Biochar

A comparison of biochar volumes to increase plant growth and reduce soil acidity

RS

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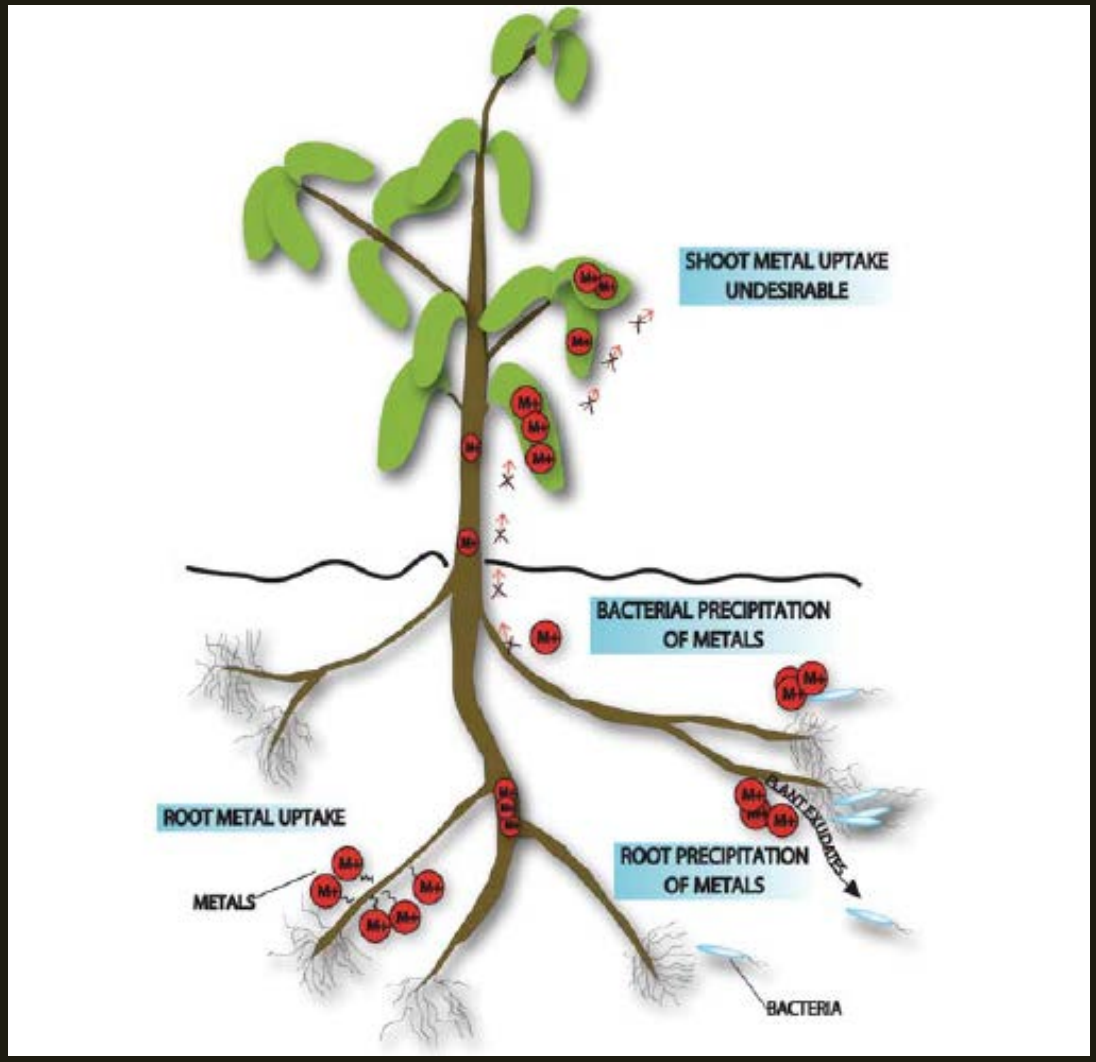


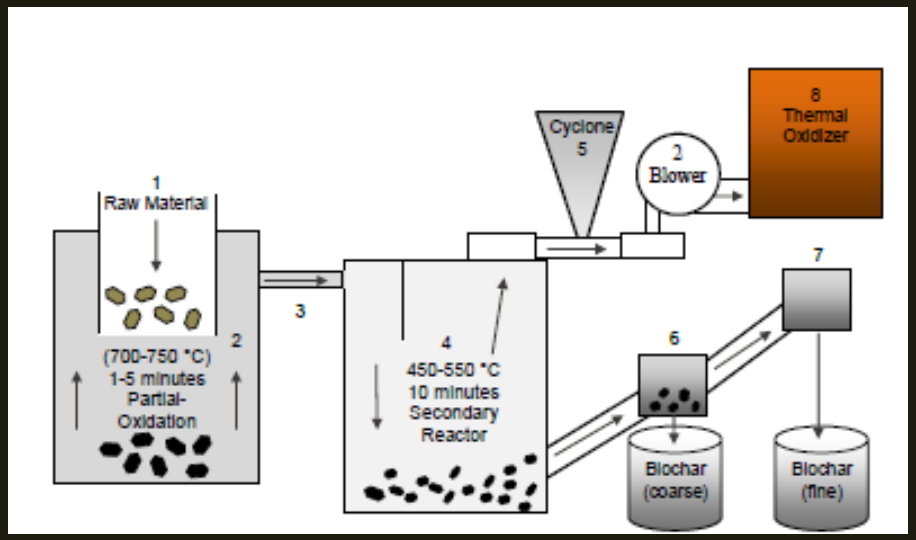
Phytostabilization of Mine Tailings in Arid and Semiarid Environments—An Emerging Remediation Technology

Monica O. Mendez and Raina M. Maier

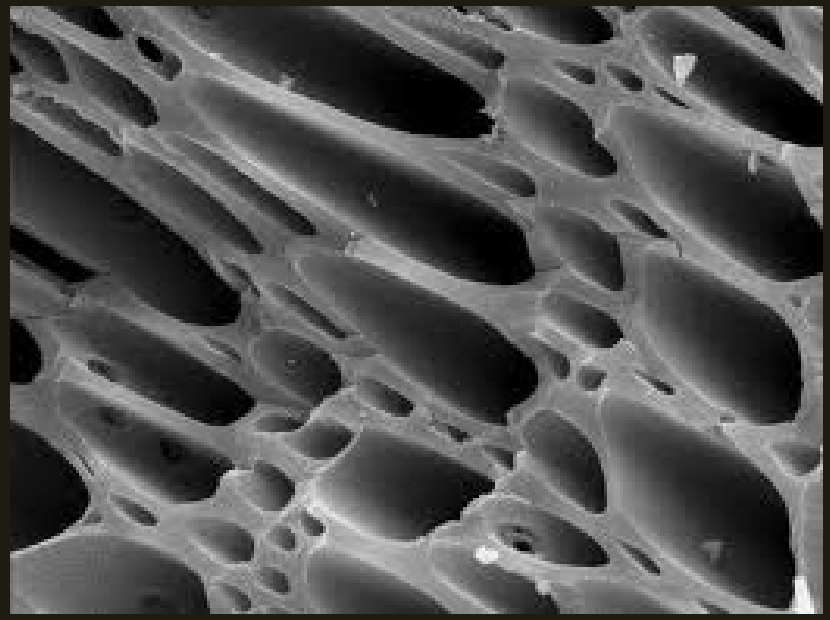
Department of Soil, Water, and Environmental Science, University of Arizona, Tucson, Arizona, USA


Living organisms <5%
Fresh residue <10%
Stabilized organic matter (humus) 33% - 50%
Decomposing organic matter (active fraction) 33% - 50%

What is biochar?



A carbon-rich (85%) product obtained when biomass is heated in a closed container with little or no oxygen (Lehman, 2009)



Biochar: A Synthesis of Its Agronomic Impact beyond Carbon Sequestration

Kurt A. Spokas,* Keri B. Cantrell, Jeffrey M. Novak, David W. Archer, James A. Ippolito, Harold P. Collins, Akwasi A. Boateng, Isabel M. Lima, Marshall C. Lamb, Andrew J. McAloon, Rodrick D. Lentz, and Kristine A. Nichols

One Step Forward toward Characterization: Some Important Material Properties to Distinguish Biochars

Sonja Schimmelpfennig* and Bruno Glaser

Table 1. Description of advanced thermal conversion processes.†

Conversion type	Temp. range	Residency time	Heating rate	Product production (% of original feedstock mass)			Solid proximate analysis‡			
				Solid	Liquid	Gas	Moisture	VM	Ash	Fixed C
	°C		°C s^{-1}	%						
Torrefaction	200–320	hours	<1	40–90	–	10–60	0–1	50–85	2–10	13–38
Slow pyrolysis	350–700	hours	1–100	15–40	20–55	20–60	0–5	5–20	2–10	40–90
Fast pyrolysis	450–550	<1 min	>1000	10–30	50–70	5–15	0–5	40	30	40–60

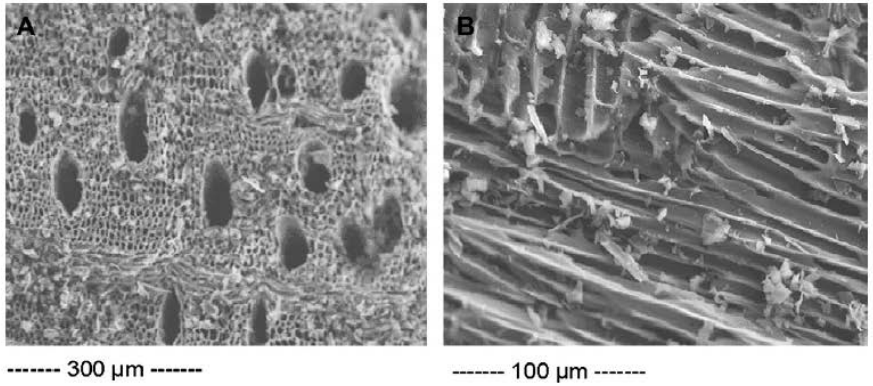


Fig. 4. Scanning Electron Microscope (SEM) image of the surface of biochar at 190× magnification showing variously sized pores (A.) and longitudinal, vertically cut cross-section of those pores at 550× magnification (B.). Note both the vast surface area and interior pore structure.

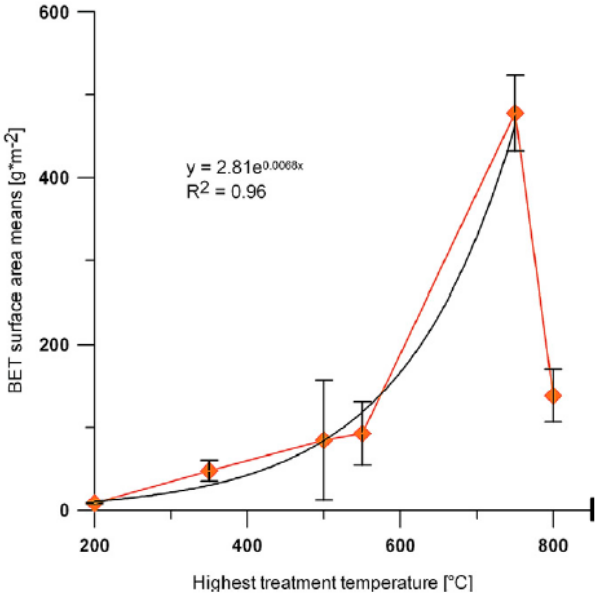
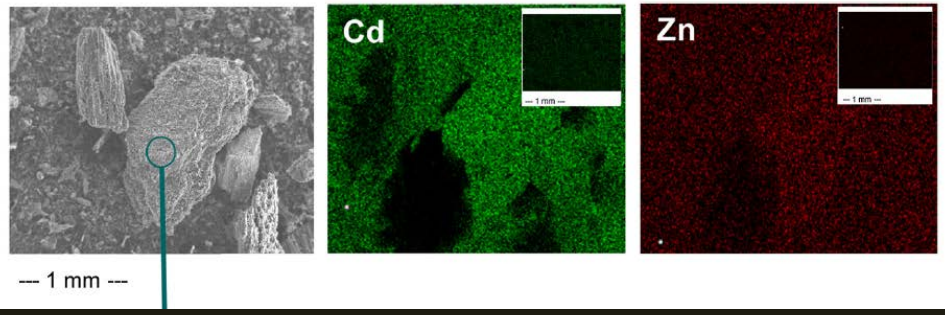
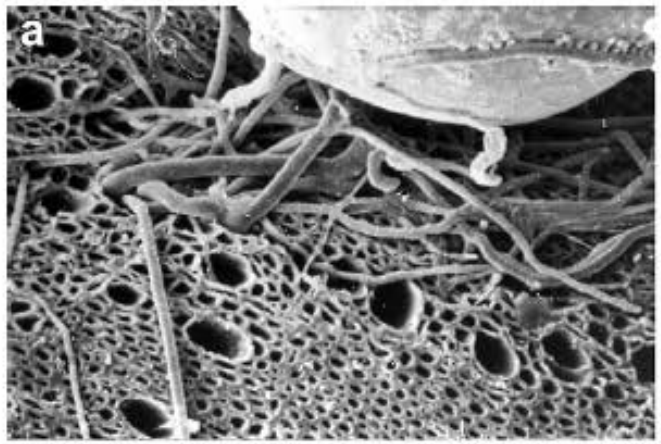


Fig. 5. Brunauer–Emmett–Teller (BET) surface area means and standard error as a function of highest treatment temperature. Data for hydrothermal carbonization samples taken from Geffers (2010).





What does biochar do?

- Increase soil organic carbon;
- Increase water holding capacity of soils;
- Increase pH and cation-exchange capacity;
- Decrease soil bulk density;
- Increases percentage of 1-2 mm water stable aggregates;
- Increase population and diversity of soil microorganisms;
- Sequester carbon (70-80% fixed C/mass);
- Reduce transport of PAH's in soils
- Reduce the concentrations of As, Cd, Zn, Pb, Cu, Fe, and N, K in soil leachates

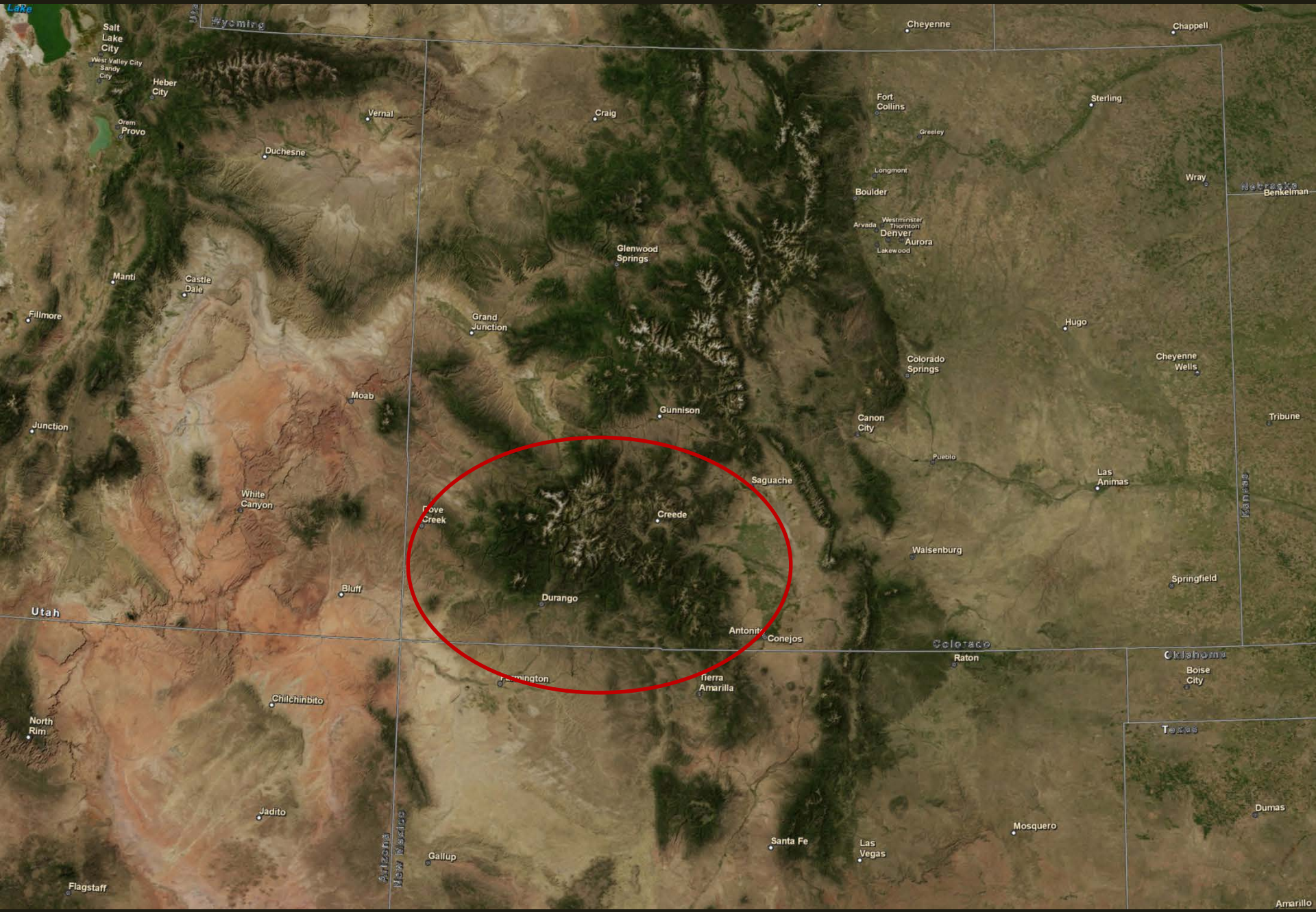
Questions

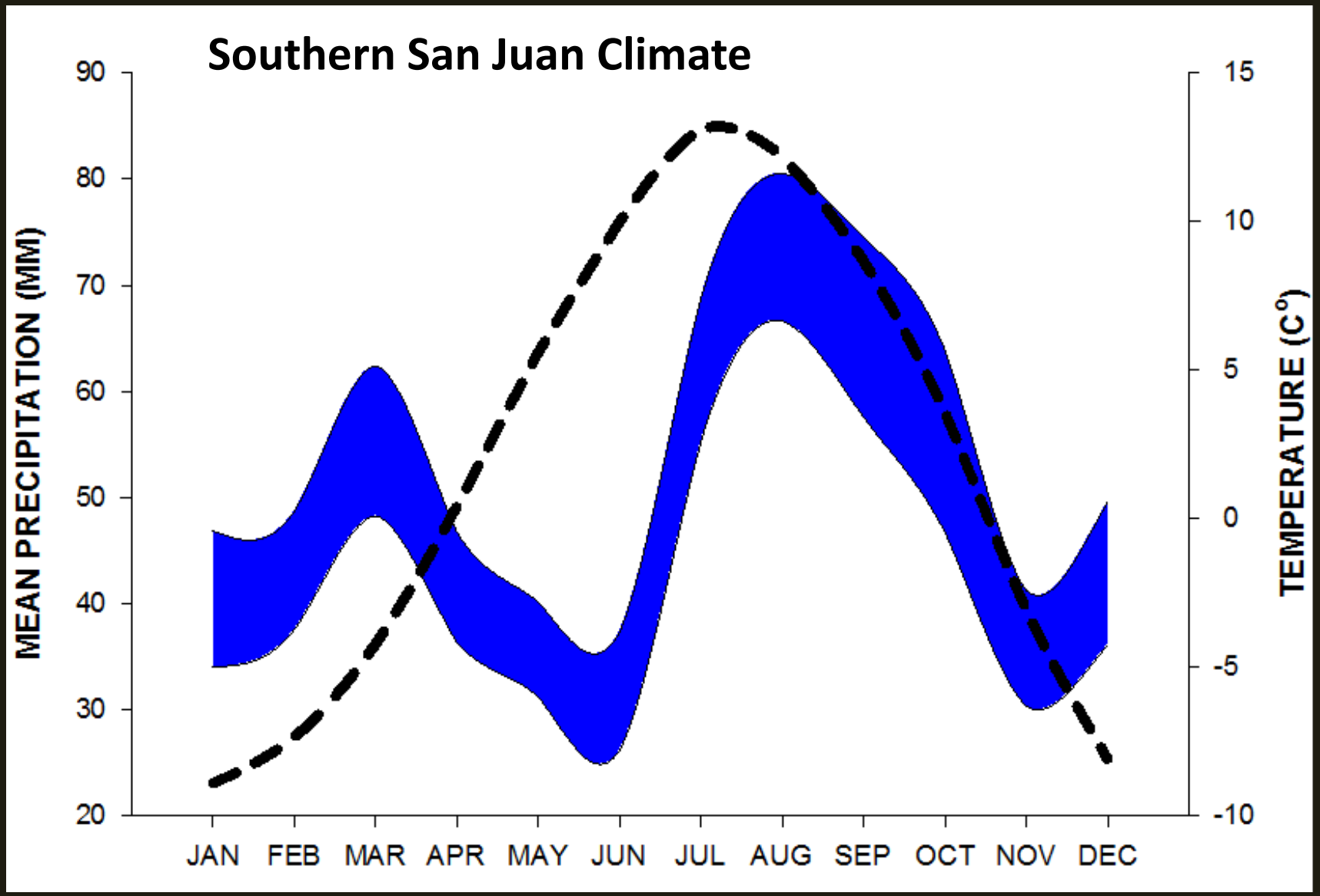
Will applying biochar improve soil conditions and increase plant growth?

