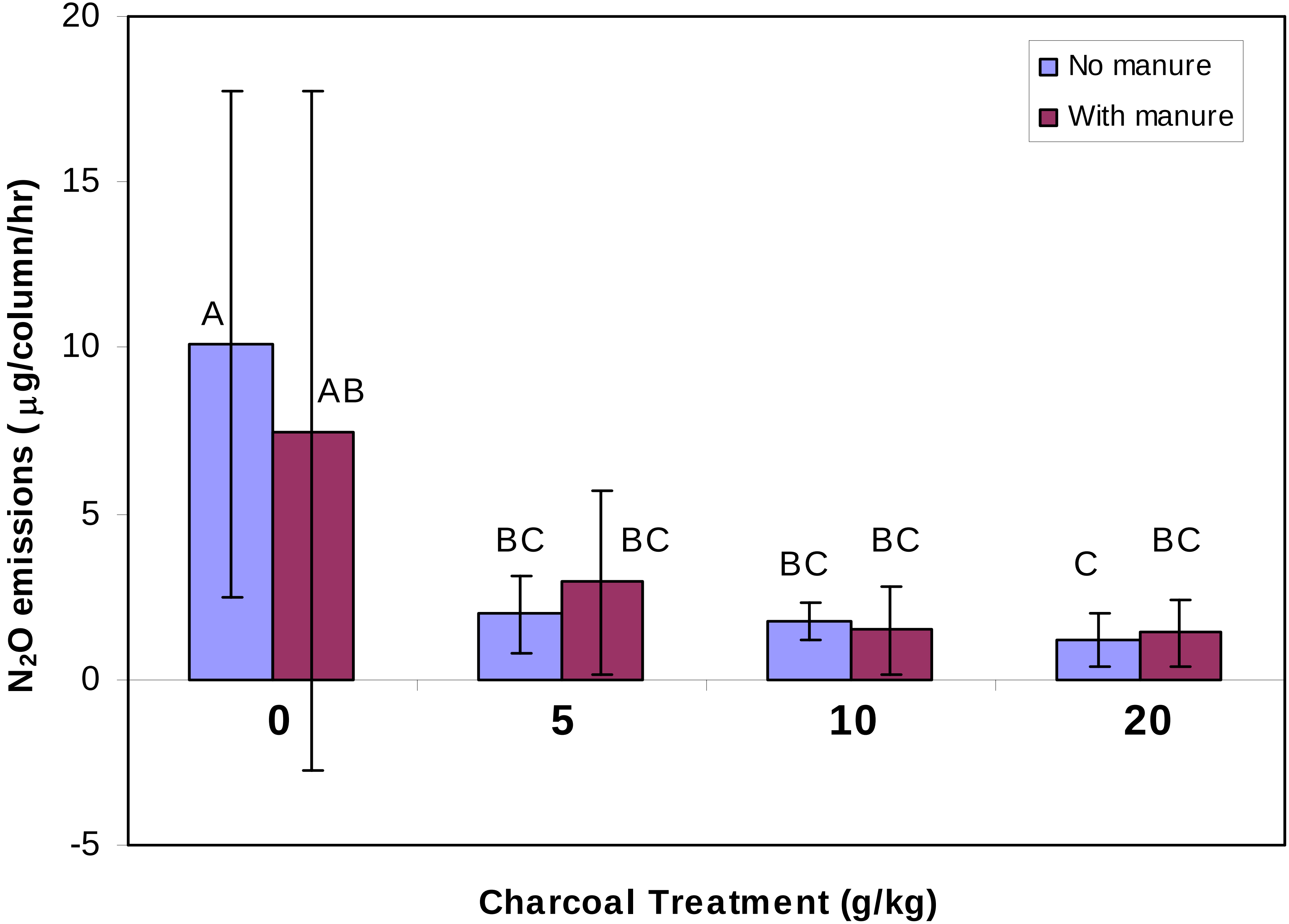
Recovery of charcoal C whole column

Char added (g/kg)	C recovery (%)
0	-
5	99
10	108
20	98



Recovery of manure C in 0-3 cm

Char added (g/kg)	C recovery (%)
0	11
5	18
10	18
20	17

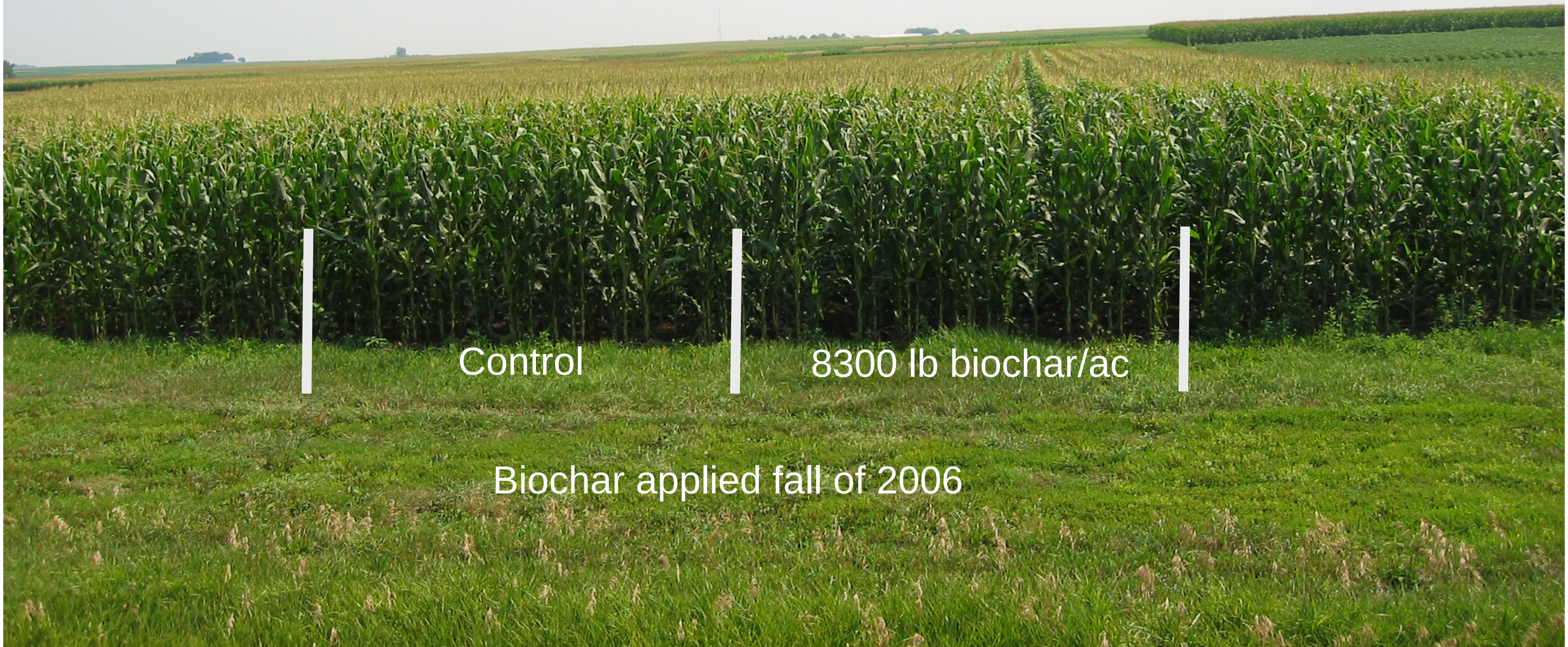


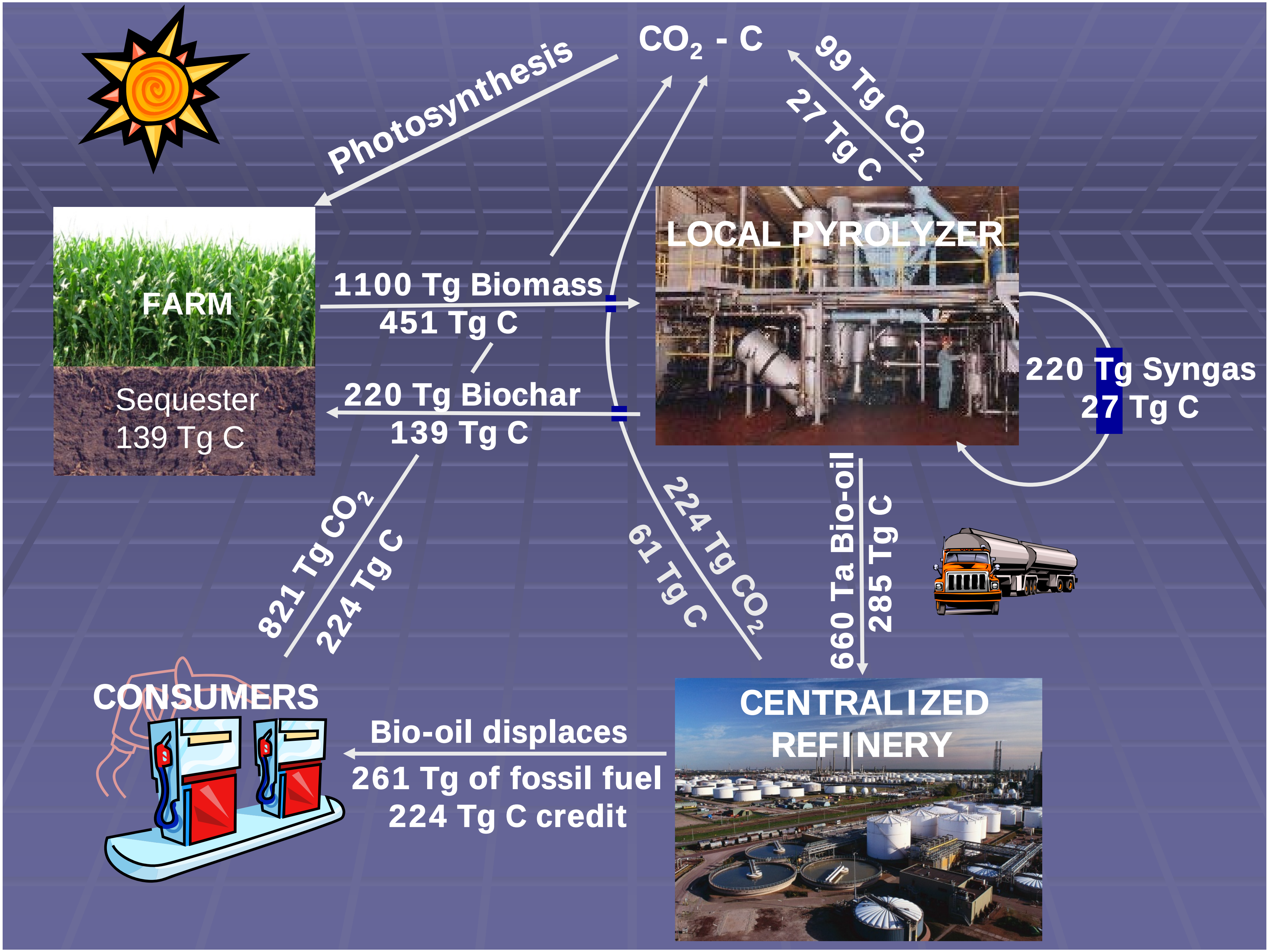
No manure
With manure
A
AB
BC
BC
BC
BC
C
BC
20
15
10
5
0
-5
0
5
10
20
N2O emissions (µg/column/hr)
Charcoal Treatment (g/kg)

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




CO_2 - C
Photosynthesis
99 Tg CO_2
27 Tg C
LOCAL PYROLYZER
FARM
Sequester
139 Tg C
1100 Tg Biomass
451 Tg C
220 Tg Biochar
139 Tg C
220 Tg Syngas
27 Tg C
821 Tg CO_2
224 Tg C
224 Tg CO_2
61 Tg C
660 Ta Bio-oil
285 Tg C
CONSUMERS
CENTRALIZED REFINERY
Bio-oil displaces
261 Tg of fossil fuel
224 Tg C credit

Impact on Global Change

Unanswered questions:

Half life of biochar C in soils 10s to 1000s years?

Potential reduction in N_2O emissions?

Stimulate biogenic humus formation/degradation?

Lime and fertilizer credit?

Conservative guess:

Assuming $1.1x10^9$ 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 1.1×10^9 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).