Agronomic value of sewage sludge and corn cob biochar in an infertile Oxisol

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1. Background

- Approximately 40,800 tons of biosolids are sent annually to the landfill on Oahu creating an environmental hazard.
- Imminent landfill closure poses disposal problem forcing state government to explore expensive and unpopular off-shore shipping options.
- Carbonizing sludge into biochar for land application has potential to solve disposal problem, sequester C, improve soil quality, and increase agricultural productivity.


Figure1. Municipal waste water treatment facilities in Hawaii truck biosolids to landfill.

2. Objectives

1. Characterize the physico-chemical properties of biochars made from municipal sewage sludge and corn cob waste.
2. Evaluate the effect of biochar application on soil chemical properties.
3. Determine the effect of biochar application on plant growth in an infertile tropical soil.

3. Materials & Methods

Biochar Characterization

- Proximate and elemental analysis, heavy metal analysis, pH, extractable plant nutrients, and cation exchange capacity (CEC).

Greenhouse Experiment

- Treated and untreated sewage sludge (SS) and corn cob (CC) biochars produced by the Flash Carbonization process at the Natural Energy Institute.
  - Treated: biochar used in anaerobic digester to treat effluent waste water.
- In fertile Oxisol: *Wahiawa, very fine, isohyperthermic, kaolinitic, rhodic haplustox*
- Biochar applied at 2% (w/w) and supplemented with complete fertilizer
- Four replicates per treatment
- Three 5-week planting cycles


Figure 2. Greenhouse pot study.

Table 1. Chemical characterization of treated and untreated CC and SS biochars.

Sample	Elemental Analysis					Proximate Analysis			Main Ash Components			
	C	H	O	N	S	FC†	VM‡	Ash	CaO	MgO	K_2O	P_2O_5
	-----%-----											
Raw CC	48.66	5.75	42.19	0.51	0.06	NA	NA	2.83	2.46	1.90	21.00	8.56
Biochar CC	84.94	2.42	2.66	0.89	0.13	80.30	8.26	11.44	1.79	2.64	36.90	10.07
Raw SS	37.67	5.22	14.59	7.05	3.58	NA	NA	31.89	9.11	3.69	2.36	21.26
Biochar SS	30.24	1.29	<0.01	3.13	3.81	25.83	8.64	65.53	9.13	3.99	2.13	20.86
Heavy Metals												
	As	B	Cd	Cr	Cu	Hg	Mn	Mo	Ni	Pb	Se	Zn
	-----mg kg^{-1}-----											
Raw CC	0.18	2.6	0.1	9.56	4.27	<0.02	6.90	2.8	1	1.5	<0.05	35.1
Biochar CC	0.56	24	0.5	24.7	24	0.59	21.2	16.4	14	2.1	0.89	164
Raw SS	22	197	3.3	97.4	325	0.02	66	11	30	13	8.58	956
Biochar SS	15.9	168	8.6	245	771	0.06	160	30.5	71.5	33	15.7	2260
pH & Extractable Nutrients												
	pH	CEC	NH_4^+-N	NO_3^--N	P	K^+	Ca^{++}	Mg^{++}	Na^+			
			-----mg kg^{-1}-----									
Untreat CC	9.20	11.3	10.6	1.04	129	16371	136	432	535			
Treat CC	9.45		24.7	0.03	175	10547	140	471	441			
Untreat SS	6.81	15.5	216	ND	372	1200	1240	190	11077			
Treat SS	6.86		33.5	ND	1285	1015	1683	255	4205			