- Vegetation growth and vigor
- Soil moisture dynamics
- Soil chemistry

What are the most effective methods of using biochar for mine lands in terms of $, C, and restoration outcomes?

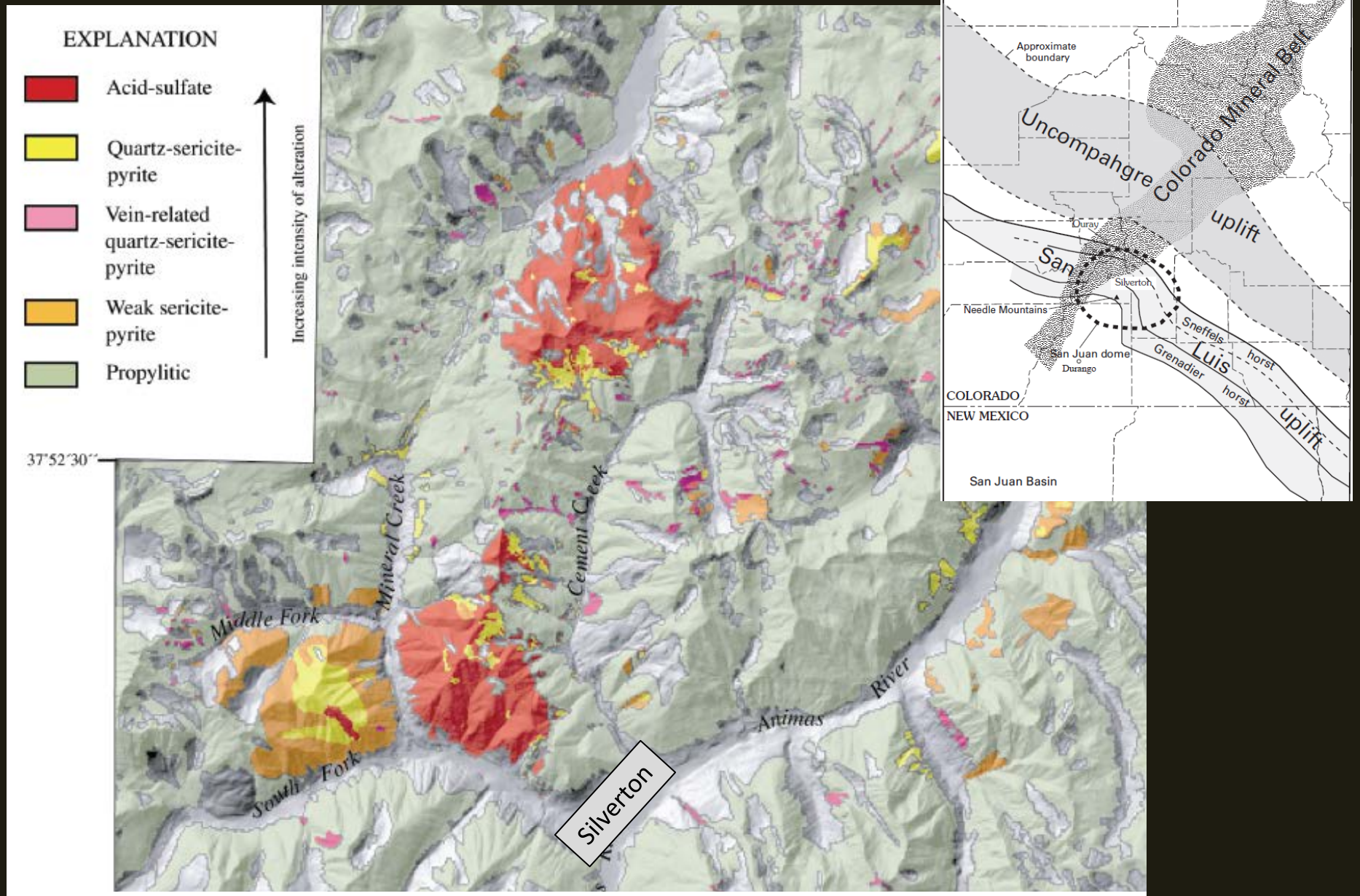
- Application rates and methods
- Determine site or site-type specific restoration methods
- Conduct large scale and paired experiments


Salt Lake City
West Valley City
Sandy City
Heber City
Orem
Provo
Vernal
Duchesne
Craig
Cheyenne
Chappell
Fort Collins
Sterling
Greeley
Longmont
Boulder
Wray
Nebraska
Benkelman
Arvada
Westminster
Thornton
Denver
Aurora
Lakewood
Glenwood Springs
Manti
Castle Dale
Fillmore
Grand Junction
Hugo
Colorado Springs
Cheyenne Wells
Moab
Gunnison
Canon City
Tribune
Junction
Pueblo
Las Animas
Saguache
White Canyon
Creede
Walsenburg
Springfield
Bluff
Durango
Utah
Conejos
Raton
Oklahoma
Boise City
Tierra Amarilla
Chilchinbito
North Rim
Texas
Jadito
Arizona
New Mexico
Gallup
Santa Fe
Las Vegas
Mosquero
Dumas
Flagstaff
Amarillo



Precipitation and temperature patterns for Silverton Colorado. Dashed line - mean monthly temperature (C^0), blue area - 95% confidence interval of mean monthly precipitation - 105 year record - www.wrcc.dri.edu


Cunningham Creek
Cement Creek
Animas River
Mineral Creek



Yager, Douglas B., and Bove, Dana J., 2002, Generalized Geologic Map of the Upper Animas River Watershed and Vicinity, Silverton, Colorado: U.S. Geological Survey Miscellaneous Field Studies Map MF-2377, U.S. Geological Survey, Denver, Colorado.

Yager , Choate and Stanton 2008. USGS Scientific Investigations Report 2009-5063

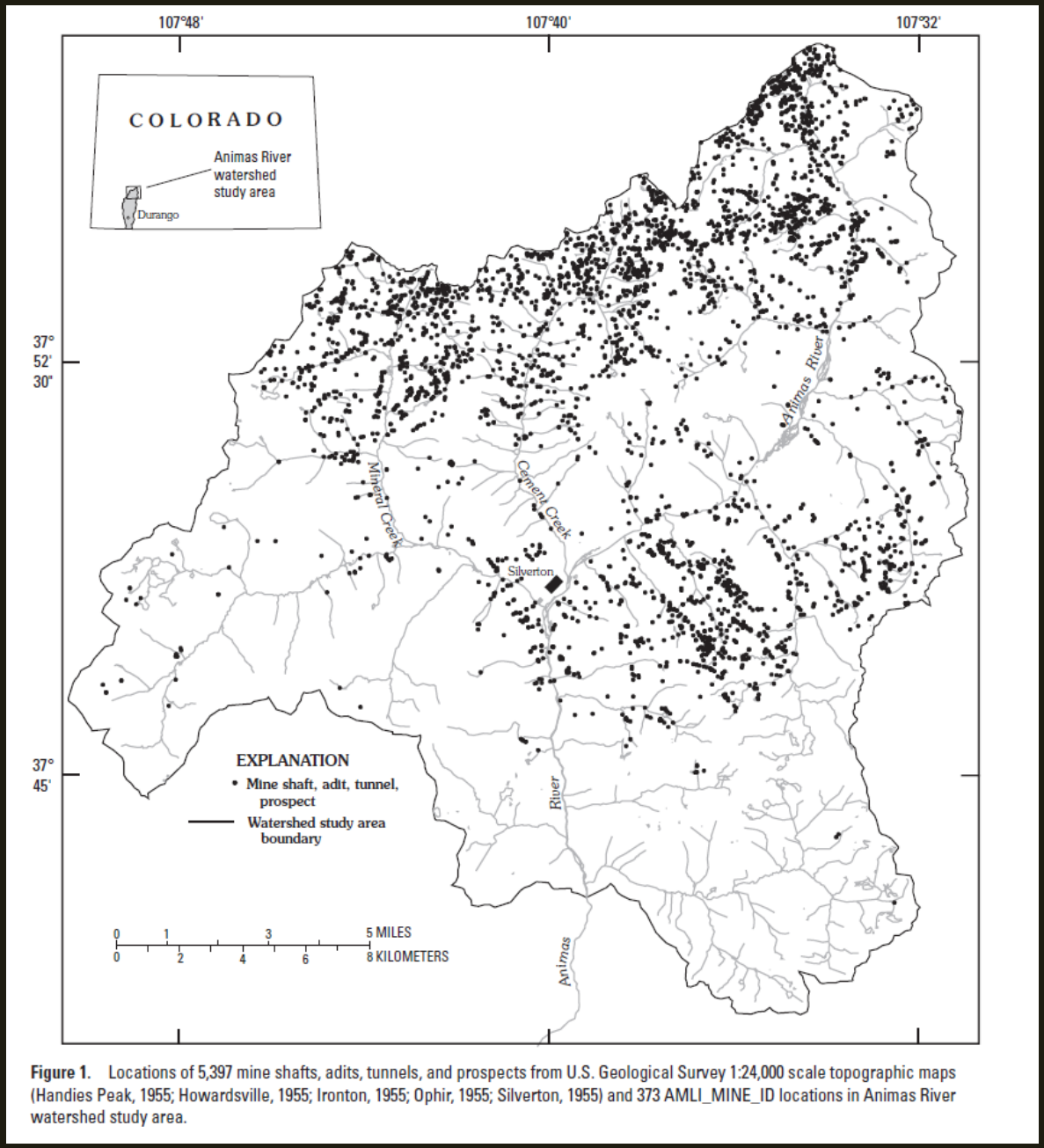


Figure 1. Locations of 5,397 mine shafts, adits, tunnels, and prospects from U.S. Geological Survey 1:24,000 scale topographic maps (Handies Peak, 1955; Howardsville, 1955; Ironton, 1955; Ophir, 1955; Silverton, 1955) and 373 AMLI_MINE_ID locations in Animas River watershed study area.

Church, Mast, Martin and Rich 2007

Four Mining Periods:
Smelting 1871-1889
Gravity Milling 1890-1913
Early Flotation 1914-1935
Modern Flotation 1936-1991
~121 years

mines, adits, prospects, other sites >5,300

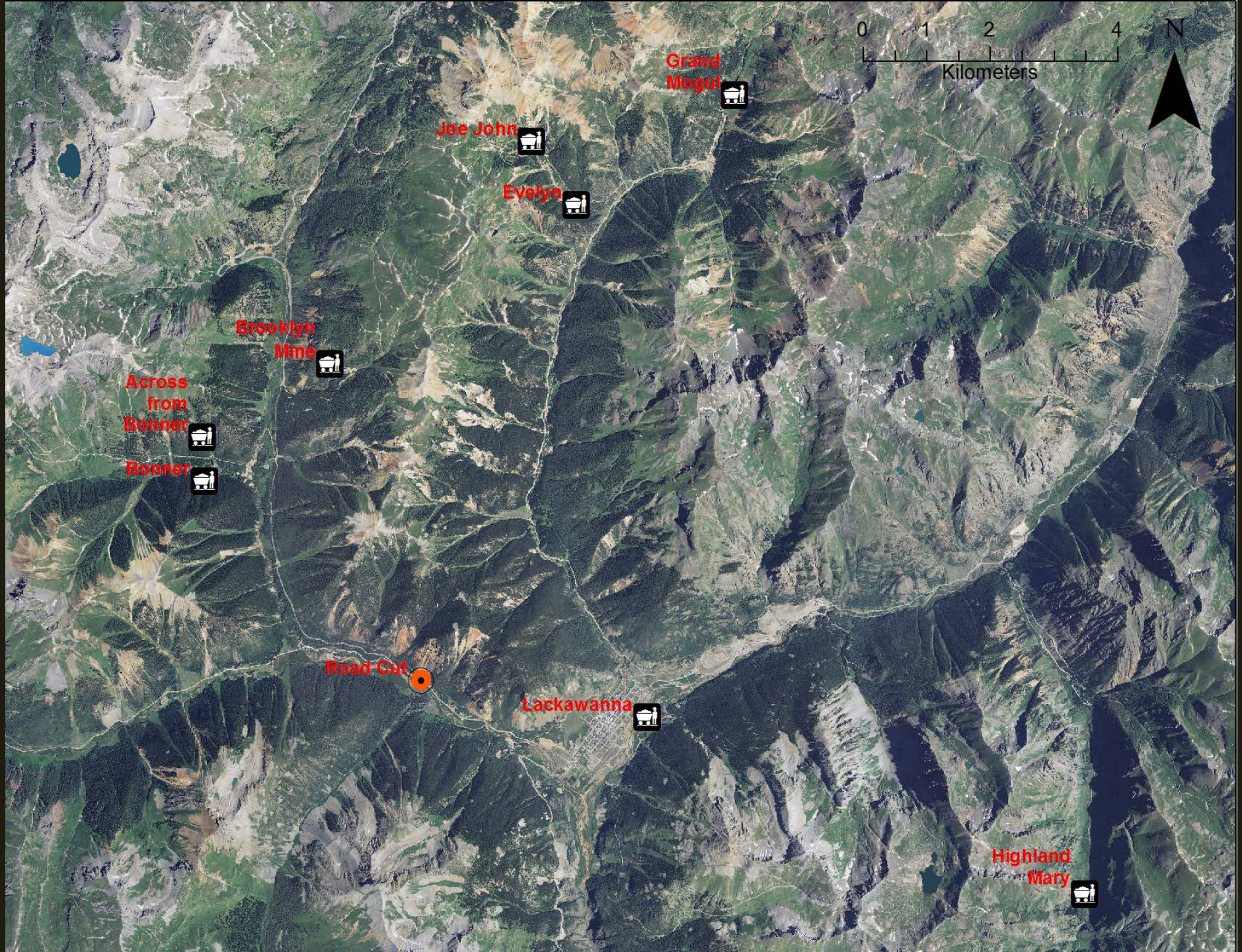
large mines, mills, mill-tailings deposits 373

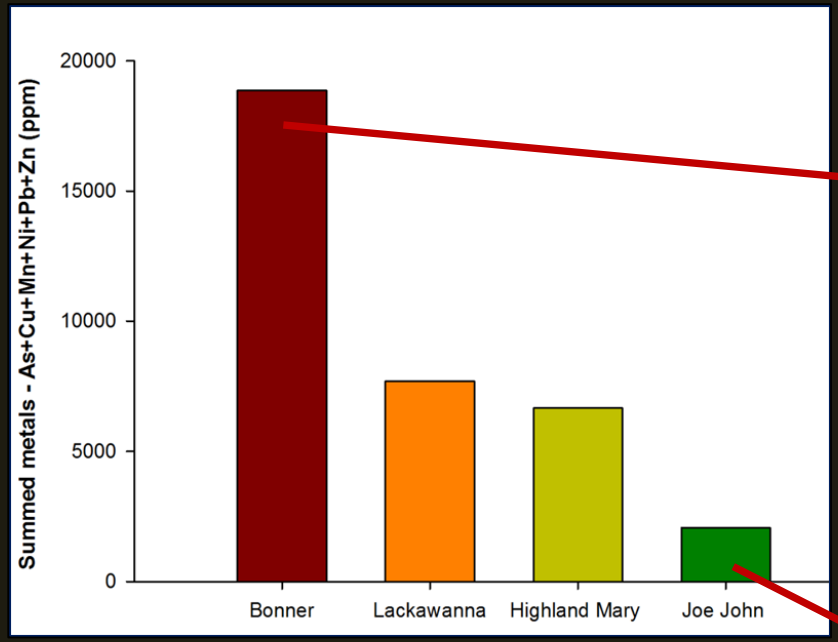
Total ore production ~18.1 Ma short tons

