INNOVATIVE CONSERVATION PROGRAM
Metropolitan Water District of Southern California

DISCLAIMER

This project was conducted with financial assistance from a grant from the Metropolitan Water District of Southern California (Metropolitan), the U.S. Bureau of Reclamation, the Central Arizona Project, and the Southern Nevada Water Authority through Metropolitan's Innovative Conservation Program (ICP). The ICP provides funding for research to help document water savings and reliability of innovative water savings devices, technologies, and strategies. The findings of this project, summarized in this report, are solely from the project proponent.

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Biochar: Waste-to-Energy By-Product That Reduces Landscape Water Needs and Environmental Footprint

Innovative Conservation Project Final Report

Metropolitan Water District of Southern California

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1. Project background and objectives

Biochar is organic matter that has been heated in the absence of oxygen, a process called pyrolysis. After pyrolysis, the carbon is in a very stable form with a large surface area comparable to clay minerals and an abundance of charged functional groups. Depending on how it is made, biochar can last in the soil for hundreds of years. It is one of the few carbon sequestration schemes that is both truly long-term and readily verifiable – you simply multiply the biochar weight by %carbon to know how much carbon was sequestered. Biochar's water and nutrient holding characteristics are often used to explain the many reports of increased yield and nitrogen use efficiency. In the scientific literature biochar is often suggested as a means of enhancing soil productivity while reducing greenhouse gas emissions and runoff water contamination associated with agriculture (see http://www.biochar-international.org/).

Pure biochar is a collection of carbon sheets. Stacking sheet upon sheet results in graphene, which has several unique properties.

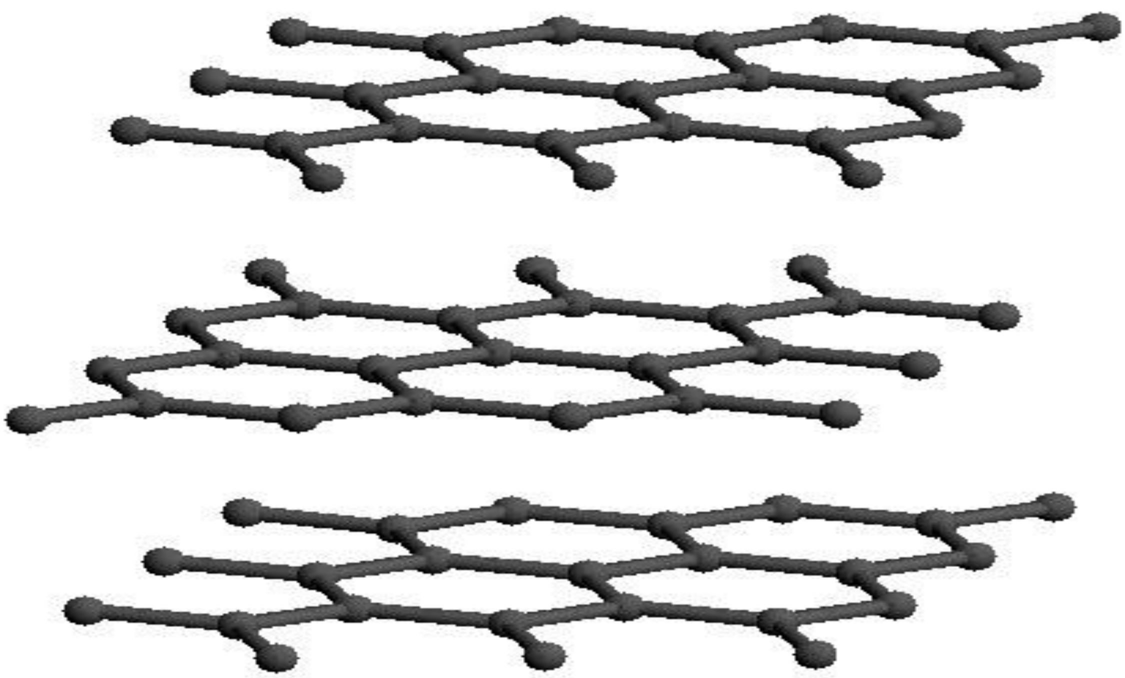


Figure 1. Graphite sheets. Pure biochar contains these same sheets, but in more amorphous form that allows greater water and nutrient holding.

Individually, the carbon ring structure in each of these graphite sheets is very strong and resistant to degradation, and one of the special properties of biochar is that it can persist in the soil for hundreds of years. When the graphite sheets are stacked, they are held with weaker Van Der Waals bonds. In the case of biochar, the sheets are not so evenly arranged, and have an even looser assemblage. The result is that the individual sheets resist degradation, but also allow the exchange of ions between the sheets. Thus biochar can supply additional cation and anion exchange capacity that allows it to hold and release fertilizer ions, greatly increasing fertilizer efficiency and reducing potential leaching into groundwater.

Biochar's ability to increase plant water use efficiency is a little more complicated. There is the obvious capillary effect that is brought on by biochar's honeycomb structure. But that alone does not explain all of the effects observed. Biological factors such as biochar's ability to shelter beneficial microbes are probably also important. And there are other unproven hypotheses involving water vapor and plant roots. But whatever the mechanism, we have been hearing persistent reports of biochar reducing irrigation water use by 30-60 percent.

The objective of our Innovative Conservation Project was to verify that biochar could increase the water holding capacity of the soil, and reduce the amount of irrigation water applied. We recognized that turf, especially golf courses, consumed more water per acre than most any other urban landscape, and was thus made a focus of this investigation.

2. Experimental Design:

Our research included a number of experiments around the theme of testing applications of biochar in urban settings.

Five groups of field and greenhouse experiments were implemented:

A. Effect of compost and biochar on turf quality, establishment, and productivity in standard and reduced watering regimes.

- Tall fescue was established in April of 2014 at the University of California Riverside campus experiment station. During the first year, no drought conditions were initiated to allow establishment.
- Beginning in May 2015, irrigation rates were set at 80% of ET plus correction for distribution uniformity (DU) and 50% of ET plus correction for distribution uniformity (DU).
- Every 15 days during the drought stress period, the following data were collected: Visual quality, a subjective gauge of a few variables such as cover and uniformity on a scale of 1-9; NDVI, a quantitative measurement of reflectance; and DIA, the digital analysis of images collected with the light box for coverage and color. These measurements were collected on the same day to allow correlation.
- Soil samples were collected to measure volumetric water content of the plots every 15 days. This measurement required that there be a period of no irrigation lasting approximately 24 hours before collection.
- Clipping yield were also measured every 15 days, the day after visual ratings were collected.
- Three root cores were collected from each plot (a/k/a replicate). These cores were 2” in diameter, and 6-8” deep. Cores were collected at the beginning and end of the imposition of drought stress. Roots were washed, measured using winRHIZO sofware, then dried and weighed.
- Soil samples were collected for analysis at the beginning and ending of drought stress as well to be analyzed for: Nitrate and Ammonia, total N, total C, Phosphate, pH, and Iron.

A. COMPOST AND BIOCHAR FIELD EXPERIMENT PLOT PLAN

rrig trt		Amend trt	
A	full	A	control
B	reduced	B	1 ton/ac Biochar
		C	5 ton/ac Biochar
		D	10 ton/ac Biochar
		E	2 inches composted biosolids
		F	2 inches composted greenwaste
		G	2 inches composted greenwaste plus 5 ton/ac Biochar
		H	4 inches composted greenwaste

TURF LAB

North

Block	Irrig trt								
Block 1	Irrig trt B	F	C	B	G	D	E	H	A
	Irrig trt A	E	B	H	F	D	A	G	C
Block 2	Irrig trt B	C	H	E	B	G	A	D	F
	Irrig trt A	E	G	A	C	F	B	H	D
Block 3	Irrig trt B	E	C	A	B	H	D	G	F
	Irrig trt A	G	E	B	A	H	D	F	C
Block 4	Irrig trt A	B	A	C	D	H	F	E	G
	Irrig trt B	B	H	D	E	A	C	G	F

Irrigation mains

B. <u>Greenhouse Establishment Study (5/11/2015-currently)</u>

A replication of the field establishment study is currently being conducted. Replicates were increased to 5, and an additional treatment, 2" of biosolids compost with 5 ton/A biochar was included. To translate the field rates into percentage of the pot volume, each percentage of pot volume is equivalent to 1 ton per acre field application rate

C. <u>Field Experiments/Demonstrations Conducted with the Public Works Departments of the Cities of San Jacinto and Riverside, and LA County Public Works.</u>

We are collaborating with the Public Works Departments of the Cities of Riverside and San Jacinto and the County of Los Angeles to test potential applications of biochar in real world settings, particularly where it may be difficult to establish and irrigate plants.

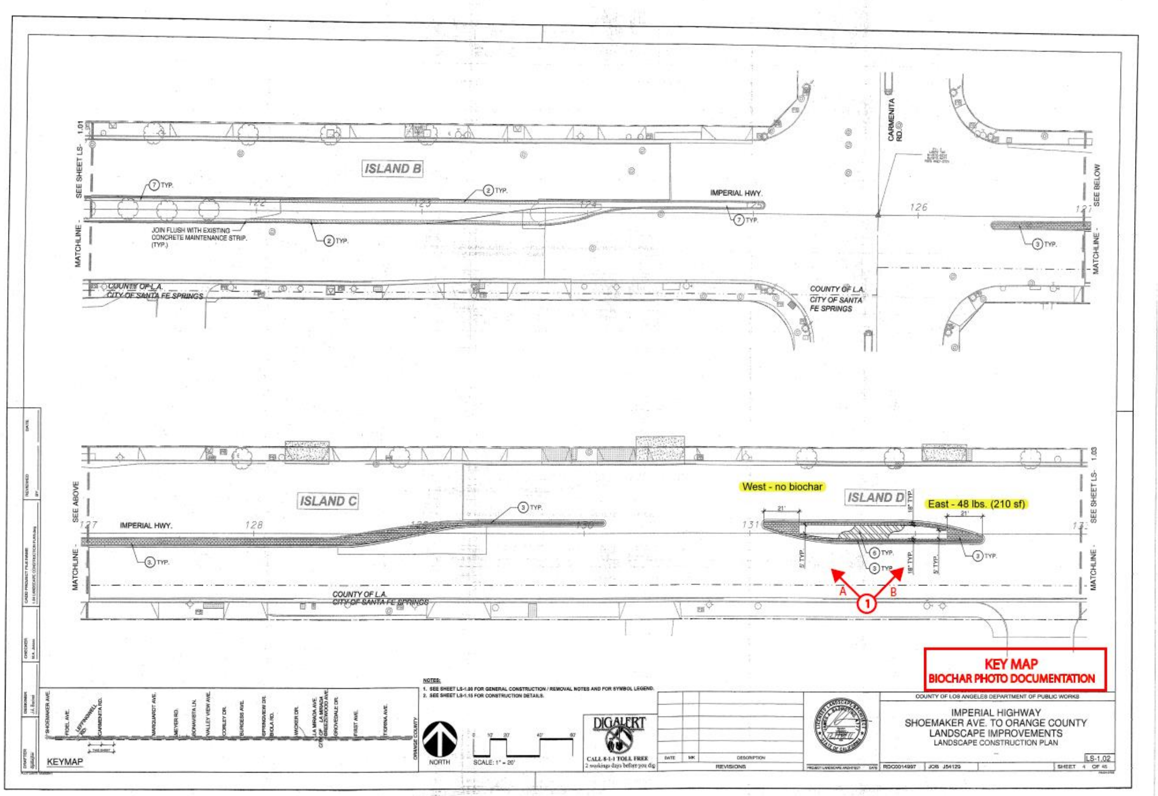
The largest of these studies were the road medians on Imperial Highway in La Mirada. The nature of the medians meant that arranging the experiment as a randomized design with distinct blocks was not possible, so we instead used the experiment to test several different types of biochars:

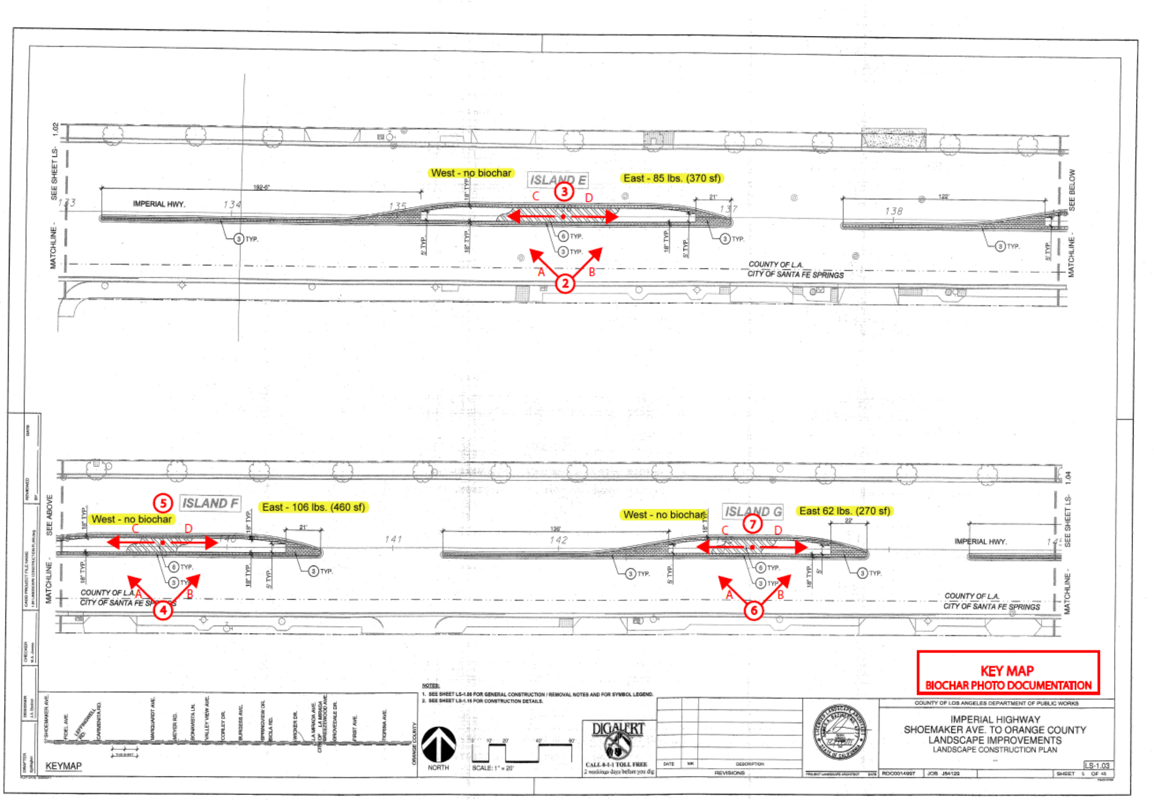
IMPERIAL HWY BIOCHAR TESTING

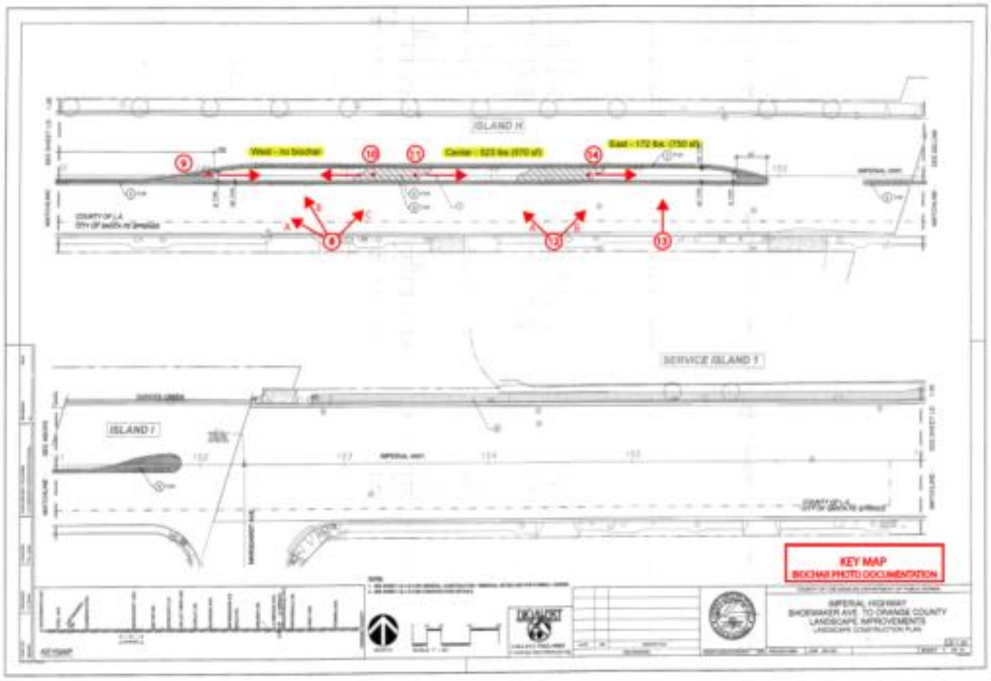
7/23/2014

biochar was installed on 7/23/14

Island		*type of biochar*	*quantity of biochar (per acre)*	*area sq.ft.*	*revised biochar qty. (lbs)*	*original biochar qty (lbs.)*
Island D	west	no biochar	0	200	0	0
	east	Cool Planet #2	5 ton/acre	210	96	48
Island E	west	no biochar	0	350	0	0
	east	Blue Sky pellet	5 ton/acre	370	170	85
Island F	west	no biochar	0	380	0	0
	east	Blue Sky pellet	5 ton/acre	460	211	106
Island G	west	no biochar	0	210	0	0
	east	Cool Planet #2	5 ton/acre	270	124	62
Island H	west	no biochar	0	775	0	0
	center	Cool Planet #1	20 ton/acre	570	523	523
	east	Cool Planet #1	5 ton/acre	750	344	172
					1,469	996


ISLAND B
IMPERIAL HWY.
CARMENTA RD.
JOIN FLUSH WITH EXISTING CONCRETE MAINTENANCE STRIP. (TYP.)
COUNTY OF L.A.
CITY OF SANTA FE SPRINGS
ISLAND C
ISLAND D
West - no biochar
East - 48 lbs. (210 sf)
A
B
KEY MAP
BIOCHAR PHOTO DOCUMENTATION
COUNTY OF LOS ANGELES DEPARTMENT OF PUBLIC WORKS
IMPERIAL HIGHWAY
SHOEMAKER AVE. TO ORANGE COUNTY
LANDSCAPE IMPROVEMENTS
LANDSCAPE CONSTRUCTION PLAN
LS-1.02
KEYMAP
NORTH
DIGALERT


IMPERIAL HWY.
West - no biochar
ISLAND E
East - 85 lbs. (370 sf)
C
D
A
B
COUNTY OF L.A.
CITY OF SANTA FE SPRINGS
ISLAND F
West - no biochar
East - 106 lbs. (460 sf)
ISLAND G
East 62 lbs. (270 sf)
KEY MAP
BIOCHAR PHOTO DOCUMENTATION
COUNTY OF LOS ANGELES DEPARTMENT OF PUBLIC WORKS
IMPERIAL HIGHWAY
SHOEMAKER AVE. TO ORANGE COUNTY
LANDSCAPE IMPROVEMENTS
LANDSCAPE CONSTRUCTION PLAN
LS-1.03
KEYMAP
NORTH
DIGALERT