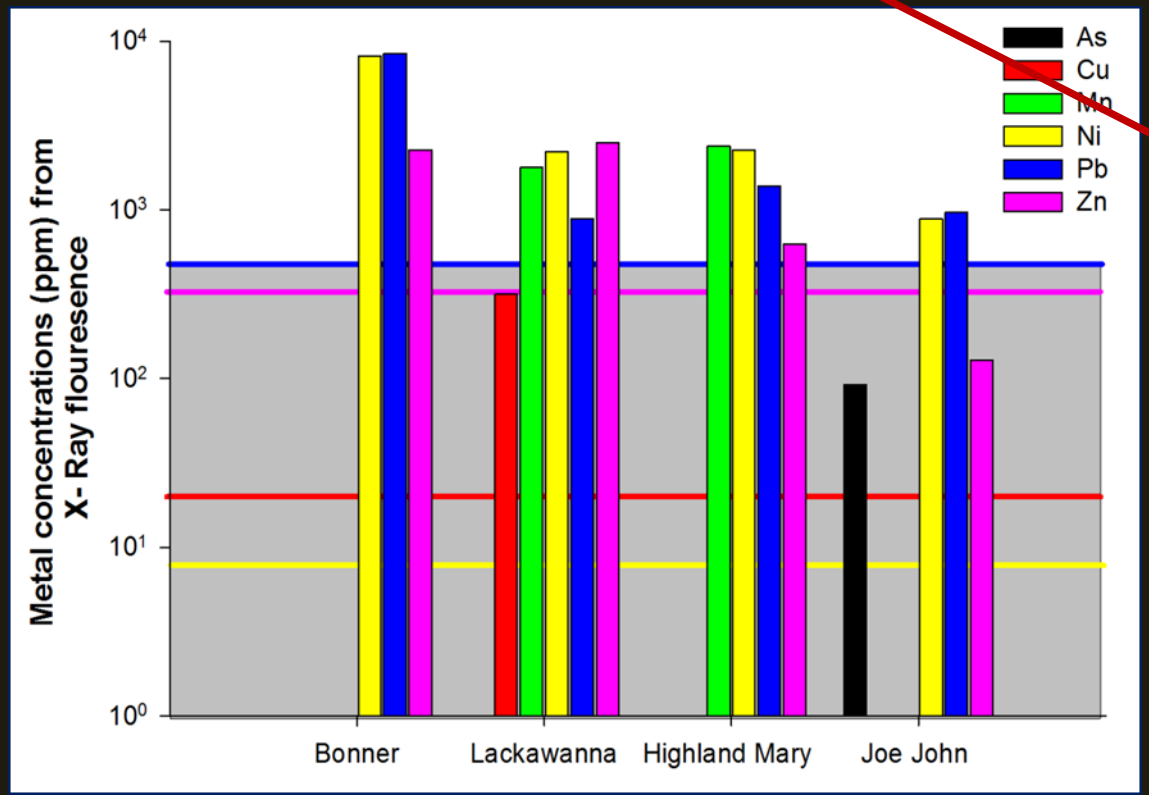
Ore discharged to Animas River 8.6 Ma short tons

+

=

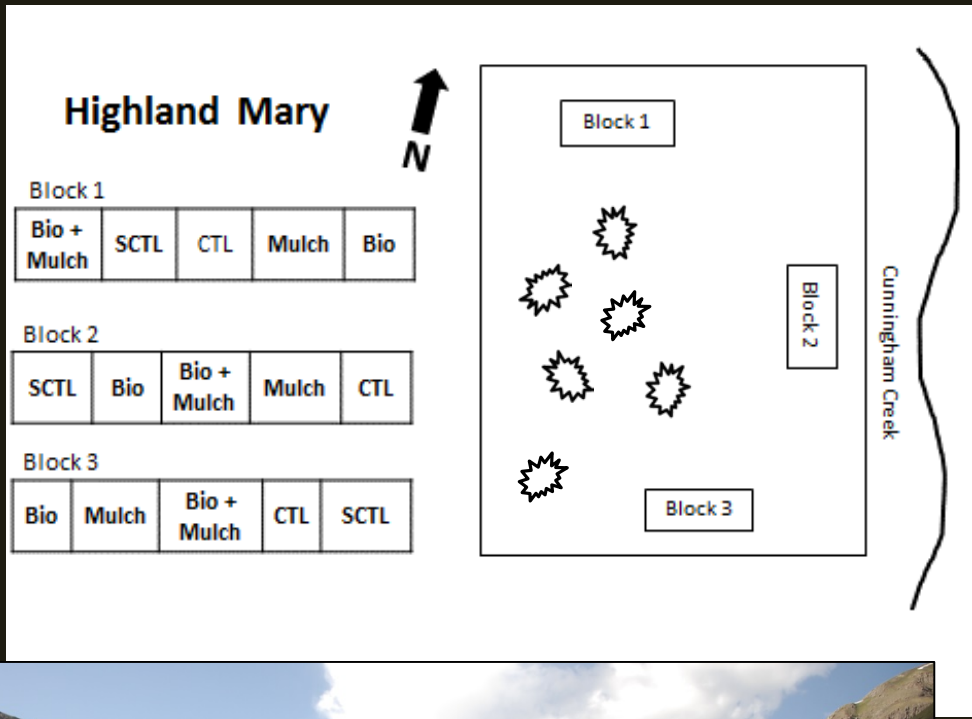

0
1
2
4
Kilometers
N
Grand Mogul
Joe John
Evelyn
Brooklyn Mine
Across from Bonner
Bonner
Road Cut
Lackawanna
Highland Mary


Summed metals - As+Cu+Mn+Ni+Pb+Zn (ppm)
20000
15000
10000
5000
0
Bonner
Lackawanna
Highland Mary
Joe John


Metal concentrations (ppm) from X- Ray flouresence
10^4
10^3
10^2
10^1
10^0
As
Cu
Mn
Ni
Pb
Zn
Bonner
Lackawanna
Highland Mary
Joe John

Field

- Randomized block design
- Three treatments (B, B+M, M)
- Alpine mix of grasses (USFS supplied)
- 30% by volume biochar additions
- VWC (%)
- Veg cover (%) estimates ~40 days , 1 year after seeding

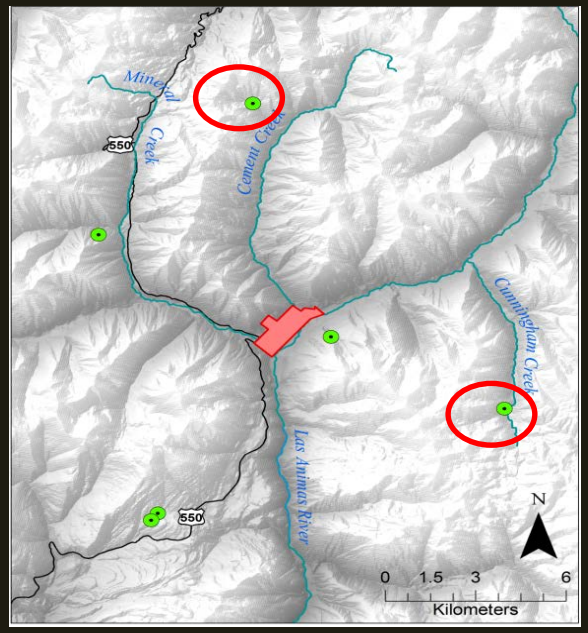


Greenhouse

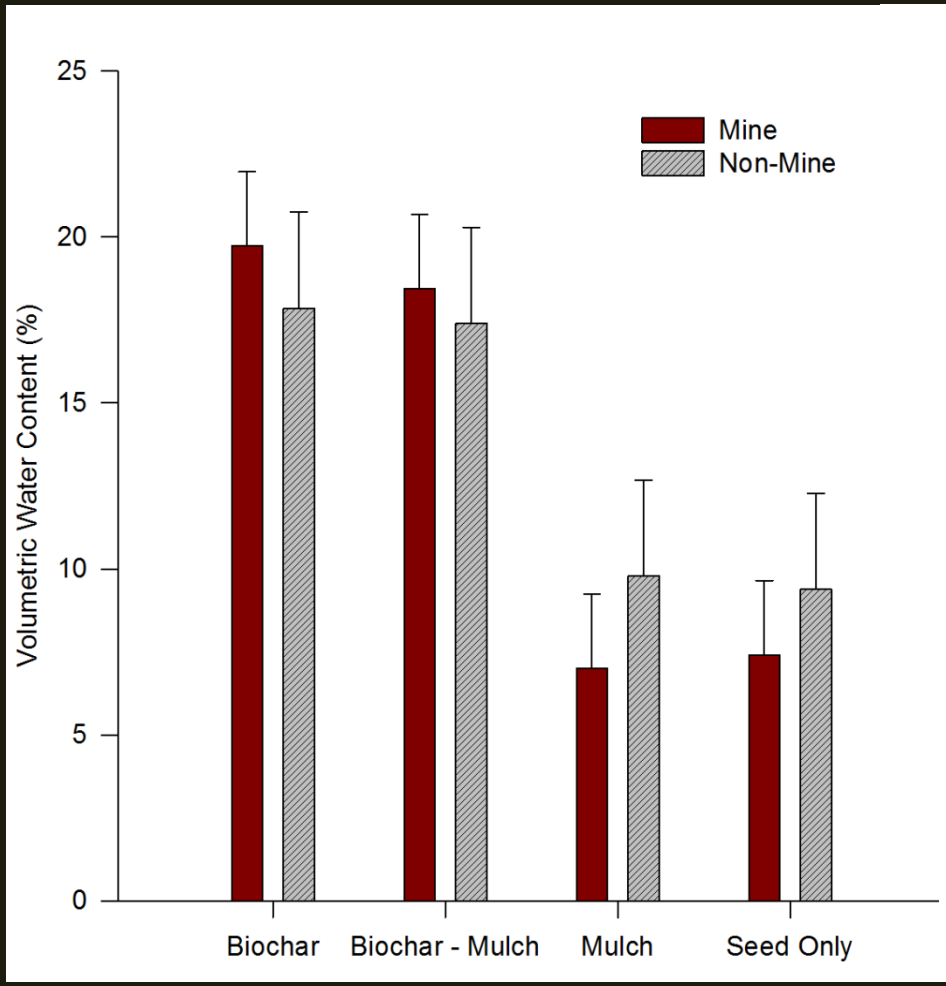
- Above ground biomass (g)
- Leachate chemistry (ICP-MS)

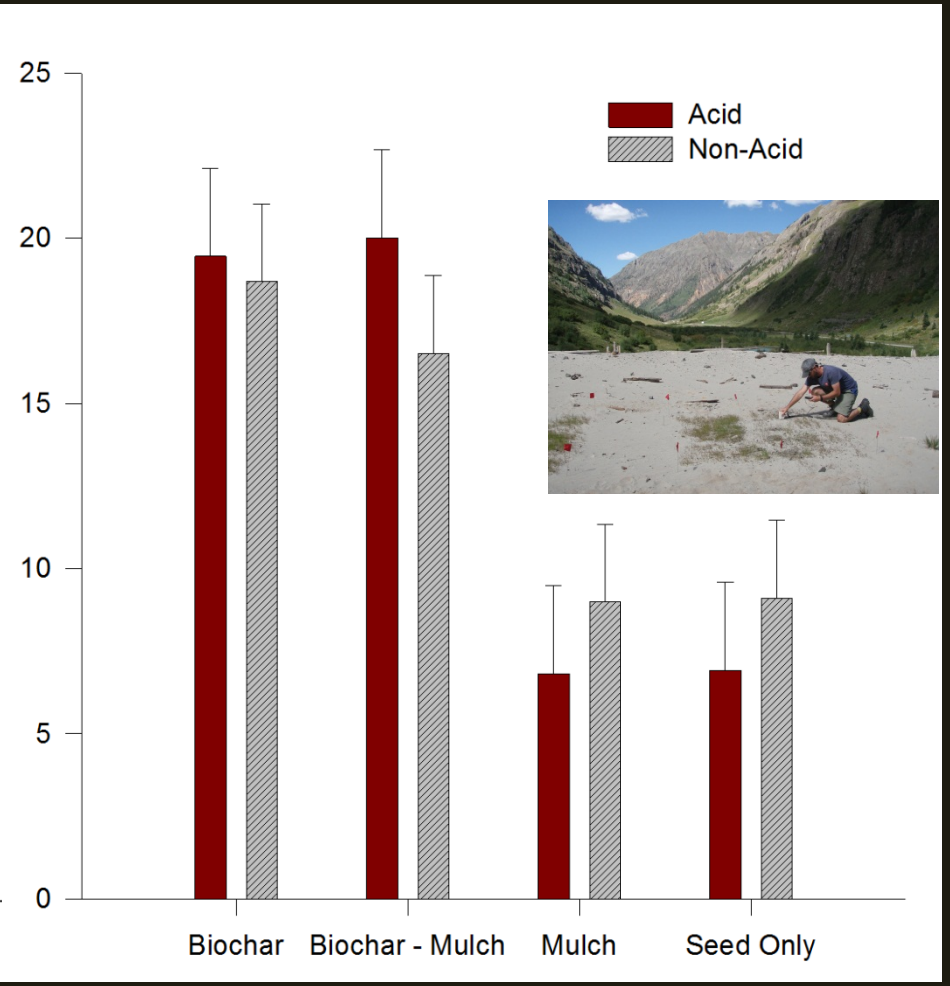
Joe John - Lark Mine
overburden soils
10,800 ft
restoration work since 1999
plant toxic levels of As
low water holding capacity

Highland Mary Tailings
pH 7-8
plant toxic levels of Pb



Volumetric Water Content(%) field

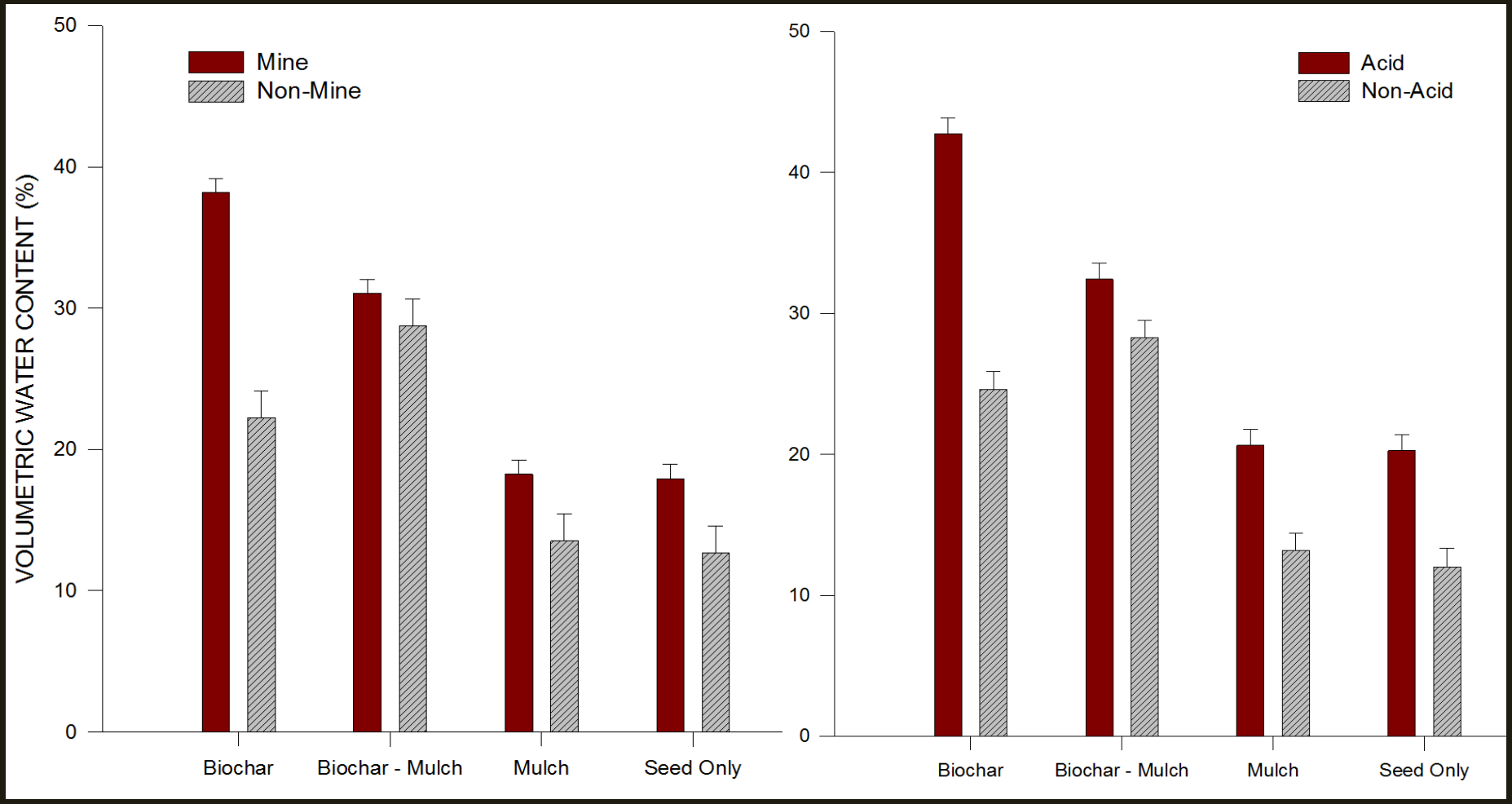




Comparison (mine)	Diff of Means	P
Biochar vs. Mulch	**12.73**	**<0.001**
Biochar vs. Seed Only	**12.32**	**<0.001**
Biochar - Mulch vs. Mulch	**11.44**	**<0.001**
Biochar - Mulch vs. Seed Only	**11.03**	**<0.001**
Biochar vs. Biochar - Mulch	1.29	0.686
Seed Only vs. Mulch	0.41	0.898

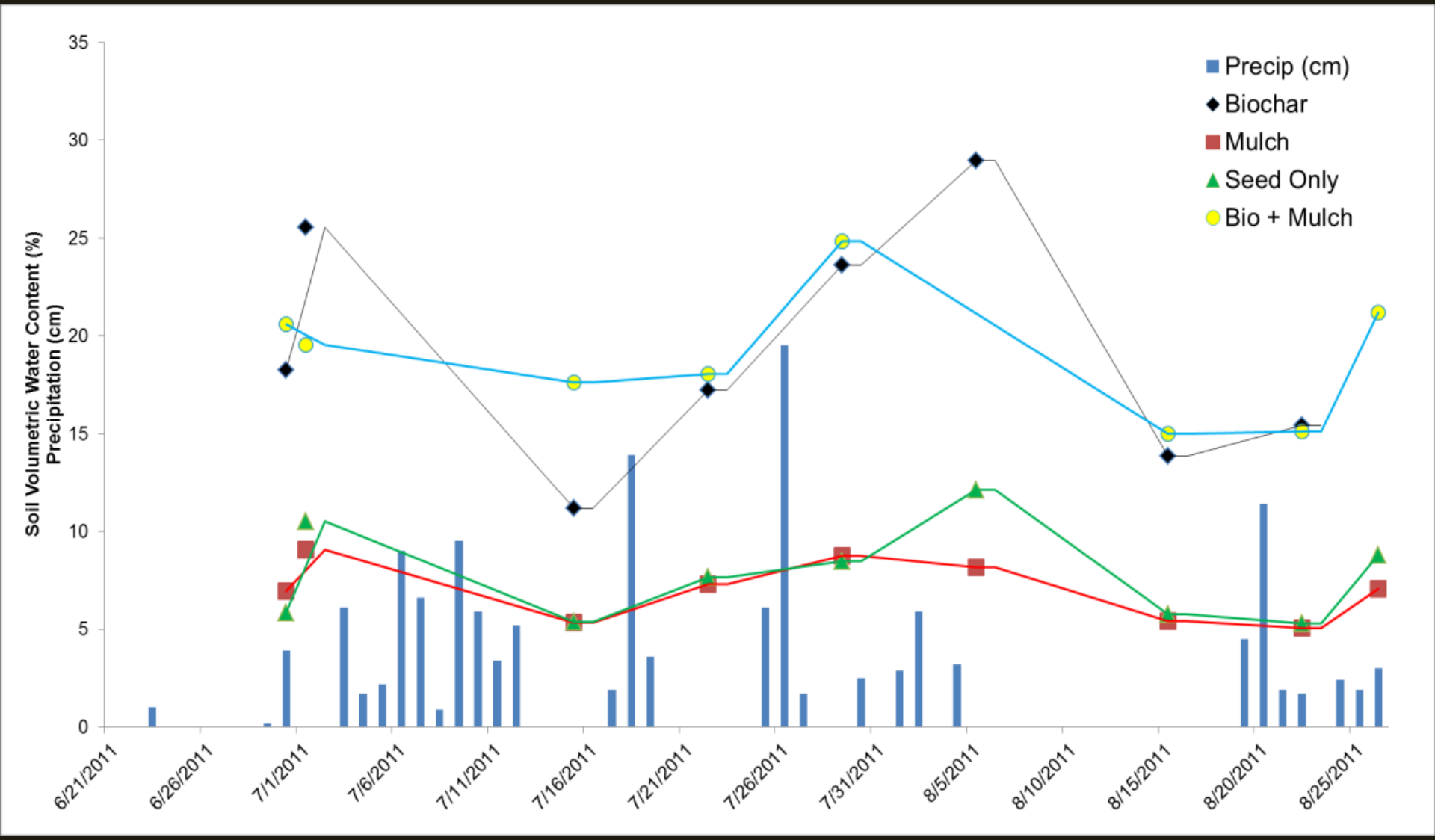
Comparison (acid)	Diff of Means	P
Biochar - Mulch vs. Mulch	**13.2**	**<0.001**
Biochar - Mulch vs. Seed Only	**13.1**	**<0.001**
Biochar vs. Mulch	**12.643**	**0.001**
Biochar vs. Seed Only	**12.543**	**0.002**
Biochar - Mulch vs. Biochar	0.557	0.883
Seed Only vs. Mulch	0.1	0.979

Volumetric Water Content(%) greenhouse

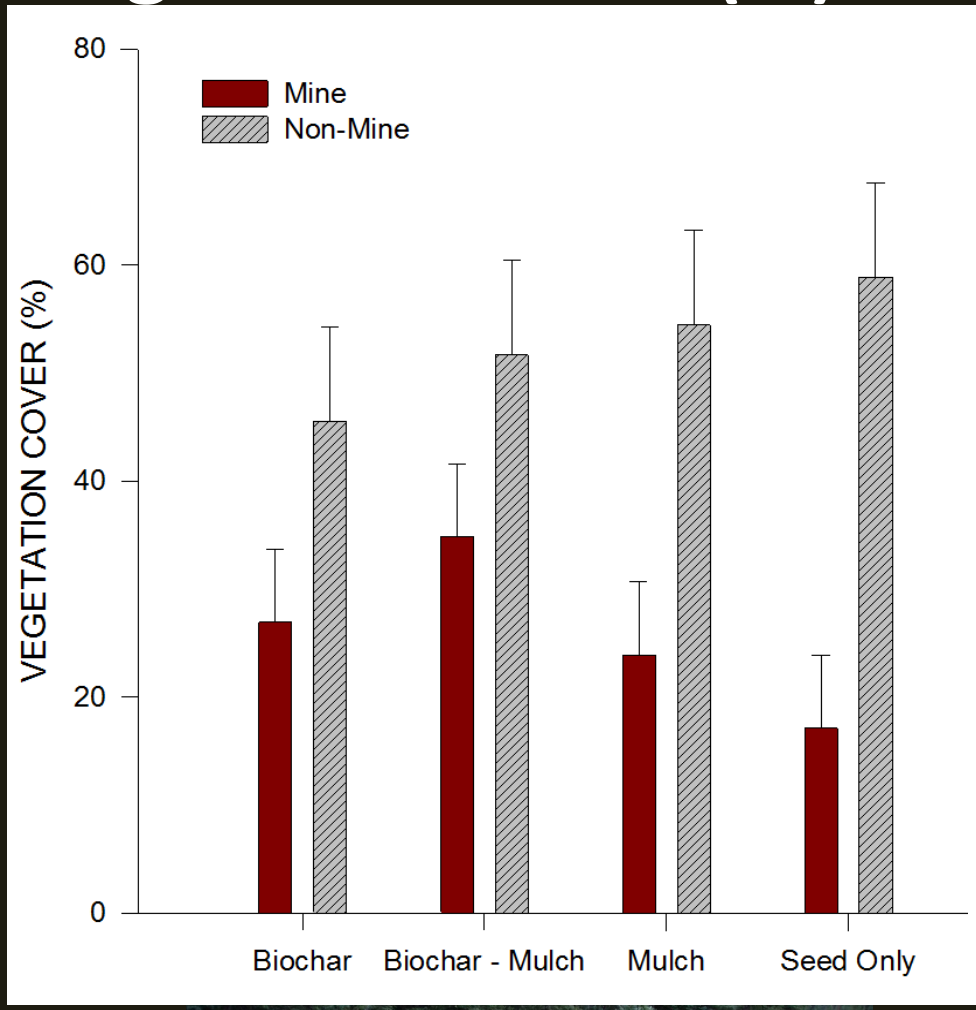


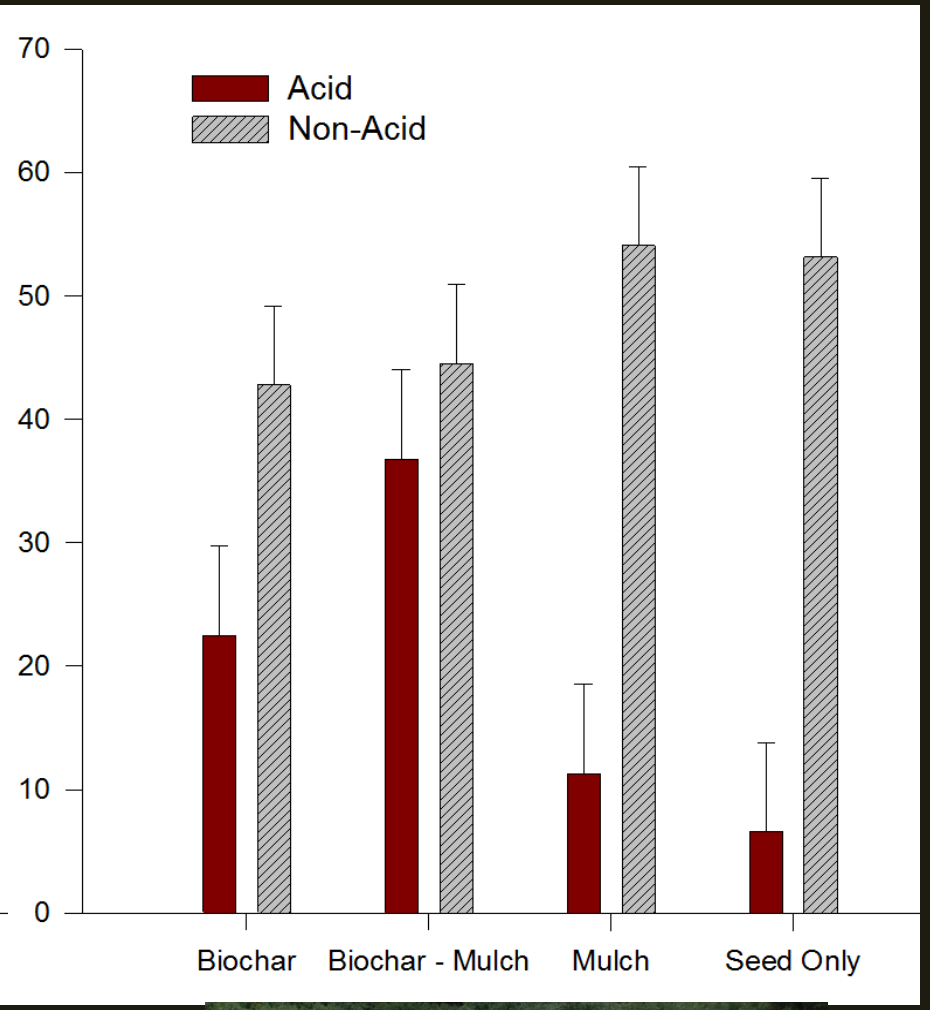
Comparison (mine)	Diff of Means	P
Biochar vs. Seed Only	**20.259**	**<0.001**
Biochar vs. Mulch	**19.954**	**<0.001**
Biochar - Mulch vs. Seed Only	**13.117**	**<0.001**
Biochar - Mulch vs. Mulch	**12.812**	**<0.001**
Biochar vs. Biochar - Mulch	**7.141**	**<0.001**
Mulch vs. Seed Only	0.305	0.831

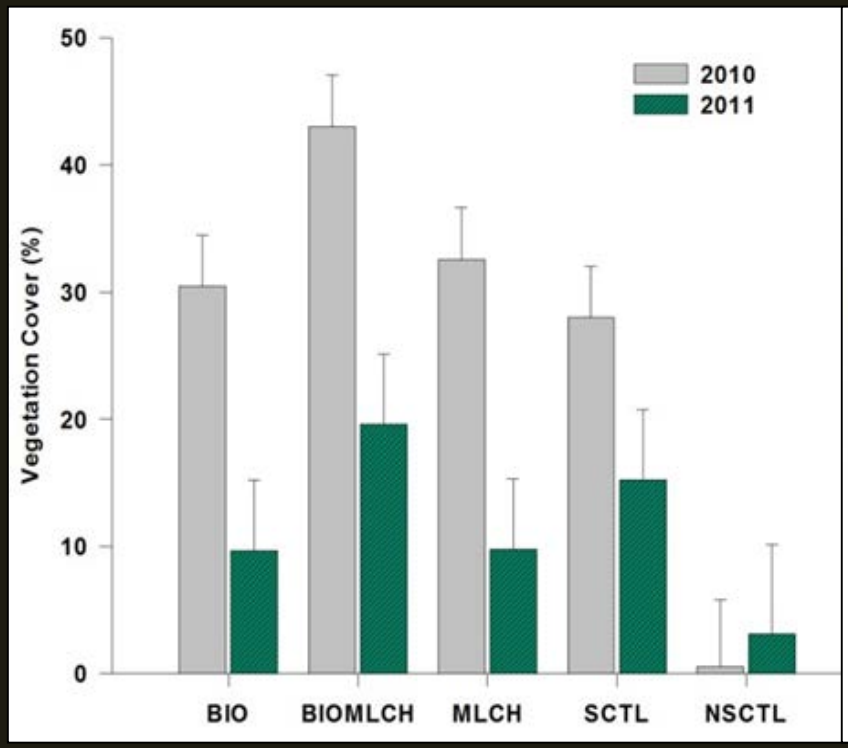
Comparison (acid)	Diff of Means	P
Biochar vs. Seed Only	**22.496**	**<0.001**
Biochar vs. Mulch	**22.125**	**<0.001**
Biochar - Mulch vs. Seed Only	**12.151**	**<0.001**
Biochar - Mulch vs. Mulch	**11.781**	**<0.001**
Biochar vs. Biochar - Mulch	**10.345**	**<0.001**
Mulch vs. Seed Only	0.37	0.817


Soil Volumetric Water Content (%)
Precipitation (cm)
35
30
25
20
15
10
5
0
6/21/2011
6/26/2011
7/1/2011
7/6/2011
7/11/2011
7/16/2011
7/21/2011
7/26/2011
7/31/2011
8/5/2011
8/10/2011
8/15/2011
8/20/2011
8/25/2011
Precip (cm)
Biochar
Mulch
Seed Only
Bio + Mulch