ISLAND H
West - no biochar
East - 172 lbs. (750 sf)
COUNTY OF L.A.
SERVICE ISLAND 1
ISLAND I
IMPERIAL HWY
KEY MAP
BIOCHAR PHOTO DOCUMENTATION
IMPERIAL HIGHWAY
SHOEMAKER AVE. TO ORANGE COUNTY
LANDSCAPE IMPROVEMENTS
LANDSCAPE CONSTRUCTION PLAN
KEYMAP

D. Effect of Biochar on Leaching of N, P, K in Direct-Seeded and Sod Established Turf

Tall Fescue was established with seed or sod and lysimeters used to measure nutrient content in soil water. Treatments compared time of establishment (Fall or Spring) method of establishment, and rate of biochar application (0, 2.8, 13.9 tons per acre):

Treatments

A	Fall	Seeded	0
B	Fall	Seeded	2.8
C	Fall	Seeded	13.9
D	Fall	Transplanted	0
E	Fall	Transplanted	2.8
F	Fall	Transplanted	13.9
G	Spring	Seeded	0
H	Spring	Seeded	2.8
I	Spring	Seeded	13.9
J	Spring	Transplanted	0
K	Spring	Transplanted	2.8
L	Spring	Transplanted	13.9

Suction lysimeters were installed to sample soil water 6” below the surface, i.e. just below the root zone. Water samples were extracted each summer and fall and analyzed for nitrate, ammonium, phosphate and potassium.

E. **Effect of biochar on plant water use efficiency (WUE).**

We have been collaborating with the University of Massachusetts to use the stable isotope method and direct measurement of plant photosynthetic parameters to determine if and how biochar makes plants more water efficient. Small batches of biochar were made under carefully controlled conditions from cardboard or wood, then mixed with clay to create a planting media. Plants exposed to red oak biochar achieved higher WUE on both intrinsic measures in seven out of eight cases. Cardboard biochar was found to exert a less influential effect compared with red oak biochar but still greater than the untreated clay. Soil C abundance was greater for clay blended with oak biochar ($\delta^{13}C=23.66\ ^{o}/_{oo}$) compared to the cardboard biochar blend ($\delta^{13}C=30.67\ ^{o}/_{oo}$). The upshot of the data is that biochar appears to increase water use efficiency by both improving the structure of the planting media, and apparently affecting the plant's physiology. The latter finding is both very encouraging and surprising, but should not be quoted until we can confirm and publish the results.

F. **Biochars vary in their effect on soil water holding capacity**: Biochar is becoming much more commercialized, often sold with claims of reducing irrigation requirements by 50 percent. However, there is little solid research to back up many of these claims. Additionally, the effect of any soil amendment usually varies with soil type, and the particle size of the amendment.

Depending on the pyrolysis conditions and feedstock, biochar varies in their potential to benefit soil quality and sequester carbon. We selected four representative biochars: biosolids feedstock pyrolyzed at 350˚C (provided by the Encina Waste Management District and abbreviated as En), yellow pine at 550˚C (sold as Cool Terra by Cool Planet, abbreviated as CP2), coconut shells at 550˚C (CP1), and pine wood at 300˚C (HW, for Hugh wood, produced by pyrolysis expert Hugh McLaughlin) on water retention capacity (WRC) on soil samples of three different textures—sand, sandy loam, and clay—

Our research objective is to quantify the effects of the four biochars on water retention capacity (WRC) in soil samples of three different textures—sand, sandy loam, and clay—by measuring water content at 0.1 bar, 0.3 bar, 1.0 bar, 5 bar, and 15 bar in pressure chambers. Each biochar was first separated into 3 size fractions (large, > 50 µm; medium, 2 µm to 50 µm; and small, < 2 µm) to assess the effect of char particle size on water retention. The biochar/soil mixtures were placed upon pressure plates to simulate how water retained of each mixture varies as the soil dries.

Not all the water held in soil is useful to plants. Soils with water content above field capacity are considered waterlogged, and any water held more tightly than the wilting point cannot be withdrawn by plant roots. Thus gravimetric pressures at wilting point and field capacity set the lower and upper thresholds of plant available water (PAW), a key concept in plant water stress and irrigation practices. PAW is calculated as the difference between field capacity (0.3 bar) and wilting point (15 bar).

G. **Effect of biochar and compost on microbial community structure**

The large turf experiment was sampled to determine changes in microbial community structure due to biochar and compost application. The following analyses were performed:

Microbiological Analyses:

- PLFA
- 20,000 16S rRNA gene sequences
- MiSeq high throughput sequencing
- sequences sorted by phylum, order

Soil Analyses:

- Substrate induced respiration (SIR)
- Selective inhibition of SIR (F:B ratios)

3. RESULTS

A. Effect of compost and biochar on turf quality, establishment, and productivity in standard and reduced watering regimes.

Data for this experiment are still being processed and analyzed, and the experiment will be continued next year. Nonetheless, we have amassed quite a lot of data for the experiment. What follows is a summary of significant results. A more complete report is included in the appendix.

Effect of irrigation consistently leads to differences in all variables except DGCI. One interesting note is that composted biosolids do increase soil water content, at least on some dates, but decrease quality in general.

<u>Turf Quality</u> differences appear inconsistently, mostly in the early dates of sampling. High rate of either composted greenwaste or biosolids decrease quality in the first month of sampling; greenwaste subsequently has quality comparable to control, but biosolids persisted in reducing quality throughout all sample dates:

<u>Only significant dates shown</u>

Quality (Average of visual ratings)						
Date	Amendment	Irrigation				Mean
6/30/2015	2CG	Low	A			4.8888889
	4CG	Low	A			4.8750000
	10BC	Low	A			4.7500000
	1BC	Low	A	B		4.5000000
	C	Low	A	B		4.5000000
	5BC	Low	A	B		4.2500000
	2CG5BC	Low	A	B		3.8750000

	2CB	Low		B		3.2857143
	10BC	High	A			8.0000000
	5BC	High	A			7.7500000
	2CG5BC	High	A			7.5000000
	C	High	A			7.5000000
	1BC	High	A	B		7.2500000
	2CG	High	A	B		7.2500000
	4CG	High		B	C	6.5000000
	2CB	High			C	6.2500000
7/13/2015	2CG	Pooled	A			4.8888889
	4CG	Pooled	A			4.8750000
	10BC	Pooled	A			4.7500000
	1BC	Pooled	A	B		4.5000000
	C	Pooled	A	B		4.5000000
	5BC	Pooled	A	B		4.2500000
	2CG5BC	Pooled	A	B		3.8750000
	2CB	Pooled		B		3.2857143
9/21/2015	10BC	Pooled	A			5.2500000
	4CG	Pooled	A			5.2500000
	1BC	Pooled	A			5.2500000
	C	Pooled	A			5.2500000
	5BC	Pooled	A	B		4.8750000
	2CG	Pooled	A	B		4.3500000
	2CG5BC	Pooled		B		4.2500000
	2CB	Pooled		B		3.9583333
	4CG	High	A			6.2500000
	C	High	A			6.2500000
	5BC	High	A B			6.0000000

	1BC	High	A	B					5.7500000
	10BC	Low	A	B	C				5.5000000
	2CG	High	A	B	C				5.5000000
	10BC	High	A	B	C	D			5.0000000
	2CG5BC	High	A	B	C	D			5.0000000
	1BC	Low		B	C	D	E		4.7500000
	4CG	Low			C	D	E	F	4.2500000
	2CB	High			C	D	E	F	4.2500000
	C	Low			C	D	E	F	4.2500000
	5BC	Low				D	E	F	3.7500000
	2CB	Low				D	E	F	3.6666667
	2CG5BC	Low					E	F	3.5000000
	2CG	Low						F	3.2000000

Clipping Yield grams per plot, of a three foot wide swath of the plot						
Date	Amendment	Irrigation				Mean
5/19/2015	2CB	Low	A			58.333333
	5BC	Low	A	B		45.150000
	1BC	Low	A	B		45.000000
	4CG	Low	A	B		43.550000
	10BC	Low	A	B		42.575000
	2CG5BC	Low	A	B		36.475000
	C	Low		B		34.400000
	2CG	Low		B		30.520000
	1BC	High	A		48.125000	48.125000
	2CB	High	A	B	40.525000	40.525000

	4CG	High	A	B	40.200000	40.200000
	C	High	A	B	39.675000	39.675000
	5BC	High	A	B	36.200000	36.200000
	2CG5BC	High	A	B	35.225000	35.225000
	10BC	High	A	B	33.950000	33.950000
	2CG	High		B	48.125000	30.925000
6/18/2015	C	Low	A			89.782500
	2CB	Low	A	B		70.066667
	4CG	Low	A	B		66.807500
	1BC	Low	A	B		63.157500
	5BC	Low	A	B		59.780000
	2CG	Low	A	B		57.094000
	10BC	Low	A	B		56.577500
	2CG5BC	Low		B		53.802500
7/20/2015	1BC	Low	A			25.735000
	C	Low	A	B		24.805000
	4CG	Low	A	B	C	23.382500
	2CG5BC	Low	A	B	C	22.650000
	5BC	Low	A	B	C	21.995000
	10BC	Low	A	B	C	19.860000
	2CG	Low			C	18.040000
	2CB	Low			C	17.423333
8/13/2015	1BC	Low	A			172.95000
	C	Low	A	B		120.00000
	5BC	Low	A	B		108.67500
	10BC	Low	A	B		107.55000
	4CG	Low	A	B		106.60000
	2CB	Low	A	B		106.30000