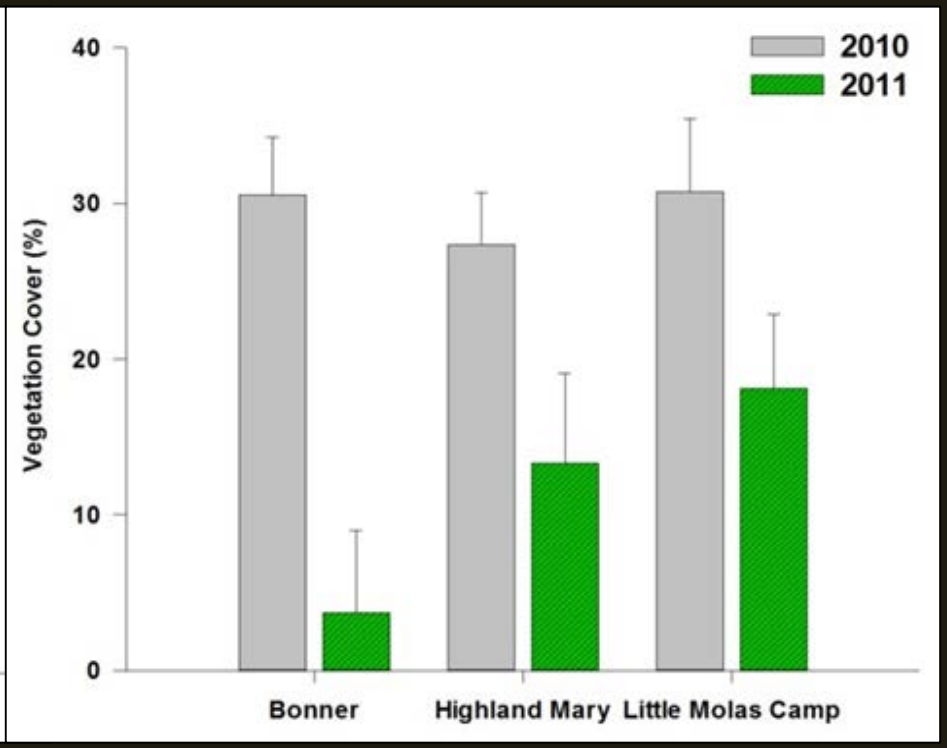
Vegetation Cover (%) field



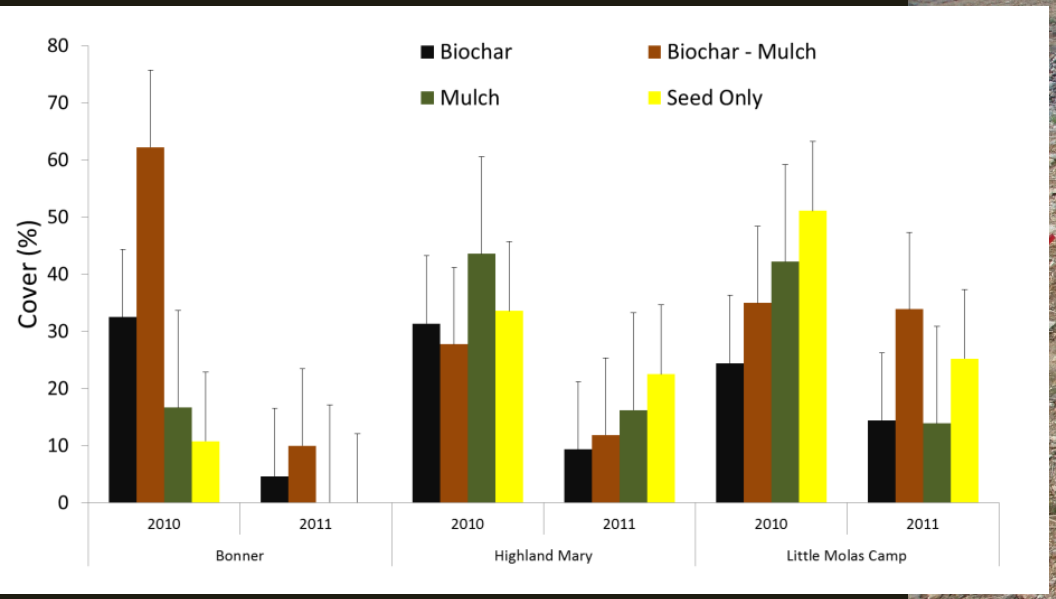


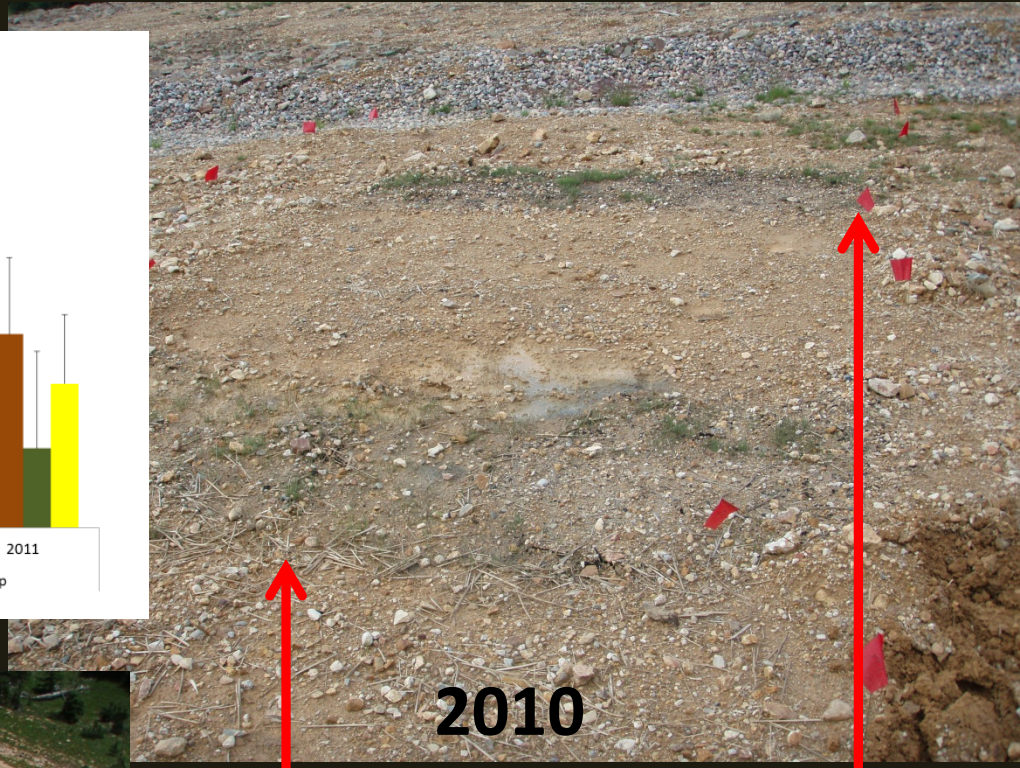


Vegetation cover by treatment



Vegetation cover by site

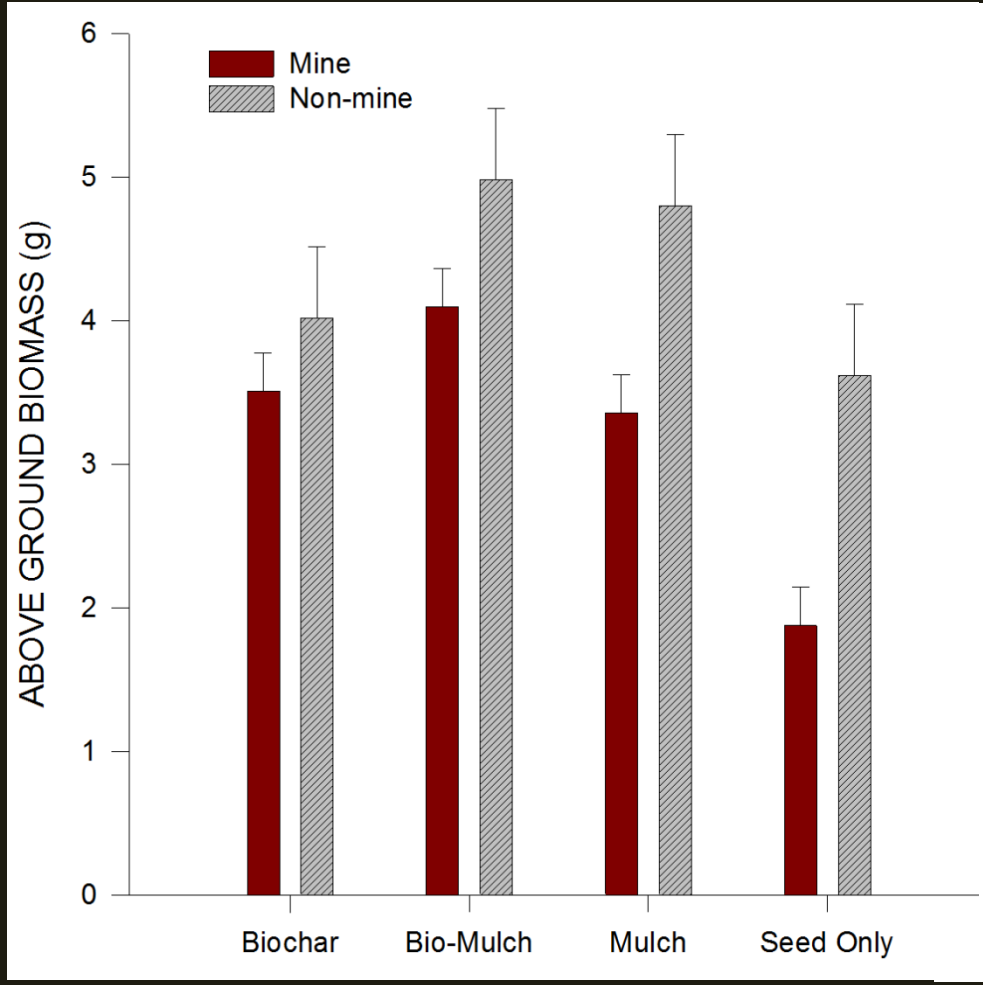


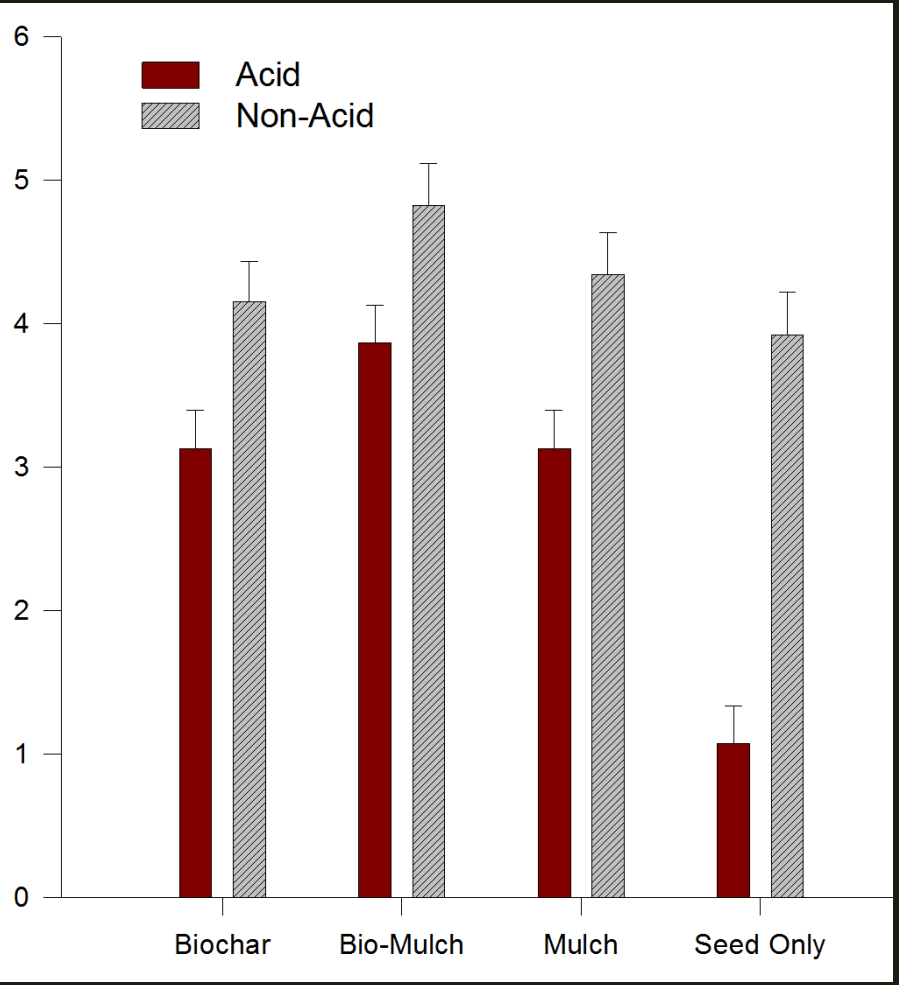


Biochar
+ Mulch

Biochar

Above Ground Biomass(g) greenhouse





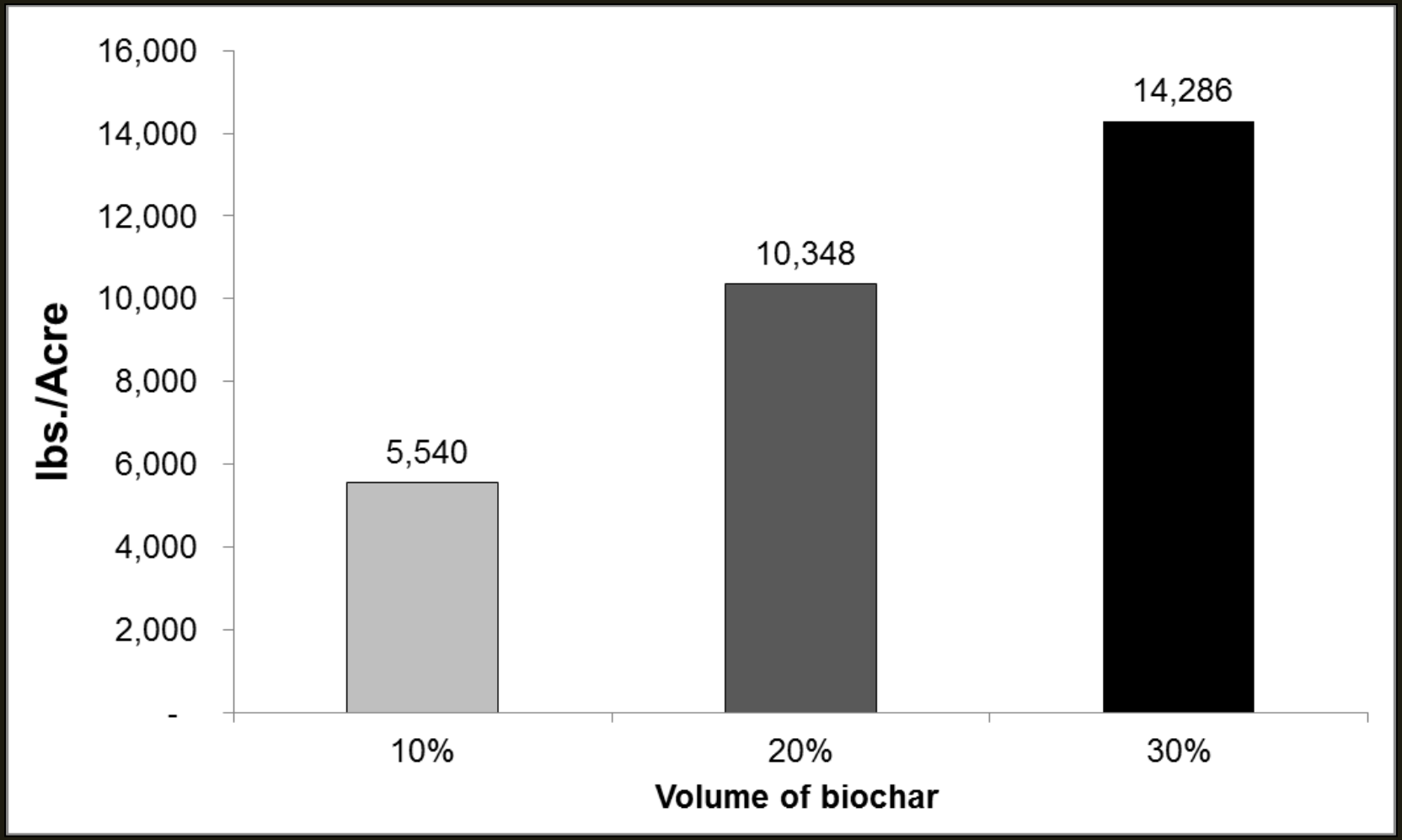
Comparison (mine)	Diff of Means	P
Bio-Mulch vs. Seed Only	**2.22**	**<0.001**
Biochar vs. Seed Only	**1.635**	**<0.001**
Mulch vs. Seed Only	**1.48**	**<0.001**
Bio-Mulch vs. Mulch	0.74	0.054
Bio-Mulch vs. Biochar	0.586	0.121
Biochar vs. Mulch	0.155	0.684

Comparison (acid)	Diff of Means	P
Bio-Mulch vs. Seed Only	**2.793**	**<0.001**
Biochar vs. Seed Only	**2.055**	**<0.001**
Mulch vs. Seed Only	**2.055**	**<0.001**
Bio-Mulch vs. Mulch	0.738	0.051
Bio-Mulch vs. Biochar	0.738	0.051
Biochar vs. Mulch	0	1


Bonner 2 MULCH
Bonner 2 biochar + mulch
Bonner 2 SOIL
Bonner 2 Biochar


Highland Mary #1
Mulch
Highland Mary #1
Soil
Highland Mary #1
5% Biochar
Highland Mary #1
Bio + Mulch


7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
pH
2.1
3.3
3.7
4.1
4.7
5.5
6.1
BST
RB
AFB
BNR
BRK
JJ
RC



Vol. Addition	lbs/meter^2	lbs/acre	tons/acre	Yard^3/Acre
10%	1.4	5,540	2.8	14
20%	2.6	10,348	5.2	26
30%	3.5	14,286	7.1	35.5

Common	Genus	Species	% by weight	Cummulative %
Slender Wheatgrass	Elymus	trachycaulus	20	20
Mountain Brome	Bromus	marginatus	20	40
Tufted Hairgrass	Deschampsia	cespitosa	15	55
Sheep Fescue	Festuca	ovina	12.5	67.5
Alpine Bluegrass	Poa	alpina	10	77.5
Mountain Lupine	Lupinus	pusillus	10	87.5
Rocky Mountain Penstemon	Penstemon	strictus	7.5	95
Mutton Grass	Poa	fendleriana	5	100

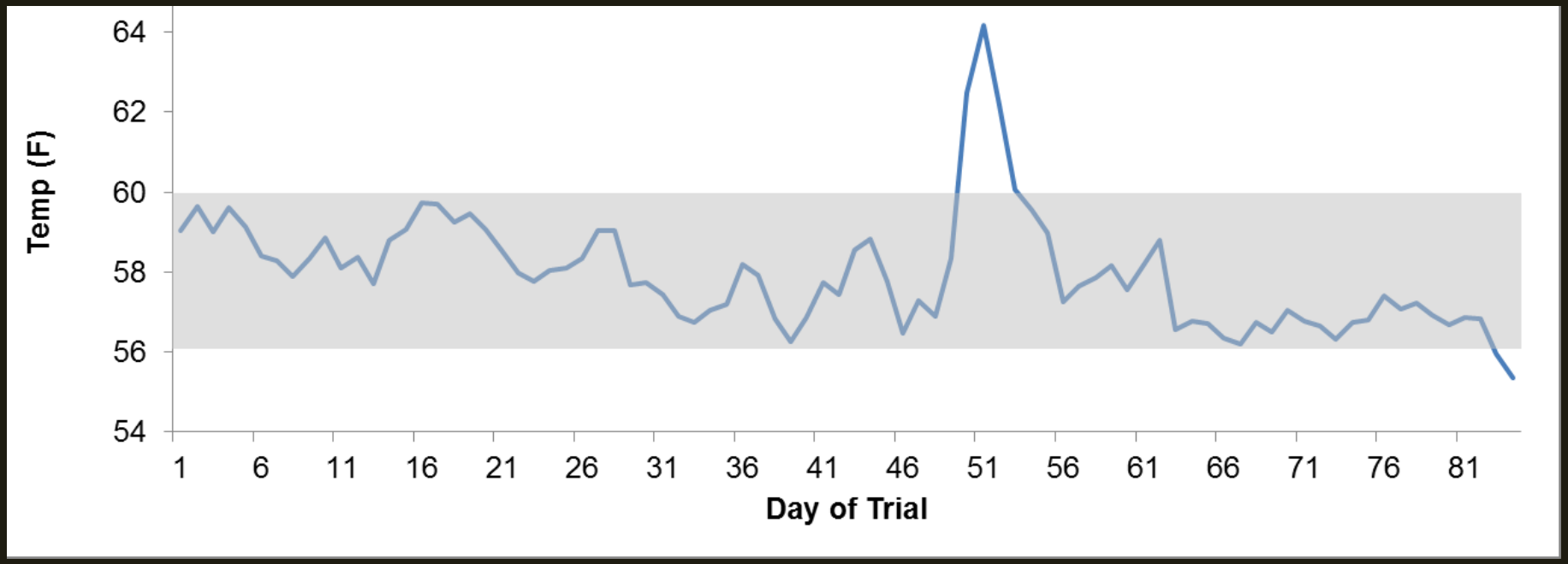

Tamarack Farms
Apple Cider

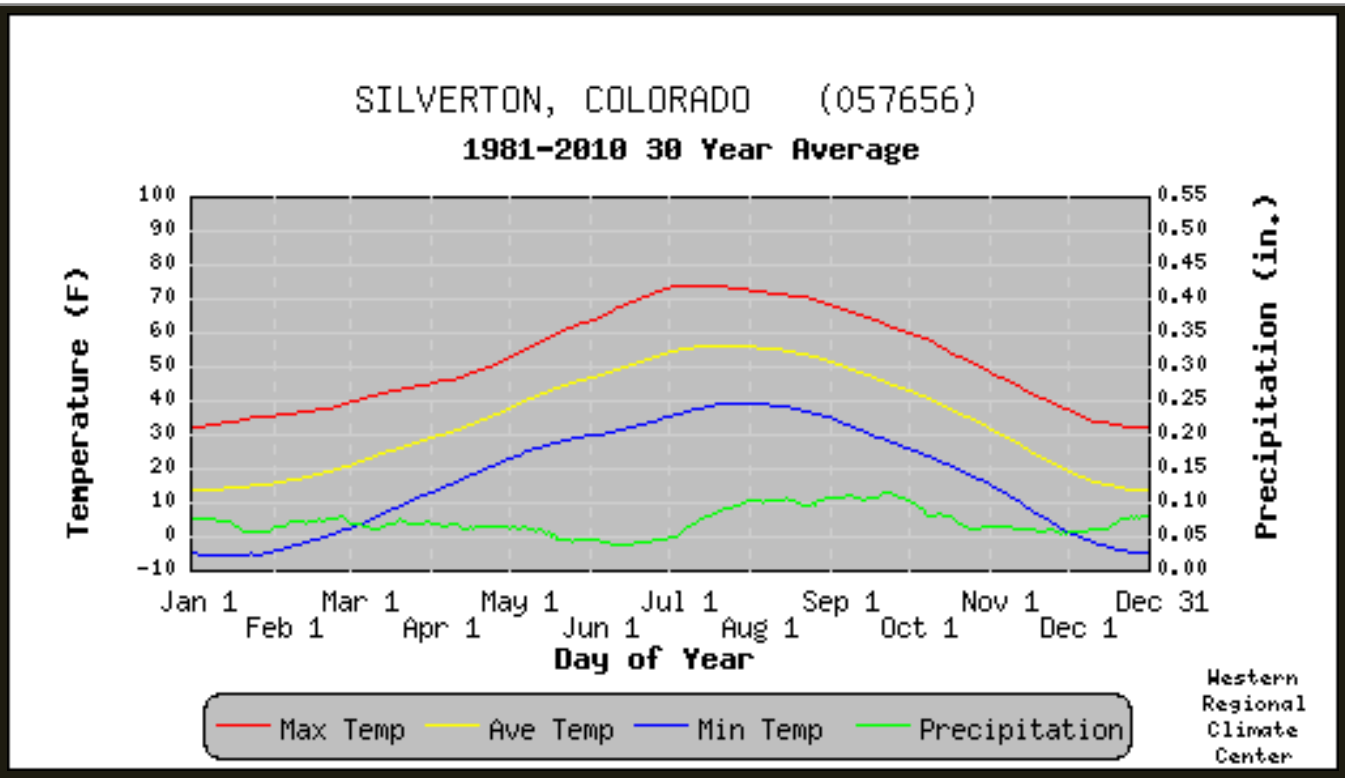
Climate statistics for Silverton CO (1907 - 2005) from wrcc@dri.edu

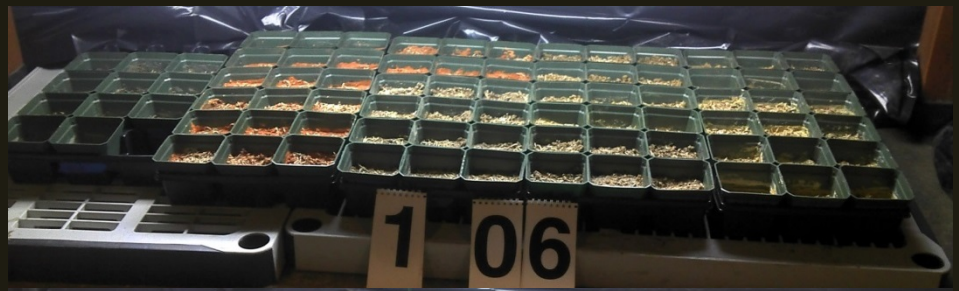
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average Max. Temperature (F)	34	36.6	40.6	47.3	57.6	67.9	73.1	70.5	64.7	55.1	43.2	35.1	52.2
Average Min. Temperature (F)	-1.9	1	8.1	18.5	26.4	31.9	37.9	37.2	30.3	22	9.5	0.2	18.4
Average Total Precipitation (in.)	1.68	1.75	2.3	1.72	1.46	1.39	2.72	3.1	2.81	2.34	1.49	1.73	24.5