	2CG5BC	Low	A	B		103.65000
	2CG	Low		B		95.58000

Rooting Data from Field Study (Collected 5/04/2015)

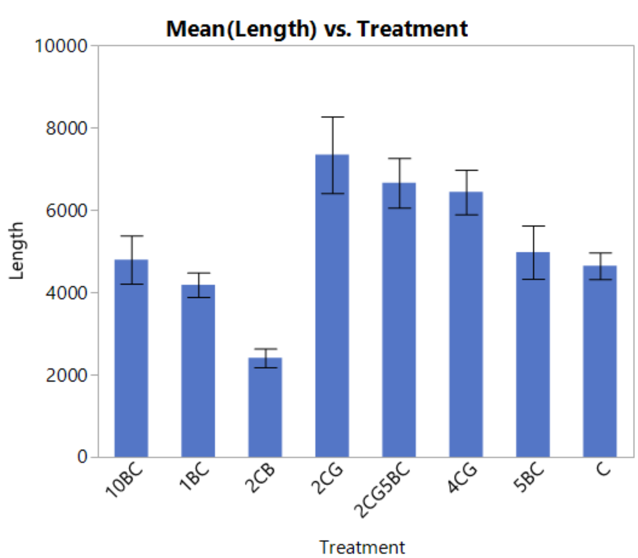
Rooting data as analyzed by WinRhizo. At the time of this collection, differential irrigation had not been initiated, therefore treatments were pooled across irrigation regimes as in the analysis above. In tables those treatments with different letters are significantly different. In bar graph the error bars represent standard error. (Student's t-test of means)

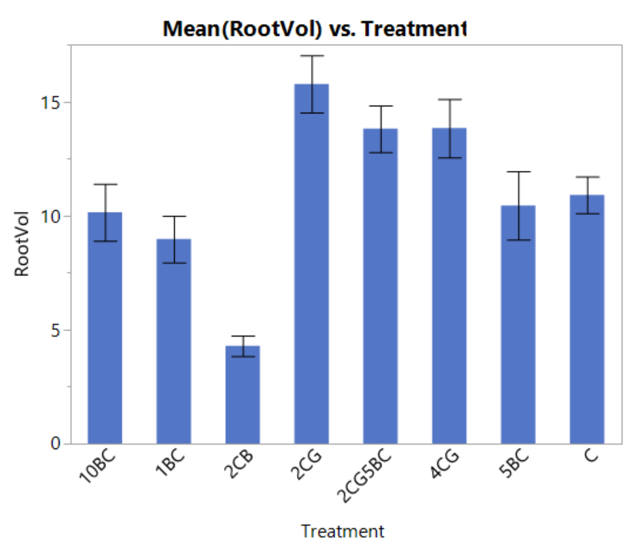
Rooting data will be collected in the same way for the greenhouse study. Based on aboveground behavior, we expect very similar results.

Analysis of rooting length vs treatment

Level					Mean
2CG	A				7340.5115
2CG5BC	A				6654.6883
4CG	A	B			6436.1035
5BC		B	C		4974.2867
10BC			C		4792.2805
C			C		4642.1907
1BC			C		4183.1550
2CB				D	2406.6796

					Mean
2CG	A				15.773250
4CG	A	B			13.833250
2CG5BC	A	B			13.809750
C		B	C		10.909125
5BC			C		10.445250
10BC			C		10.151125
1BC			C		8.969750
2CB				D	4.293625





SOIL WATER CONTENT consistently increases with either composted greenwaste or biosolids. Biochar was generally comparable to control. Composted biosolids did lead to increases in soil water content, but nonetheless reduced turf quality. *Only dates where treatment differences were significant are shown:*

TDR (percent water, soil volumetric water content)							
Date	Amendment	Irrigation				Mean	
5/4/2015	2CB	Pooled	A			36.442857	
	2CG	Pooled	A			35.644444	
	4CG	Pooled	A			35.175000	
	2CG5BC	Pooled	A	B		33.900000	
	1BC	Pooled		B	C	31.125000	
	5BC	Pooled			C	30.725000	
	C	Pooled			C	30.475000	
	10BC	Pooled			C	29.950000	
6/1/2015	2CB	Low	A			23.000000	
	4CG	Low	A	B		22.600000	
	2CG5BC	Low	A	B		22.475000	
	2CG	Low	A	B		21.480000	
	5BC	Low	A	B		21.075000	
	C	Low	A	B		20.750000	
	1BC	Low		B		20.400000	
	10BC	Low		B		20.250000	
	4CG	High	A				25.075000
	2CG	High	A	B			24.500000
	2CB	High	A	B			24.450000
	2CG5BC	High		B	C		23.625000
	C	High			C	D	22.600000
	10BC	High				D	22.075000
	5BC	High				D	21.725000

	1BC	High				D	21.575000
7/20/2015	1BC	Low	A			25.735000	
	C	Low	A	B		24.805000	
	4CG	Low	A	B	C	23.382500	
	2CG5BC	Low	A	B	C	22.650000	
	5BC	Low	A	B	C	21.995000	
	10BC	Low	A	B	C	19.860000	
	2CG	Low			C	18.040000	
	2CB	Low			C	17.423333	
8/13/2015	1BC	Low	A			172.95000	
	C	Low	A	B		120.00000	
	5BC	Low	A	B		108.67500	
	10BC	Low	A	B		107.55000	
	4CG	Low	A	B		106.60000	
	2CB	Low	A	B		106.30000	
	2CG5BC	Low	A	B		103.65000	
	2CG	Low		B		95.58000	
9/07/2015	4CG	Pooled	A			41.250000	
	2CB	Pooled	A	B		39.066667	
	1BC	Pooled	A	B	C	34.550000	
	5BC	Pooled		B	C	32.737500	
	2CG5BC	Pooled		B	C	32.025000	
	C	Pooled		B	C	31.562500	
	2CG	Pooled			C	30.810000	
	10BC	Pooled			C	30.212500	

B. Greenhouse Establishment Study (5/11/2015-currently)

Digital image analysis was conducted to track the rate of establishment of grasses.

The data presented here represents the Days After Seeding (DAS) at which pots reached a predetermined percentage of turf cover. Data has been reordered to place the most rapidly establishing treatments at the top of each list. Interestingly, the biosolids compost amended with biochar resulted in more rapid establishment than biosolids compost alone.

DAS	Trt	Mean	MS GRP
DAS10	10BC	25.3312	D
DAS10	C	27.2355	CD
DAS10	5BC	27.7661	CD
DAS10	1BC	29.763	C
DAS10	2BS5BC	35.5437	B
DAS10	2GW5BC	38.0258	AB
DAS10	4GW	39.4736	A
DAS10	2BS	41.2829	A
DAS10	2GW	41.3449	A
DAS25	10BC	32.6021	D
DAS25	C	33.1581	D
DAS25	5BC	34.4979	D
DAS25	1BC	35.6705	D
DAS25	2BS5BC	39.7388	D
DAS25	2BS	48.0611	C
DAS25	2GW5BC	53.4233	BC
DAS25	2GW	65.2103	AB
DAS25	4GW	73.0316	A

DAS50	C	42.326	B
DAS50	10BC	43.809	B
DAS50	5BC	44.9353	B
DAS50	1BC	45.1363	B
DAS50	2BS5BC	47.1502	B
DAS50	2BS	57.4139	A
DAS75	C	58.5596	B
DAS75	1BC	63.6004	AB
DAS75	5BC	68.8884	AB
DAS75	10BC	69.5266	A
DAS75	2BS5BC	77.0868	A

Note:

2GW5BC, 2GW, and 4GW never reached 50% cover. 2BS did reach 50%, but never reached 75%.