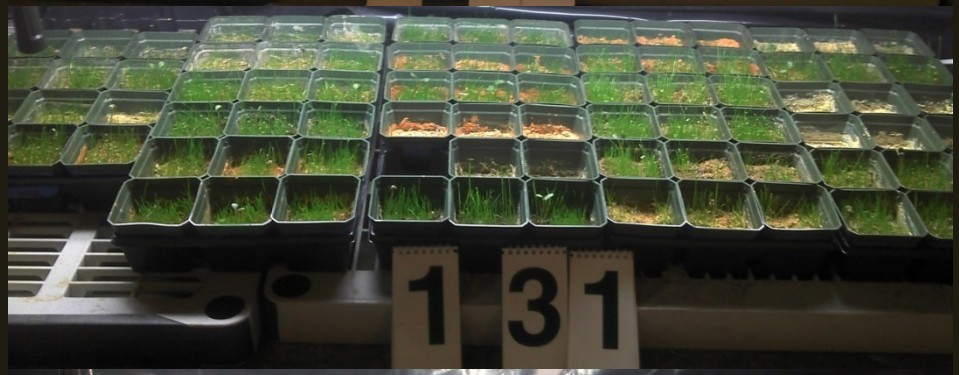
June – Aug ~8.6 inches

Date	Amount of precip. (cm)	Precip. (in)
1/12/2012	1.6	0.6
1/19/2012	3.1	1.2
1/24/2012	4.7	1.8
1/31/2012	6.2	2.4
2/6/2012	7.8	3.0
2/14/2012	9.4	3.7
2/20/2012	10.9	4.3
2/27/2012	12.5	4.9
3/7/2012	14.0	5.5
3/12/2012	15.6	6.1
3/20/2012	17.2	6.7
3/28/2012	18.7	7.3
4/4/2012	20.3	7.9


Temp (F)
64
62
60
58
56
54
1
6
11
16
21
26
31
36
41
46
51
56
61
66
71
76
81
Day of Trial

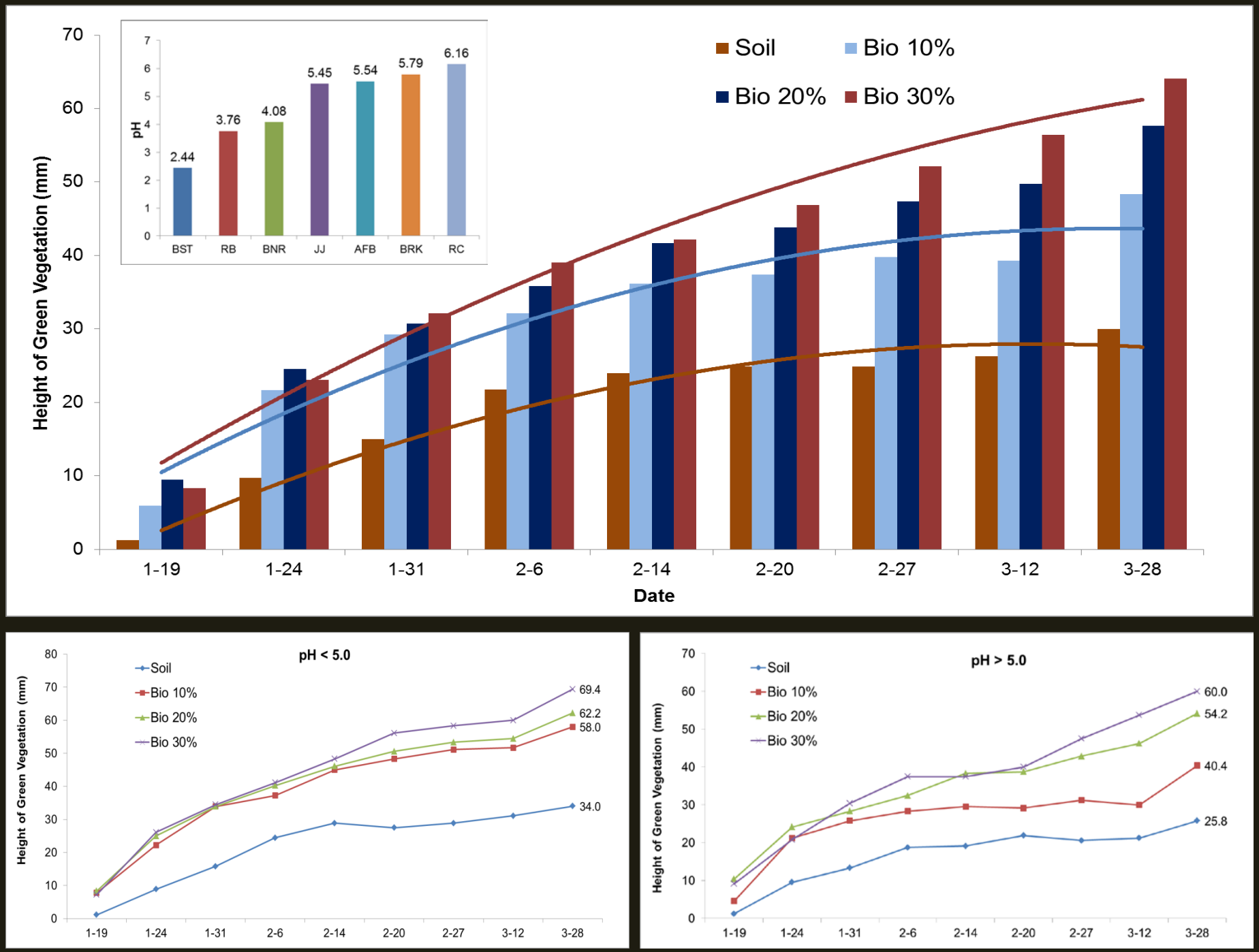

SILVERTON, COLORADO (057656)
1981-2010 30 Year Average
Temperature (F)
100
90
80
70
60
50
40
30
20
10
0
-10
Precipitation (in.)
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Jan 1
Feb 1
Mar 1
Apr 1
May 1
Jun 1
Jul 1
Aug 1
Sep 1
Oct 1
Nov 1
Dec 1
Dec 31
Day of Year
Max Temp
Ave Temp
Min Temp
Precipitation
Western Regional Climate Center

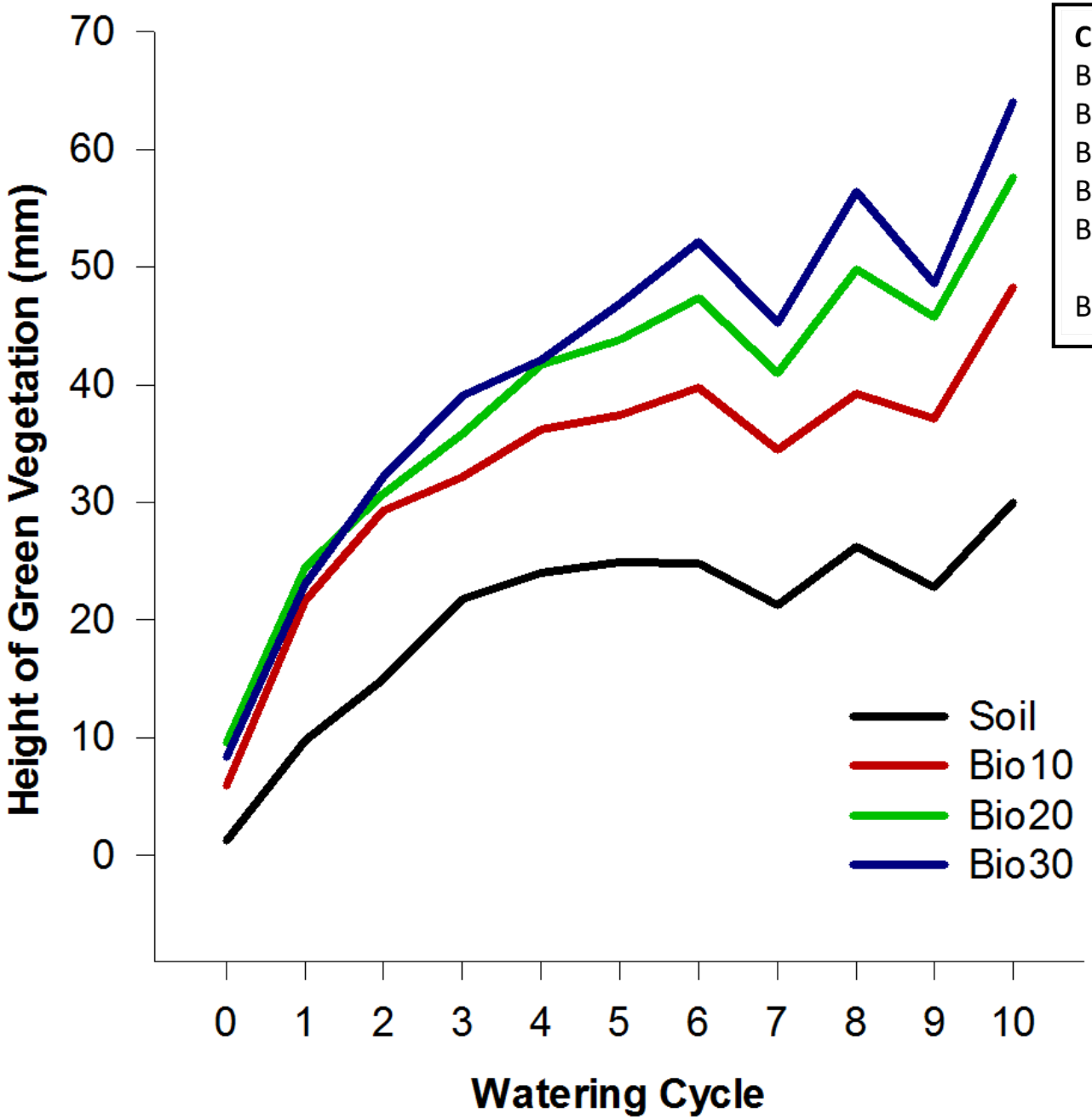

1 06


1 31


3 06

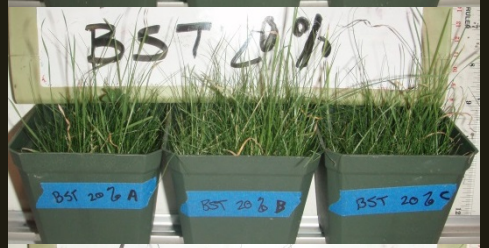

3 13

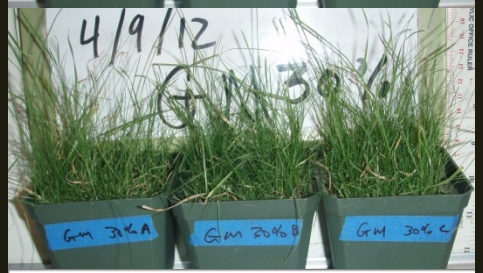

Soil
Bio 10%
Bio 20%
Bio 30%
Height of Green Vegetation (mm)
Date
1-19
1-24
1-31
2-6
2-14
2-20
2-27
3-12
3-28
pH
2.44
3.76
4.08
5.45
5.54
5.79
6.16
BST
RB
BNR
JJ
AFB
BRK
RC
pH < 5.0
69.4
62.2
58.0
34.0
pH > 5.0
60.0
54.2
40.4
25.8

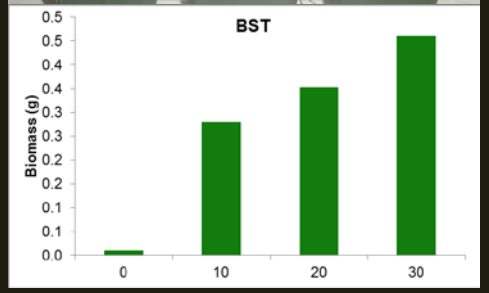


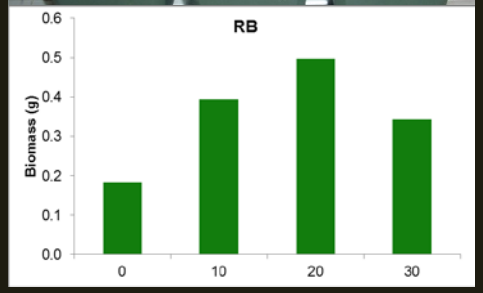
Comparison	P	P<0.050
Bio30 vs. Soil	<0.001	Yes
Bio20 vs. Soil	<0.001	Yes
Bio10 vs. Soil	<0.001	Yes
Bio30 vs. Bio10	<0.001	Yes
Bio20 vs. Bio10	0.002	Yes
Bio30 vs. Bio20	0.262	No

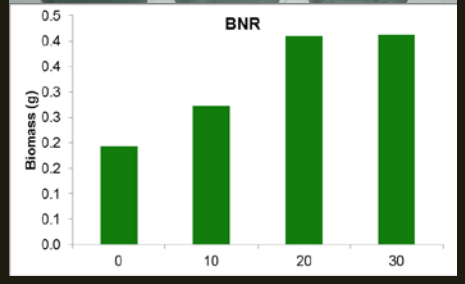
Boston	Red Bonita	Bonner
2.44	3.76	4.08



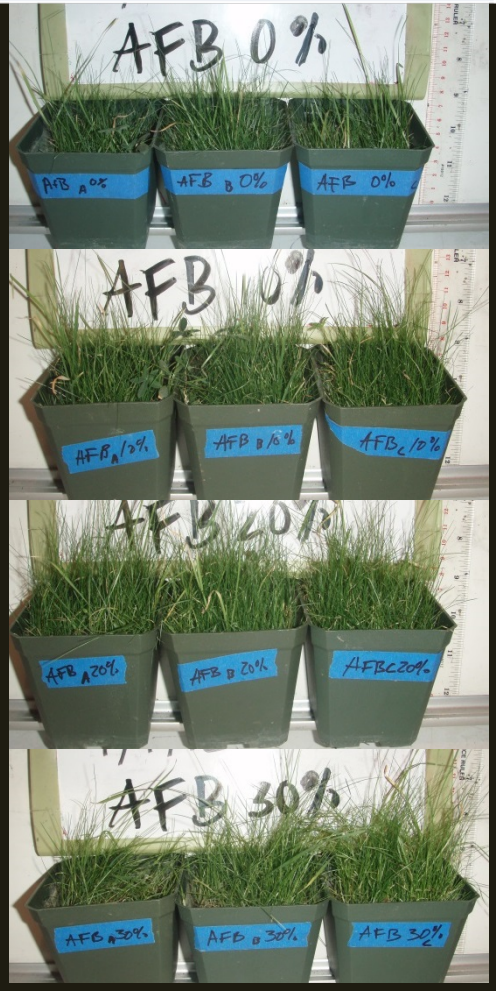


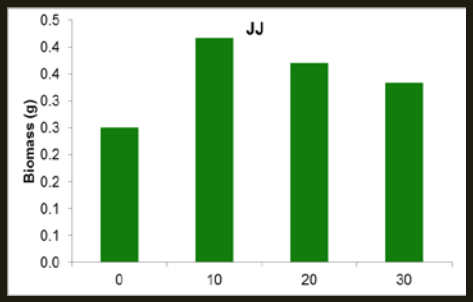


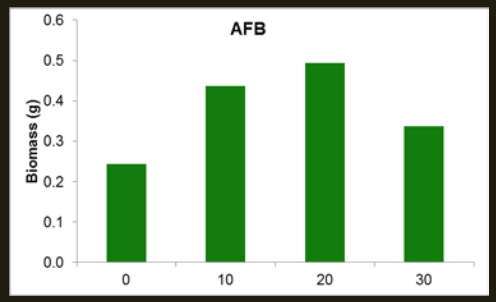


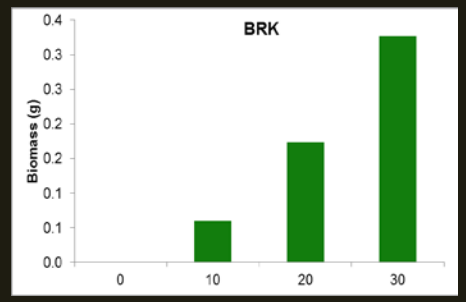


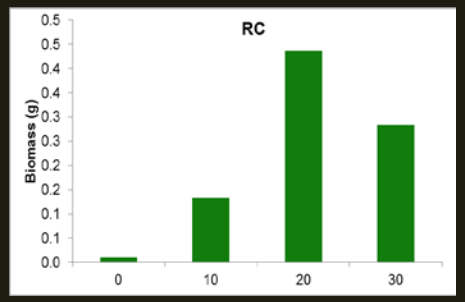
JJ	AFB	BRK	RC
5.45	5.54	5.79	6.16

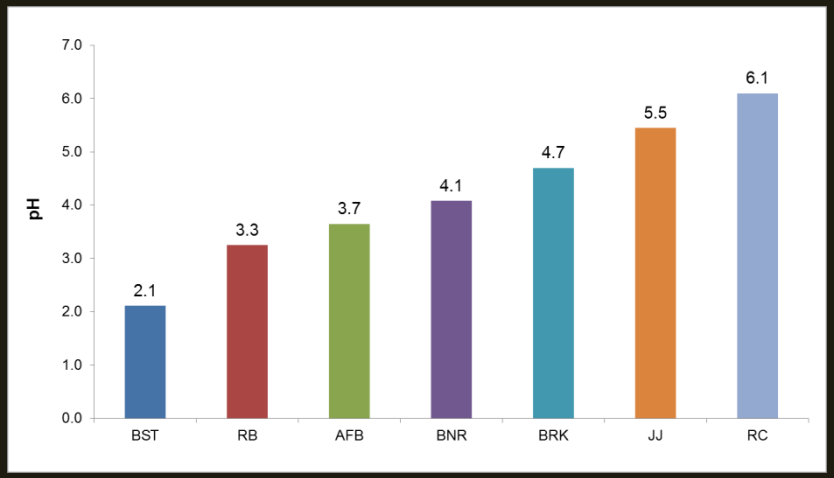


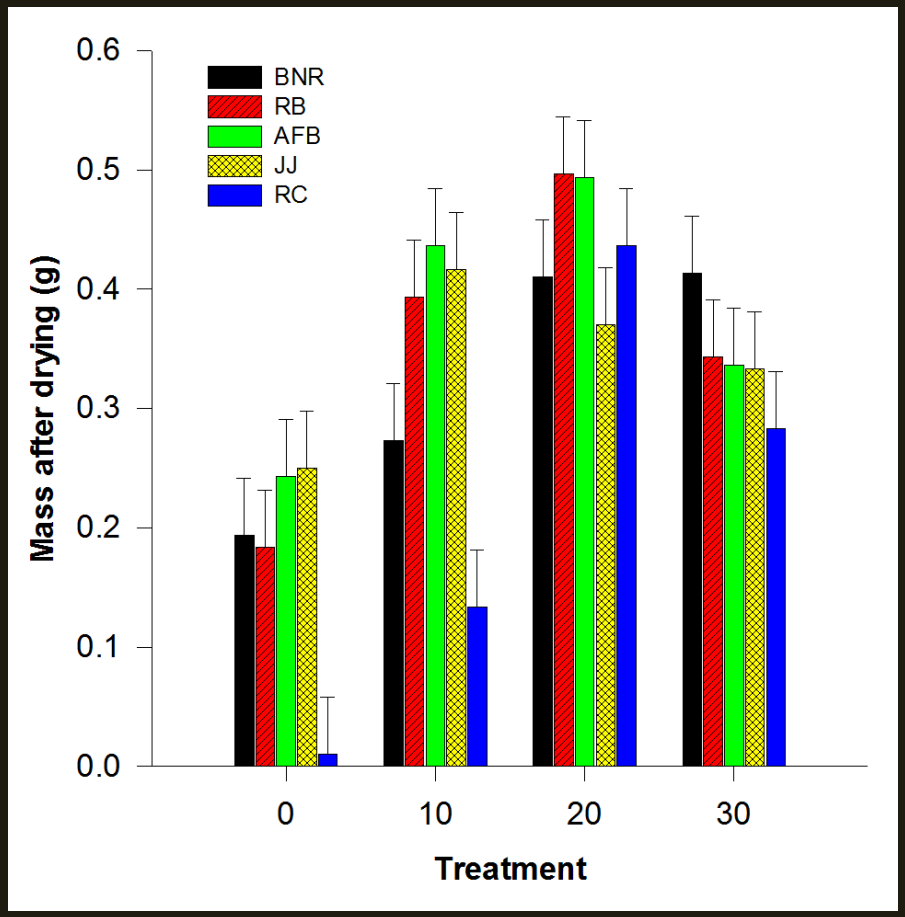


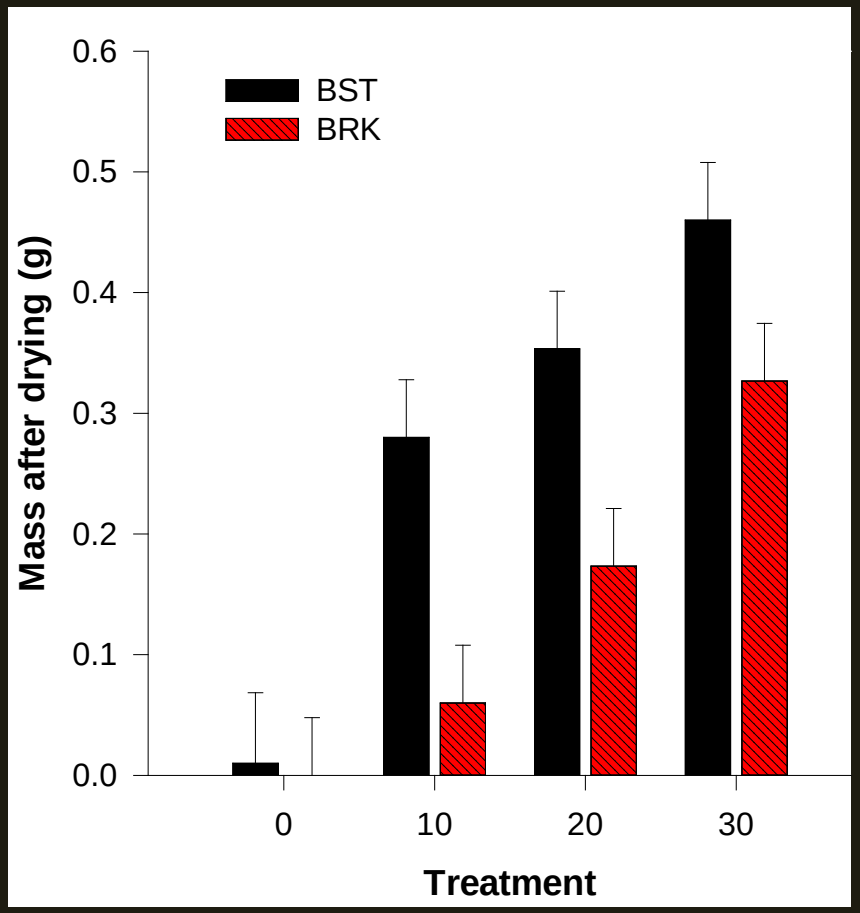


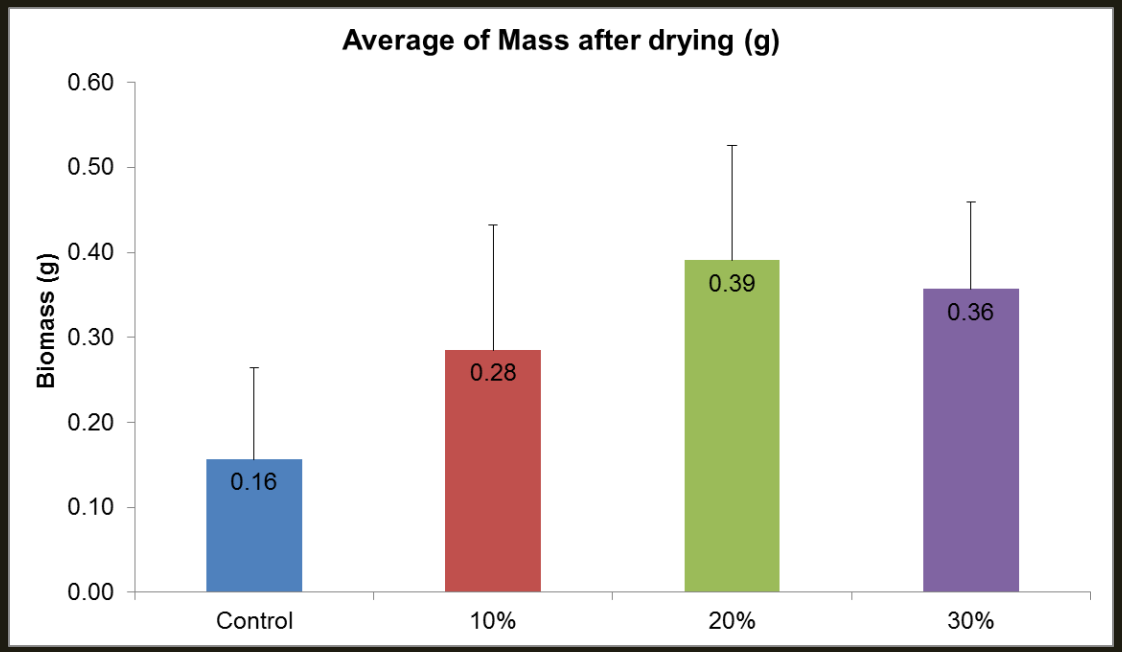


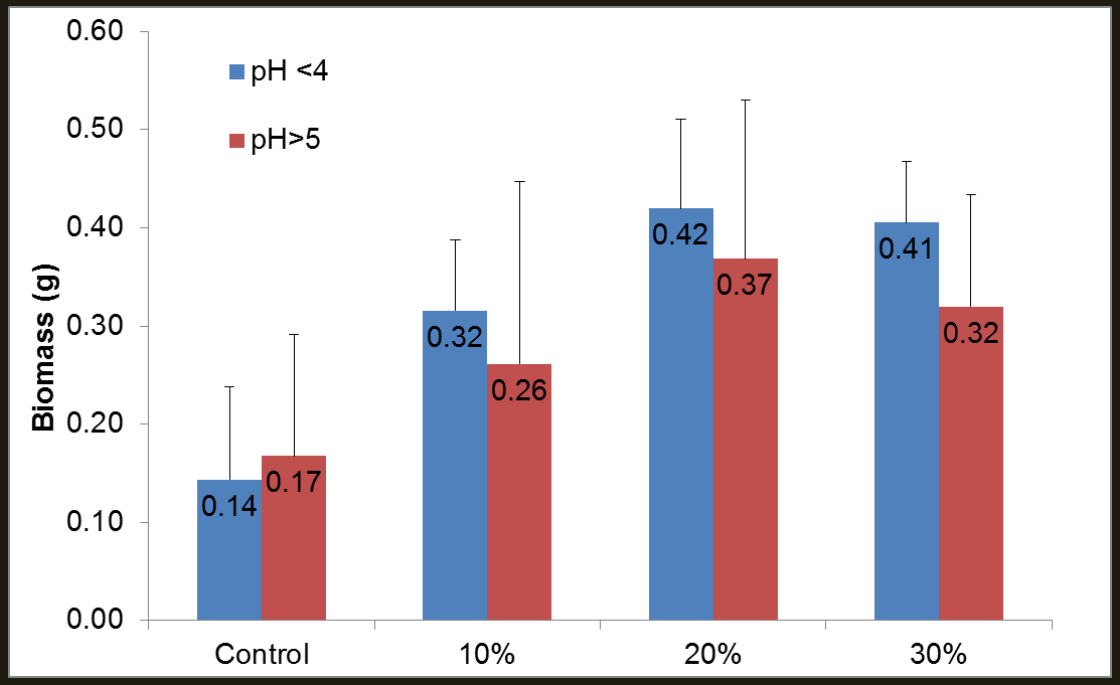



pH
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
2.1
3.3
3.7
4.1
4.7
5.5
6.1
BST
RB
AFB
BNR
BRK
JJ
RC

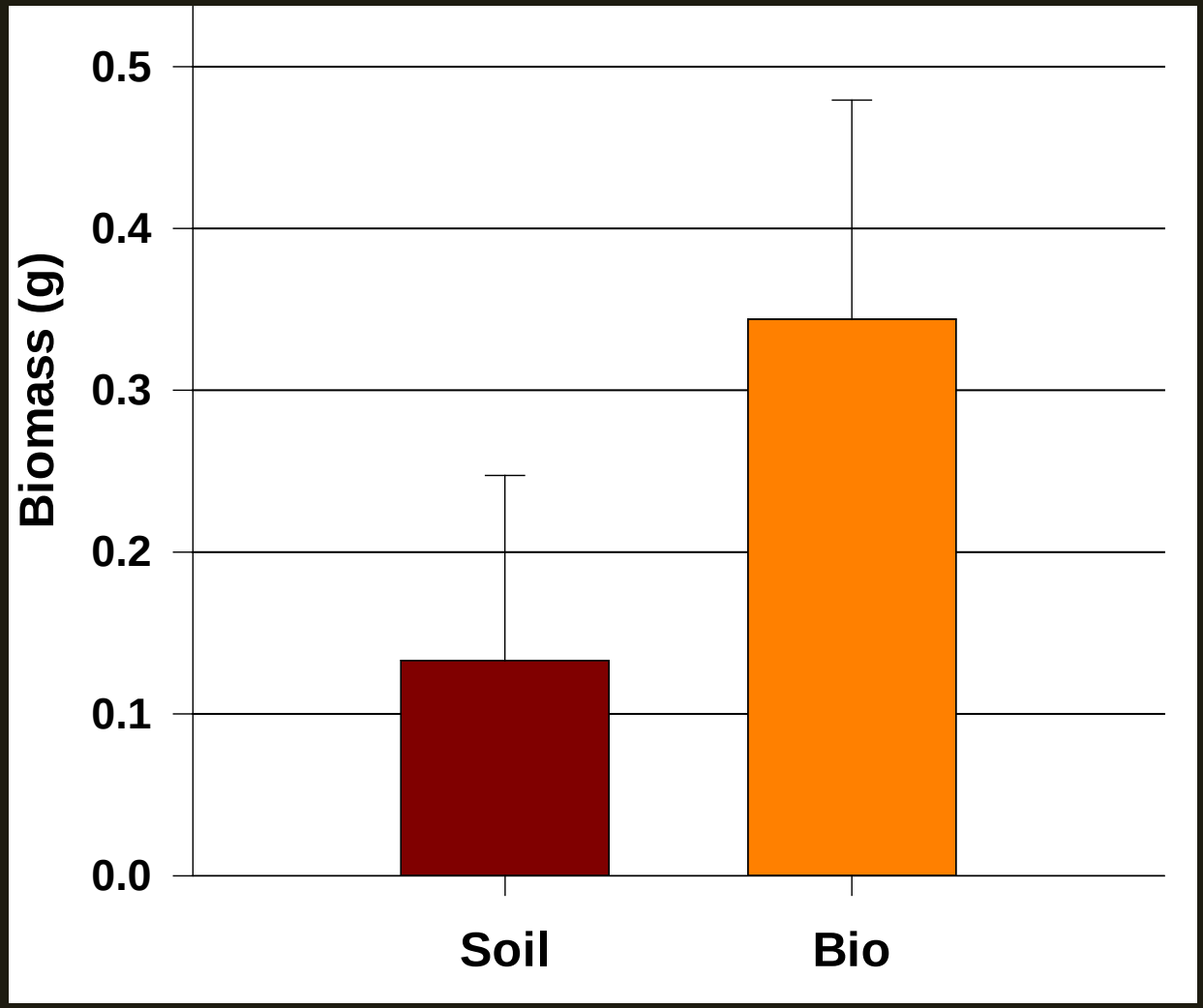

BNR
RB
AFB
JJ
RC
Mass after drying (g)
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
10
20
30
Treatment


BST
BRK
Mass after drying (g)
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
10
20
30
Treatment

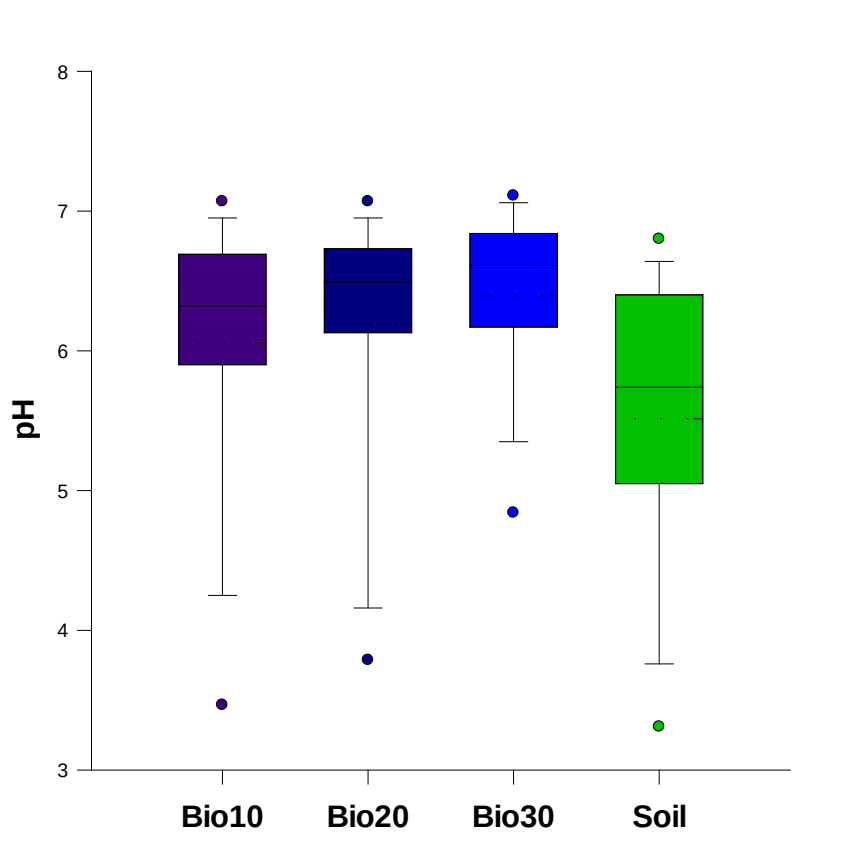

Average of Mass after drying (g)
Biomass (g)
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.16
0.28
0.39
0.36
Control
10%
20%
30%

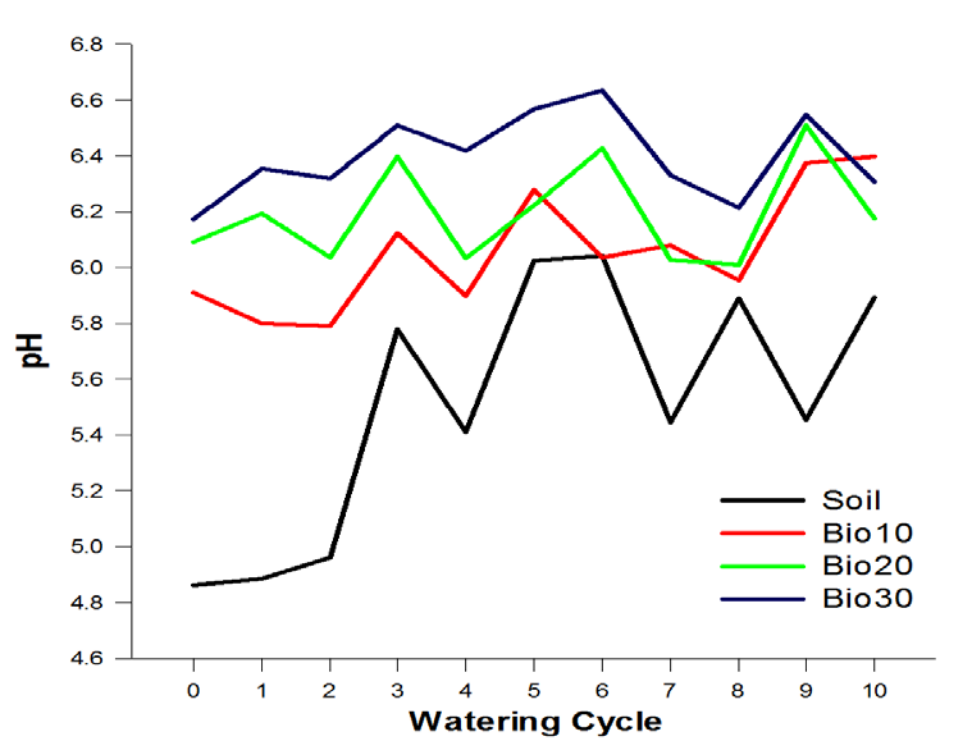

pH <4
pH>5
Biomass (g)
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.14
0.17
0.32
0.26
0.42
0.37
0.41
0.32
Control
10%
20%
30%


4/9/12
Brooklyn 0%
4/9/12
Brooklyn 10%
4/9/12
Brooklyn 20%
4/9/12
Brooklyn 30%



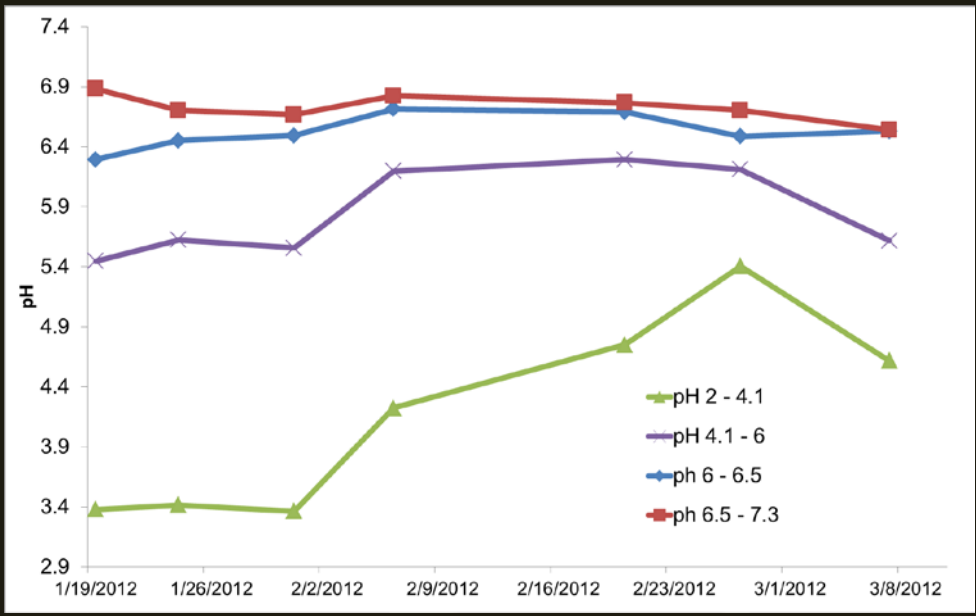
Group Name	N	Mean	Std. Dev.	SEM	
Soil	20	0.133	0.114	0.0256	
Bio	63	0.344	0.135	0.0171	
Source of Variation	**DF**	**SS**	**MS**	**F**	**P**
Between Groups	1	0.676	0.676	39.506	<0.001