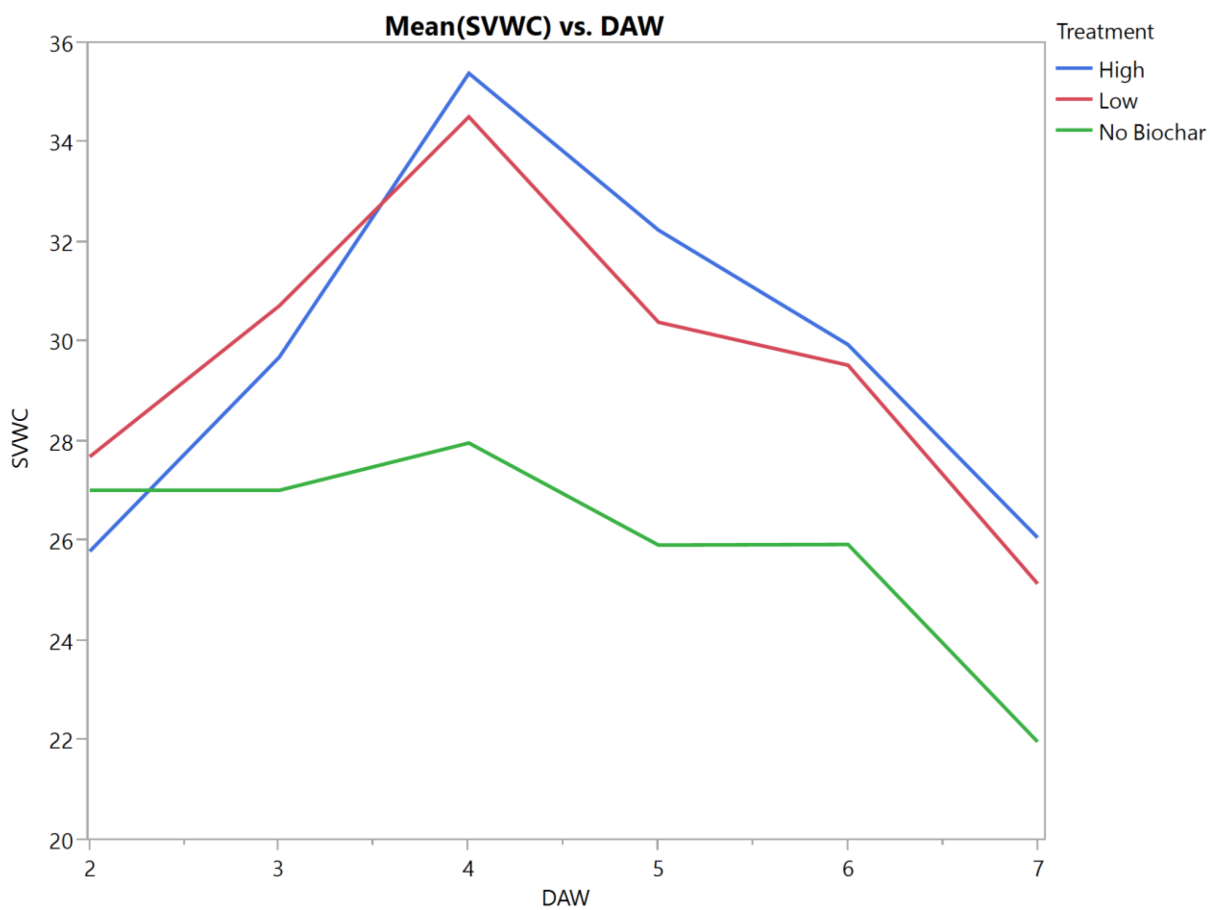
In the field study the treatments with slowest establishment were 2BS, 2GW, and 2GW5BC.

Photo of tall fescue at end of greenhouse experiment. Each pot is marked by treatment: C=Control, 1BC=1% of volumn is biochar, the remainder being soil; 5BC=5% biochar; 10BC=10% biochar; 2GW= equivalent to putting 2” greenwaste compost on top of soil then incorporating to the 6” depth; 4GW=4” greenwaste; 2GW+5BC=2”greenwaste and 5% biochar; 2BS= 2” biosolids compost; 2BS+5BC= 2”biosolids plus 5% biochar. One percent biochar by volume is roughly equivalent to 1 ton per acre application of biochar. Note the control, 1BC, 5BC have no green color and little biomass. The remaining treatments show a progression of increasing green color and biomass. 4” greenwaste compost was the greenest and had the most biomass. Greenwaste plus biochar increased greenness, productivity, and rate of establishment over greenwaste alone for both full and reduced irrigation; same for adding biochar to biosolids.

C. Field Experiments/Demonstrations Conducted with the Public Works Departments of the Cities of San Jacinto and Riverside, and LA County Public Works.

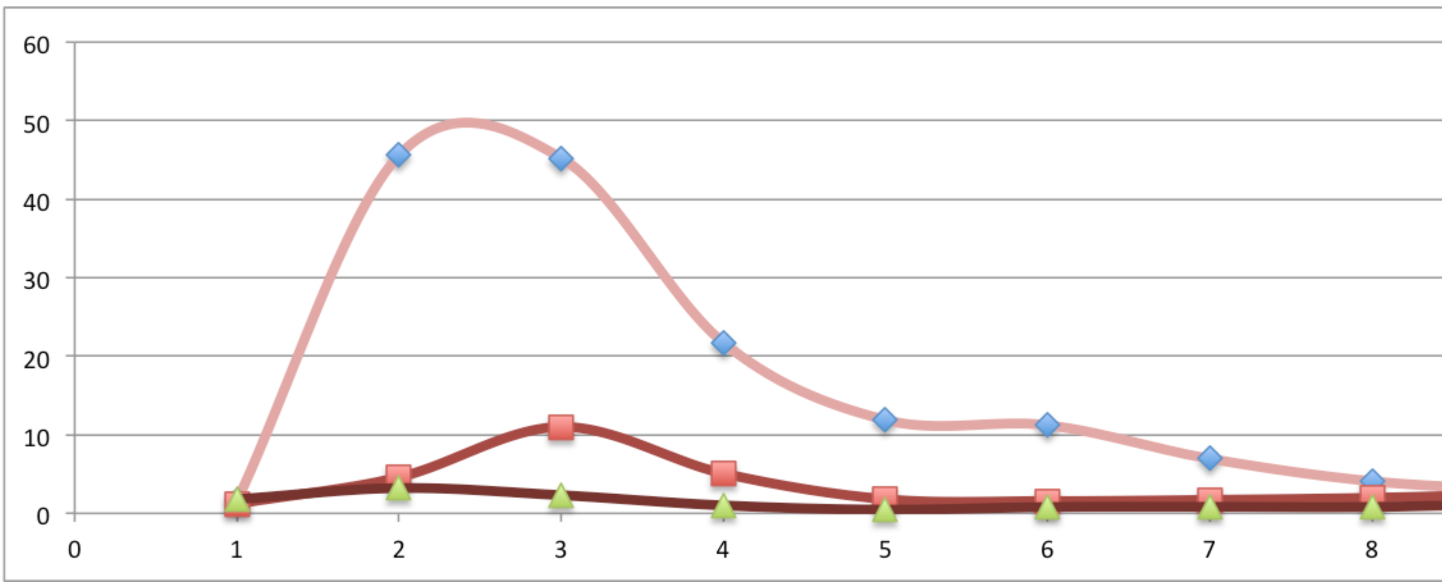
The experiment in San Jacinto failed to produce usable data due to problems with the pre-installed irrigation system. We have been slow to monitor the LA DPW meridians in La Mirada due to a variety of bureaucratic problems, including a dispute over who had control of the irrigation system. That seems to be resolved and I will begin taking data this weekend.

The City of Riverside Roadside Garden near the corner of California and Brookway has yielded interesting results. Irrigation was withheld for a week and soil dry down measured daily. There has been a clear increase in soil water content when biochar was applied versus the non-treated control:



D. Effect of Biochar on Leaching of N, P, K in Direct-Seeded and Sod Established Turf

Elizabeth Crutchfield is conducting the experiments as part of her PhD thesis research and will be finished in 2015. Lizzy just finished analyzing nearly 1000 samples for N, P, K content, and she is about to begin statistical analysis of the results. Biochar appears to be an excellent means of reducing fertilizer leaching, and could be added to planting media, used to replace peat moss and media components, or used in other applications to adsorb nutrients to prevent water pollution.



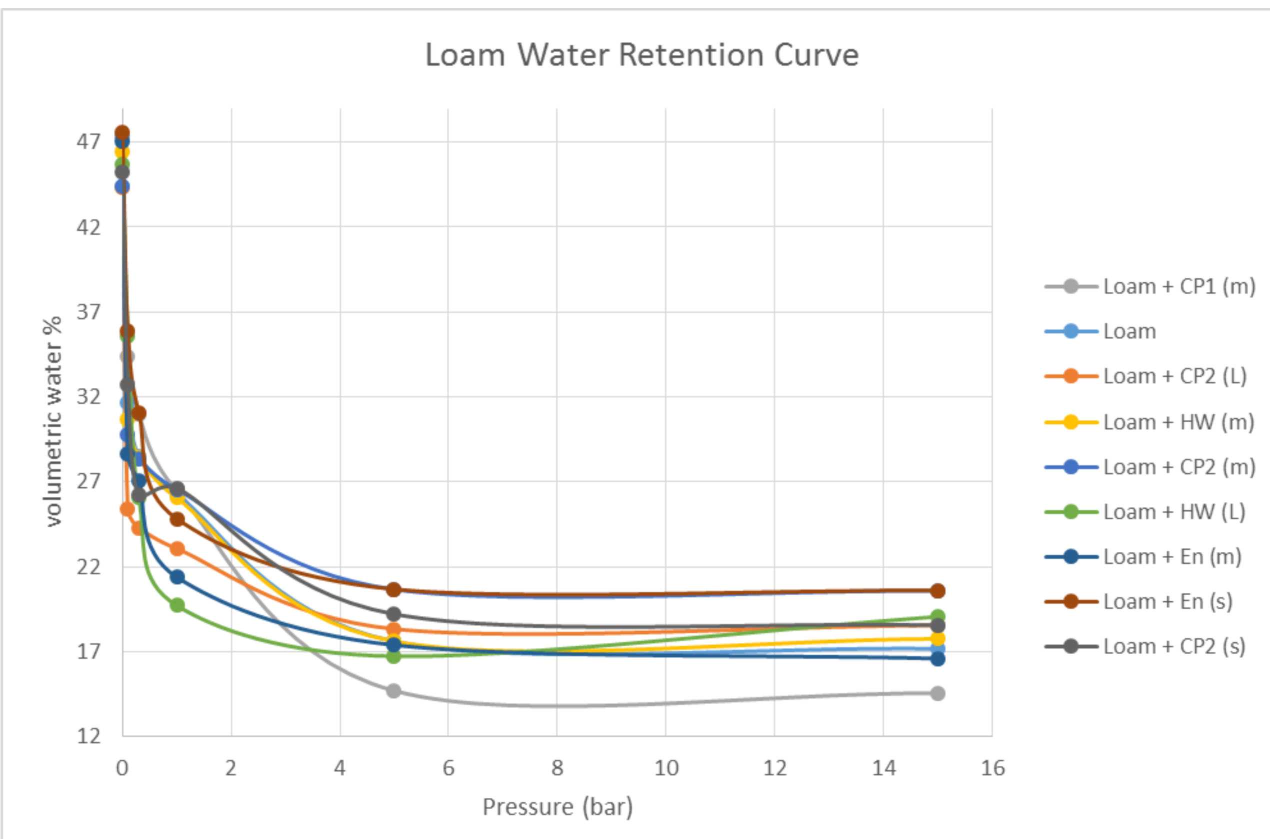
When biochar is not added to the soil (pink line, blue squares), considerable inorganic N (y axis) may be leached after each irrigation events (x axis). Incorporating either 2 (pink squares) or 13 (green triangles) tons per acre of biochar greatly reduces the amount of all forms of inorganic N that leached out of the soil.

E. Effect of biochar on plant water use efficiency (WUE).

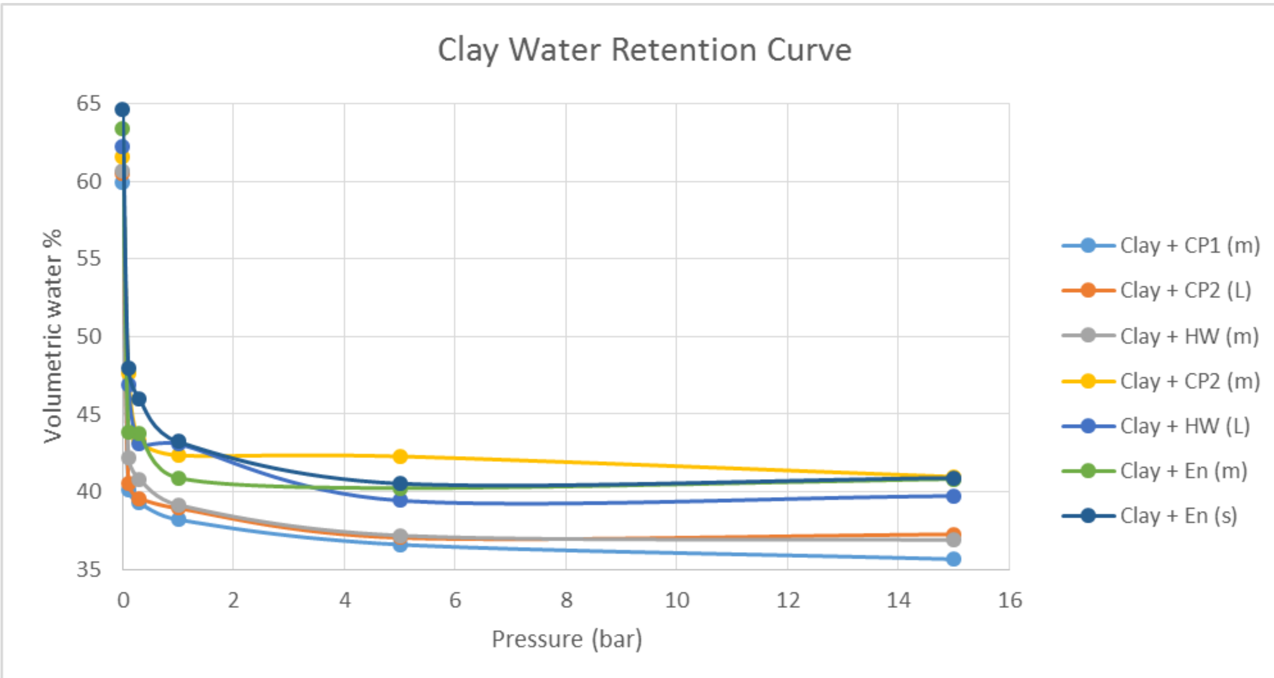
Cardboard biochar was found to exert a less influential effect compared with red oak biochar but still greater than the untreated clay. Soil C abundance was greater for clay blended with oak biochar ($\delta^{13}C$=23.66 $^{o}/_{oo}$) compared to the cardboard biochar blend ($\delta^{13}C$=30.67 $^{o}/_{oo}$). The upshot of the data is that biochar appears to increase water use efficiency by both improving the structure of the planting media, and apparently affecting the plant's physiology. The latter finding is both very encouraging and surprising, but should not be quoted until we can confirm and publish the results.

F. Biochars vary in their effect on plant water holding capacity

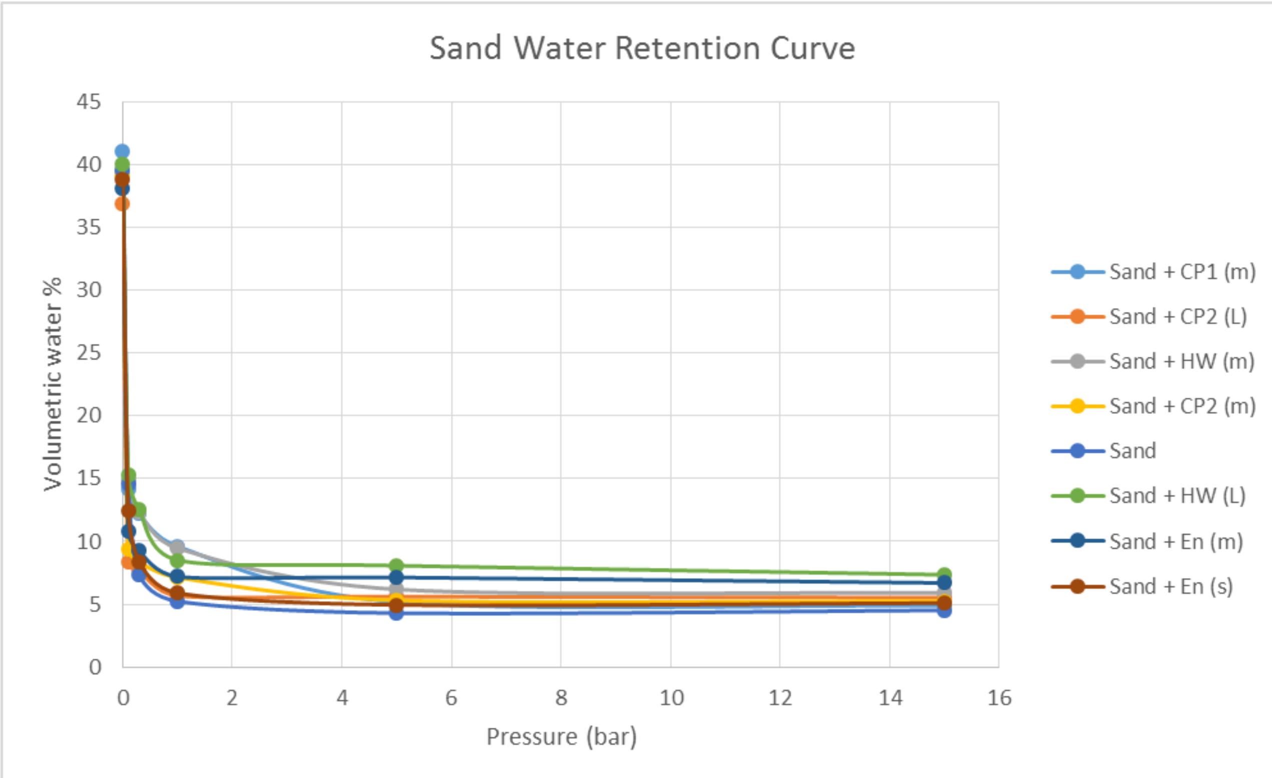
To derive PAW, we used the pressure plate data to prepare soil water retention curves:



Loamy soils contain significant amounts of all three soil particle classes: sand, silt, and clay. Loam soils have water retention properties intermediate to sands or clays – they hold water at higher pressures than sands, but not as high as clays. As a result, they generally drain reasonably well but hold water for several days to allow plant uptake. Loams are generally considered the preferred soil type for plant growth.

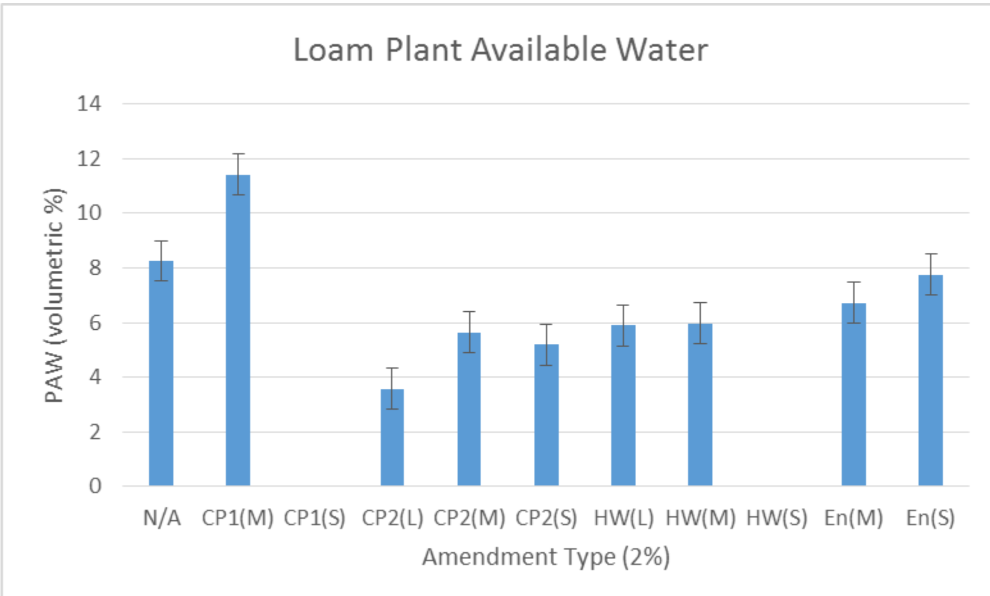


Fine clay particles hold water longer than sand or silt. Clay soils must be managed very carefully because they can hold water for too long, or when dry be very difficult for tillage or plant root growth. Amendments are often incorporated into clays to improve drainage and tilth.