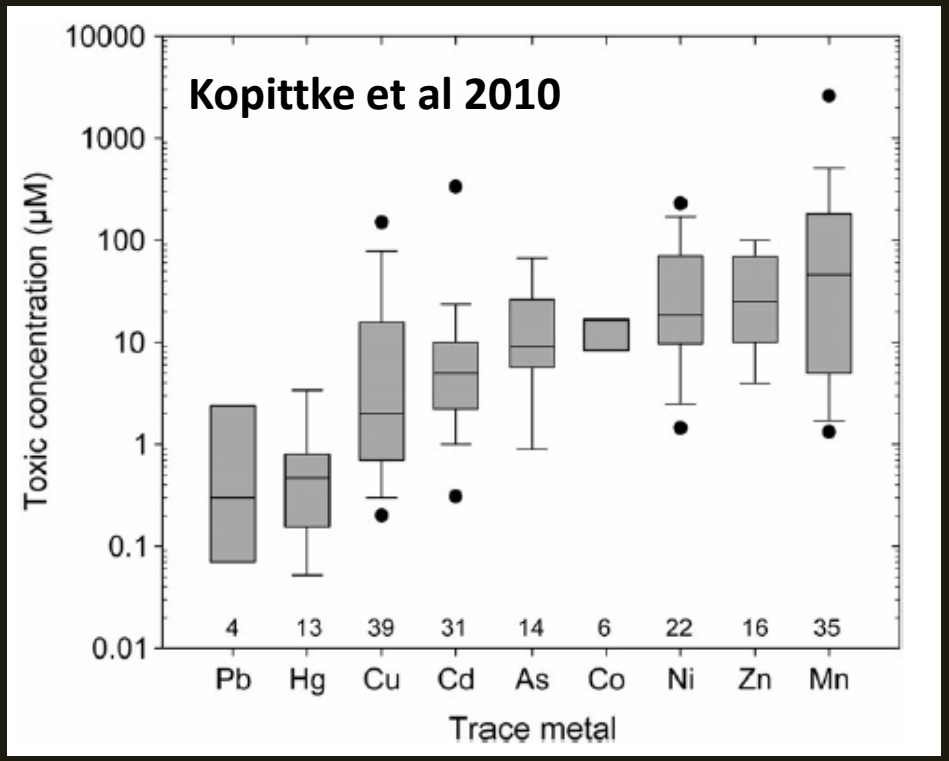


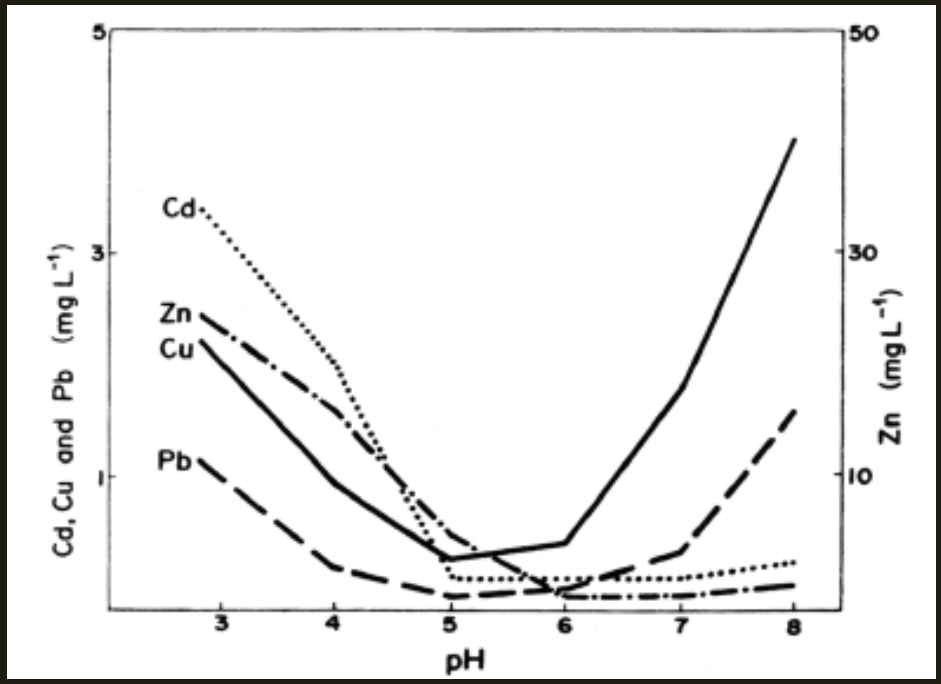


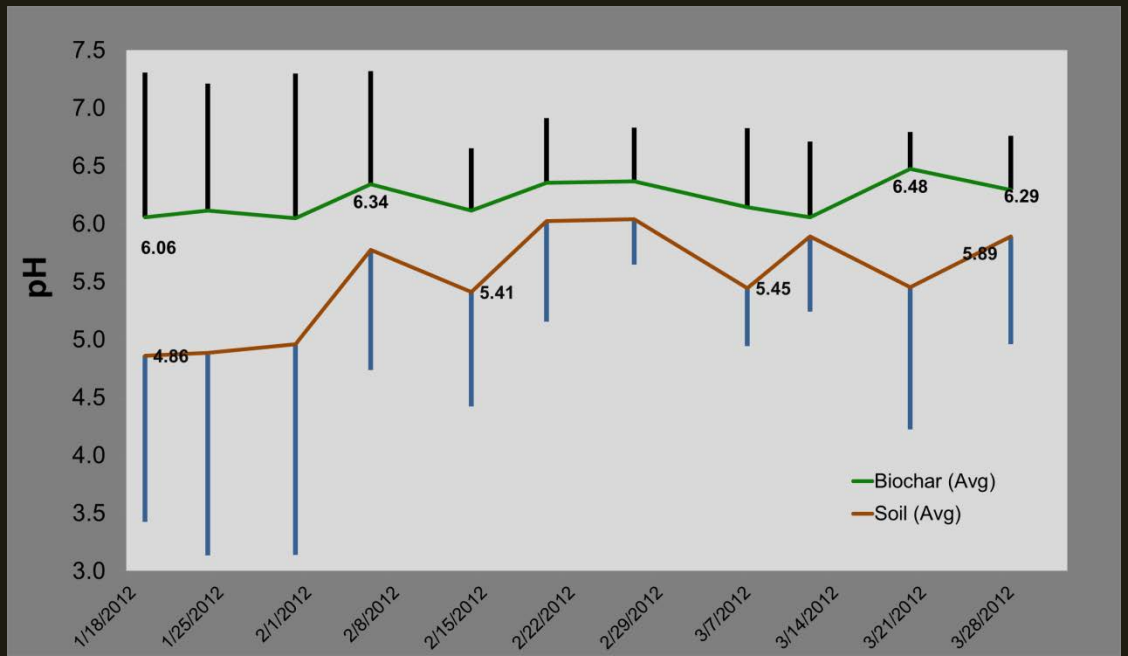
Pairwise Multiple Comparison (Dunn's Method)

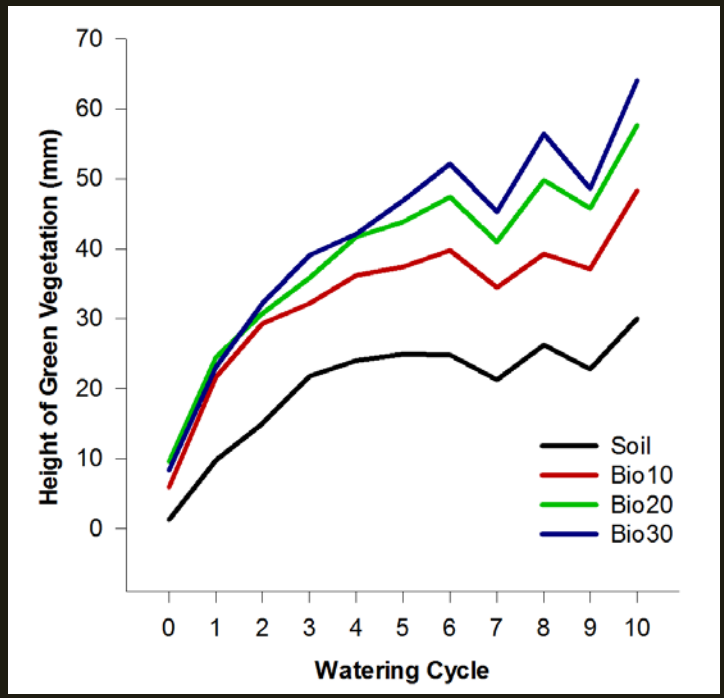
Comparison	**P<0.05**
Bio30 vs Soil	Yes
Bio20 vs Soil	Yes
Bio10 vs Soil	Yes
Bio30 vs Bio10	Yes
Bio30 vs Bio20	No
Bio20 vs Bio10	No

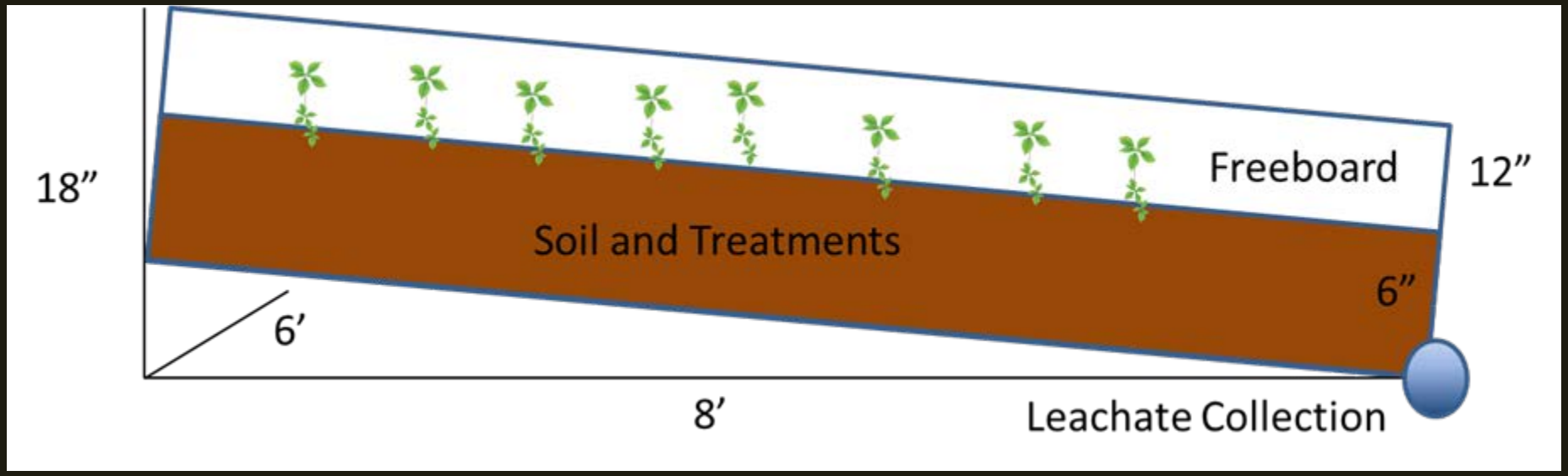


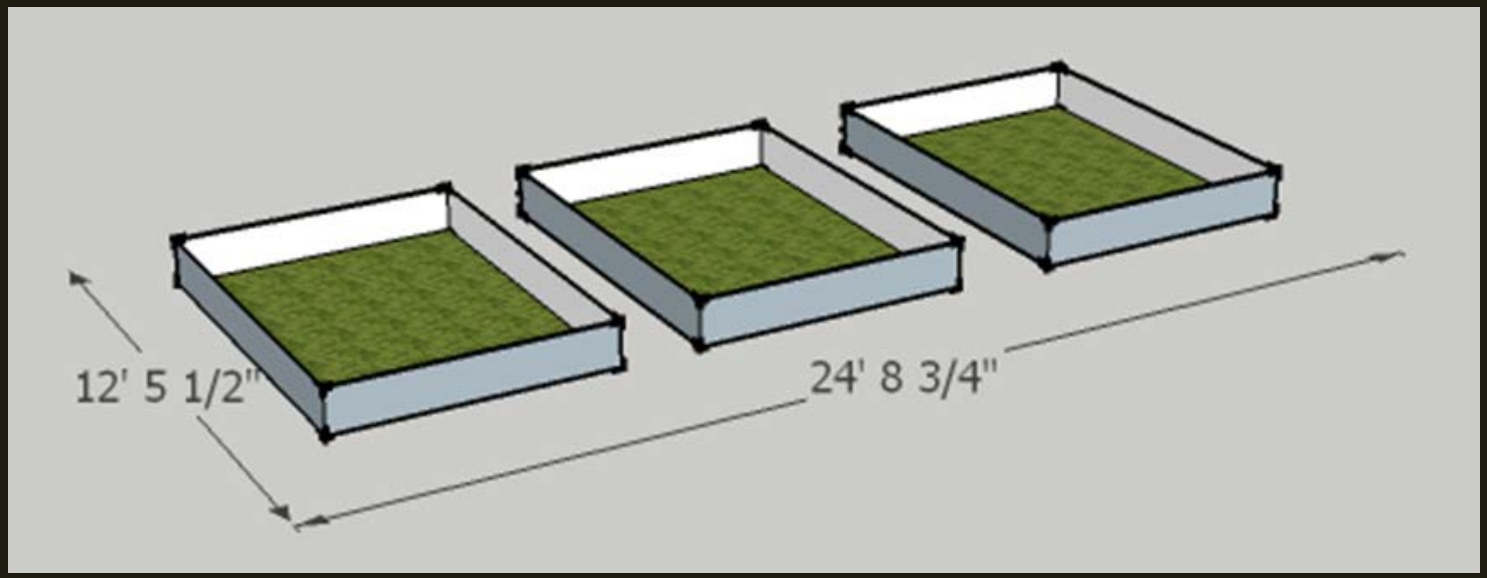

Kopittke et al 2010
Toxic concentration (μM)
10000
1000
100
10
1
0.1
0.01
4
13
39
31
14
6
22
16
35
Pb
Hg
Cu
Cd
As
Co
Ni
Zn
Mn
Trace metal

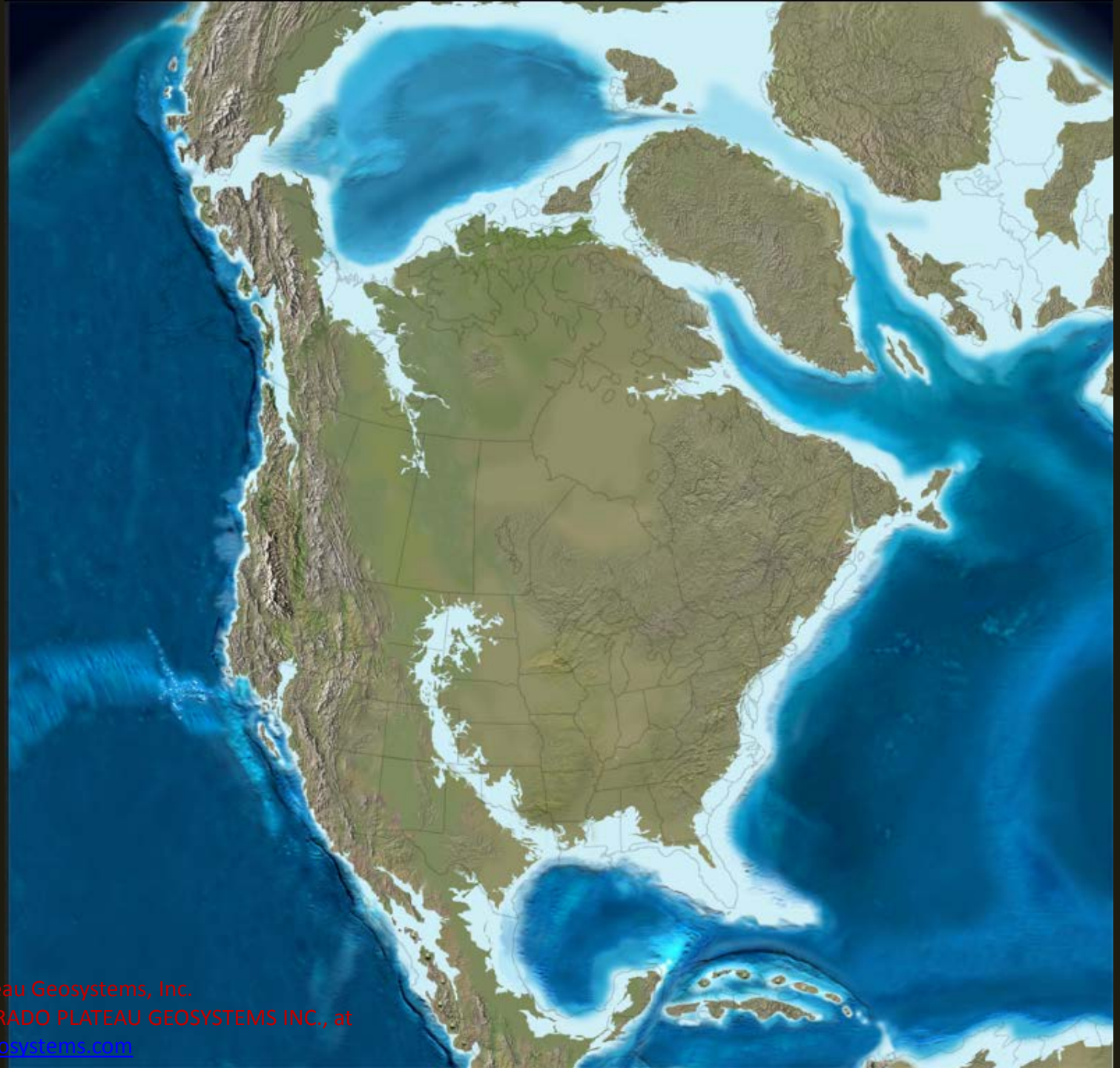

Cd
Zn
Cu
Pb
Cd, Cu and Pb (mg L⁻¹)
Zn (mg L⁻¹)
5
3
1
50
30
10
3
4
5
6
7
8
pH


pH
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
6.06
6.34
6.48
6.29
4.86
5.41
5.45
5.89
Biochar (Avg)
Soil (Avg)
1/18/2012
1/25/2012
2/1/2012
2/8/2012
2/15/2012
2/22/2012
2/29/2012
3/7/2012
3/14/2012
3/21/2012
3/28/2012


Height of Green Vegetation (mm)
70
60
50
40
30
20
10
0
0
1
2
3
4
5
6
7
8
9
10
Watering Cycle
Soil
Bio10
Bio20
Bio30


18”
Freeboard
12”
Soil and Treatments
6”
6’
8’
Leachate Collection


12' 5 1/2"
24' 8 3/4"



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rblakey@cpgeosystems.com