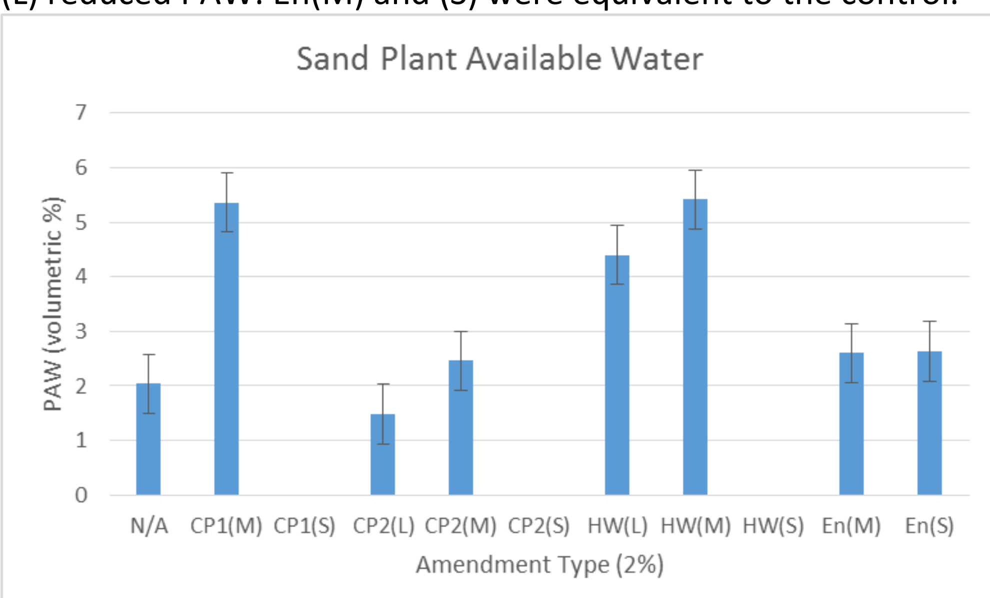


Finally, water drains quickly out of sand, and organic amendments are often suggested to increase water holding.

Below the water retention curves are converted into more useful PAW data. N/A (not applied) is the no biochar control. CP1 and HW had too few small particles to measure, which is why they appear on the x axis (CP1(S) and HW(S)) but no data to present.:

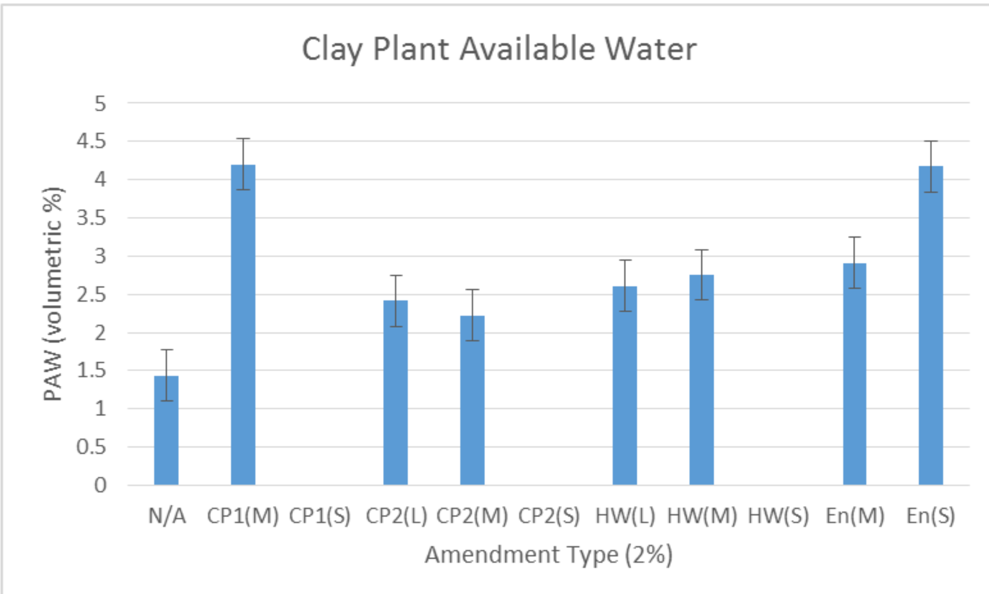


In the preferred loam soil, only the medium sized CP1 particles significantly increased water holding capacity above the controls. Both CP2 and HW (M) and (L) reduced PAW. En(M) and (S) were equivalent to the control.



Treatment differences were more evident for both the clay and sand soils. For sand, CP1 and both HW increased water holding capacity while the other treatments had little effect.

For poorly drained clays, all of the biochars increased PAW. This seems counter-intuitive, but is probably due to better drainage. Interestingly, the small En particles had a greater effect on PAW than En(M).



In the sandy loam, medium sized biochar had greater increases in PAW than small sized biochar. In contrast, in PAW increases were greater for small sized biochar amended clay soil compared to the medium sized biochar. Biochar particle size affected PAW increases in the sand, but the difference varied depending on the biochar. This analysis concludes that biochar application increases WRC in sand and clay soils, but has variable effects in sandy loam depending on the biochar.

G. Effect of biochar and compost on microbial community structure

The results were then broken done by phylum to observe the effect on species diversity and community structure:

Phylum level shifts (%) in microbial community structures

Phylum	CK	BC5	BC10	CM	BC+CM
Nitrospirae	1.04 a	0.71 b	0.82 ab	0.24 c	0.31 c
Cyanobacteria	1.67	1.14	1.18	1.21	1.67
Verrucomicrobia	2.50	1.99	2.08	2.76	2.59
Gemmatimonadetes	3.76 a	2.94 b	3.40 ab	2.20 c	2.18 c
Planctomycetes	5.30	5.65	5.49	5.54	6.27
Acidobacteria	5.13 b	6.93 a	6.05 ab	4.57 b	4.76 b
Firmicutes	5.54 a	5.56 a	5.34 ab	4.88 bc	4.83 c
Chloroflexi	6.59 b	12.77 a	10.69 ab	9.08 ab	11.01 ab
Bacteroidetes	8.25	6.01	6.61	8.00	6.97
Actinobacteria	10.59 a	9.38 ab	10.25 a	8.84 b	8.35 b
Proteobacteria	48.06 ab	45.40 b	46.61 ab	50.60 a	49.34 ab

Key to treatments experimental treatments: control (CK), compost 5 tons/acre (CM), biochar 5 tons/acre (BC5), biochar 10 tons/acre (BC10), biochar 5 tons, and compost 5 tons (BC+CM).

Bacteria, fungi, and other microbial populations clearly responded to the addition of compost, an expected result as compost was a food source for many species. The addition of biochar was less dramatic, but did occur. The results show that biochar causes changes in the soil beyond soil physics, which may explain why our pressure plate data shows a less dramatic effect then our field and laboratory plant data often demonstrates.

4. Summary

We are very grateful to MWD ICP for funding our research. It has been a catalyst for many studies, data collection, discussions, and outreach beyond the scope of the original proposal. We were able to do so by using the originally proposed experiments as a springboard to elicit cooperation and other resources not funded by our grant, including in-kind contributions, volunteers, cooperating agencies, visiting scientists, and student research projects. As a result, we have worked to give a more complete picture of what we know about biochar and its potential than was originally envisioned. This report is but a summary of a much greater pool of data that has and will be collected over the next few years as a result of the funding and other assistance from MWD and other groups.

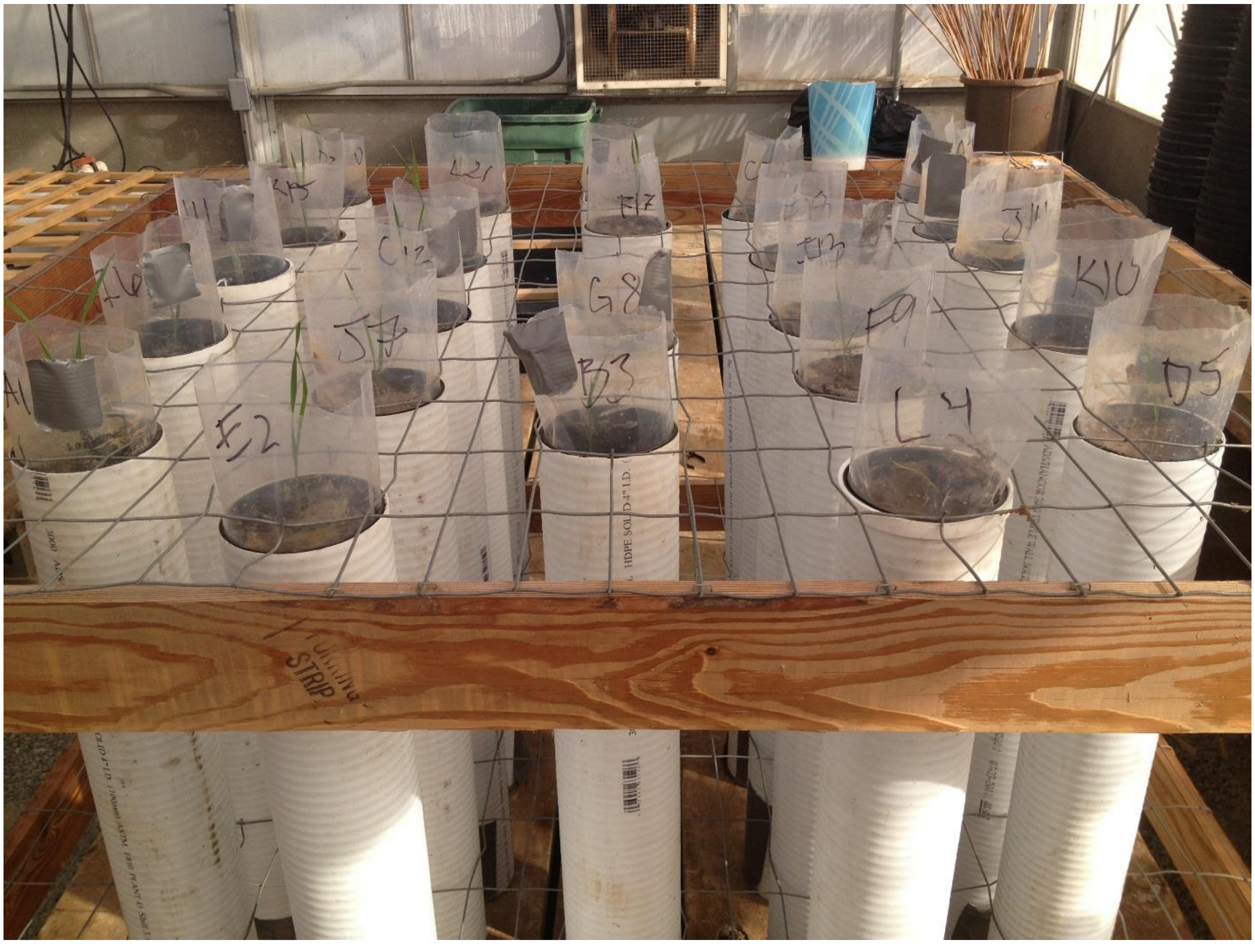
Biochar was shown to have a variety of different effects on soil and plants. Water use efficiency results varied, sometimes showing no differences from untreated controls and in other experiments finding substantial water savings. There are persistent reports of biochar soil amendments reducing irrigation requirements by over 50%. Based upon the current model of soil physics where water is stored by capillary action, the amounts of biochar that can practically be amended to the soil could not possibly cause such reductions in water requirements. However, we did see evidence of biochar effects that went beyond traditional soil physics, including effects on plant water use efficiency and microbial populations. We can also say with certainty that the anion and cation exchange capacity of biochar can increase fertilizer use efficiency and improve water quality by reducing fertilizer pollution of ground and surface waters.

A very obvious issue with biochar is that its properties are dependent on the feedstocks and pyrolysis conditions used to produce it. The exact relationship of these properties with enhancing soil water use efficiency is unclear. We are working with a range of experts to understand the mechanisms. We encourage

MWD and all our clientele to keep in touch and see what we discover in the coming months.

Photographs from biochar experiments. In no particular order are photographs from experiments and other activities related to the project:

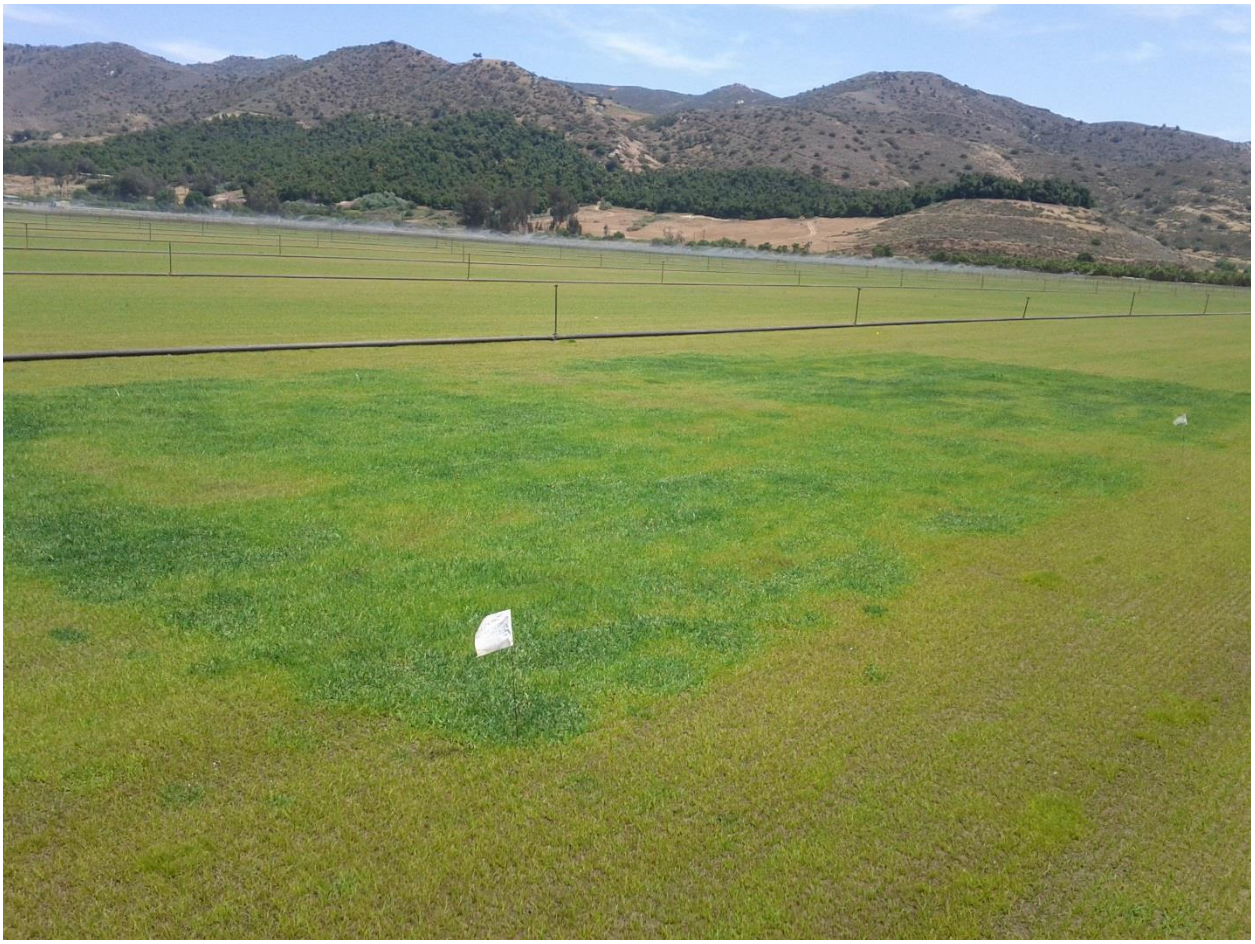
Michael Wittman from Bluesky biochar applying compost tea soaked biochar to our new demonstration site at Pilgrim's Place in Claremont, CA.



Soil columns used to study effect of biochar on wheat growth. Note the plastic liners that enable extraction of intact root systems.

Jars of feedstocks and finished biochars. Biochar can be made from a wide range of carbon-rich waste, then pyrolyzed into different forms of biochar that can improve soil and sequester carbon for decades.

Undergraduate Jacky Corona extracting water from lysimeters in turf plots at UCR to determine biochar's effect on fertilizer efficiency. Jacky is part of a program to ease the transition to UCR for junior college transfers.



Biochar installed at a sod farm in Escondido. The treated plots were so much greener than the rest of the field that they were easy to find.

Working with Los Angeles County Public Works to install biochar in medians at La Mirada.   Public Works departments in LA, Riverside, San Jacinto, and Carlsbad have been enthusiastic and valuable collaborators, which should lead to direct implementation once we confirm that biochar can save them water.

Riverside Public Works biochar installation in medians on Madison Avenue in Riverside. The supersac is what remains of the biochar. Riverside has won several international awards for its forward thinking, including “World’s Smartest City”. This project has led to working much more closely with the city on a number of projects.

Biochar is now used globally. Chinese municipalities are turning greenwaste, sewage, and other carbon-rich wastes into biochar, then using it in agriculture. Here a Chinese wheat grower near Shanghai stands in a field to show improved plant growth following soil incorporation of biochar.

INFORMATION DISSEMINATION

I have given over a dozen talks to a variety of audiences on biochar and our experimental results during the course of the grant. I worked with the Southern California Biochar Initiative to do a biochar workshop in Thousand Oaks. Thousand Oaks has begun using biochar on new landscape installations. Southern California Biochar Initiative founder

Michael Wittman gave an interview for the Thousand Oaks Go Green Initiative YouTube site, mentioning the work we are doing:

https://www.youtube.com/watch?v=9iW-68fKVU0&fb_action_ids=10204835561482131&fb_action_types=og.shares

I included information on biochar and talked about our MWD project in my Master Gardener Training classes in Moreno Valley and Palm Desert, and my CAPCA talks in Santa Ana, Redlands, and Blythe. In all cases, I was surprised at the receptiveness of the audience to the concept of using biochar as a soil amendment.

When I began mentioning biochar in talks five years ago I had to spend considerable time explaining what it was and responding to many skeptics. Things seem to have changed fairly rapidly this year. I am always asked where homeowners can get biochar, and I have long discussions after my talk with groups of people interested in our work.

YouTube videos of our talks at our MWD field site at UCR's annual Turf Field Day may be found at: https://www.youtube.com/watch?v=nElzwa7Mjhk&list=PL698CAB64ED87B5CF&index=34

And:

https://www.youtube.com/watch?v=K36GLjEVJAk&list=PL698CAB64ED87B5CF&index=35