†fixed carbon, ‡volatile matter

4. Results & Discussion

Corn Cob Biochar

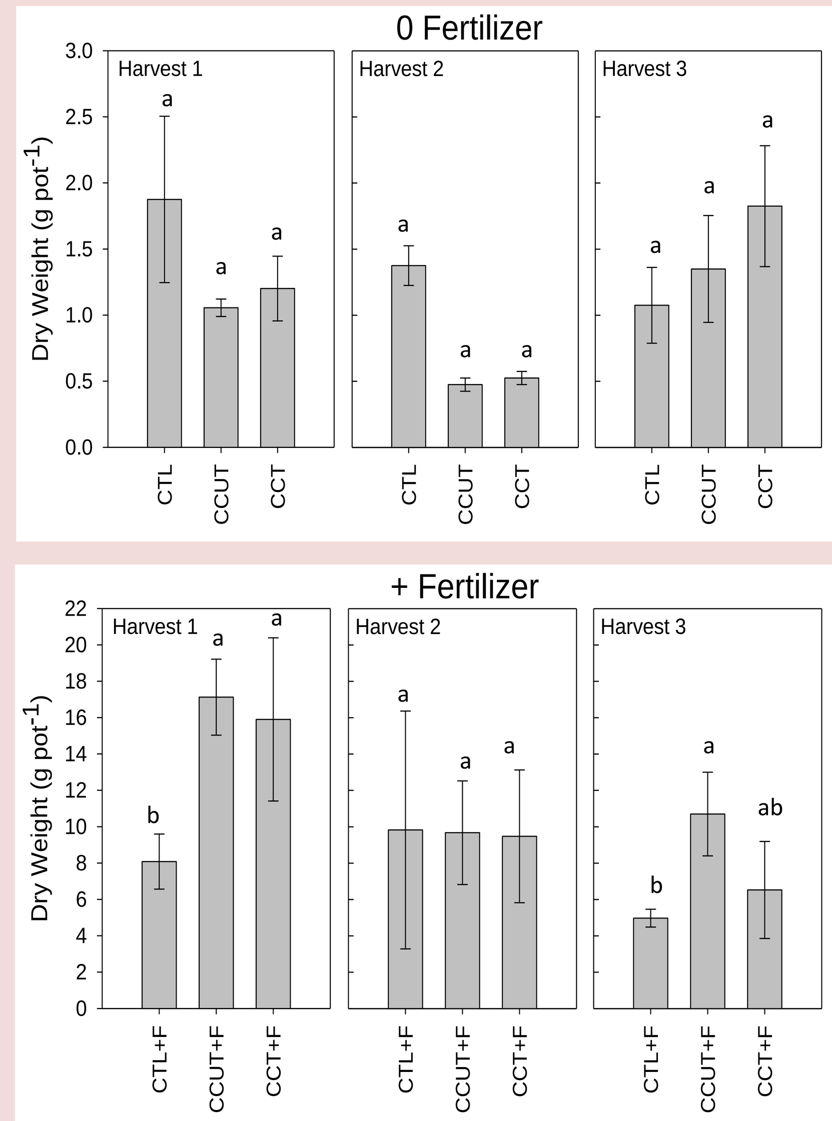

Figure 3. Corn growth response to CC biochar applications without fertilizer (top) and with fertilizer (bottom) .

Table 2. Corn cob biochar effects on soil pH, extractable P and base cations following mixing (pre-plant) and after 3 harvests.

Treatment	pH	TC	TN	P	K	Ca	Mg
		------g kg^{-1}-----		-----mg kg^{-1}-----			
Pre-Plant							
CTL	6.16b†	1.26b	0.15b	8.31b	427c	686c	219c
UT	6.31b	2.61a	0.30a	10.7b	1083a	768b	258b
T	7.00a	2.72a	0.32a	16.8a	849b	812b	296a
Planting 3							
CTL	6.53b	1.17c	0.13b	7.54d	154d	754ab	207abc
CTL+F*	4.58d	1.42c	0.16b	14.8bc	222d	650ab	181bc
UT	6.73b	3.07a	0.33a	7.76d	917a	830a	243ab
UT+F	5.44c	2.65b	0.30a	16.9ab	393c	531b	150c
T	7.08a	2.96ab	0.34a	12.2c	608b	872a	247a
T+F	5.17c	2.88ab	0.33a	19.6a	347c	544b	162ab

†Means within the same planting cycle followed by the same letter are not significantly different ($P<0.05$), *F = fertilized

Table 3. Corn cob biochar effects on corn tissue nutrient concentrations for crops 1 and 3.

Treatment	N	P	K	Ca	Mg	Mn
	-----%-----					mg kg^{-1}
Crop 1						
Control+F	2.13a	0.13b	4.56a	0.45a	0.27a	428a
Untreat+F	1.27b	0.16a	5.00a	0.31b	0.20b	114b
Treat+F	1.40ab	0.14ab	4.94a	0.34b	0.24ab	121b
Crop 3						
Control+F	2.81a	0.15a	4.59a	0.54a	0.37a	1796a
Untreat+F	2.07a	0.19a	4.24a	0.33b	0.27b	468b
Treated+F	2.77a	0.21a	5.09a	0.39ab	0.34ab	706b

- Despite showing significant increases in soil pH, TC, TN and extractable P and base cations (Table 2) , the corn cob biochar without fertilizer had no effect on corn growth (Fig. 3, top).
- Treating the biochar showed no significant effect on corn growth alone or in combination with fertilizer despite higher biochar nutrient content (Fig 3, bottom).
- The CC biochar significantly increased corn growth in the 1st and 3rd crop cycles when combined with fertilizer by increasing soil P and K availability and reducing tissue Mn concentration(Table 2 & 3).
- The greatest benefit to corn growth occurred in the 1st crop cycle suggesting only a short-lived benefit.
- Corn plants in biochar amended soils showed similar heavy metal tissue concentrations as the control.

Sewage Sludge Biochar

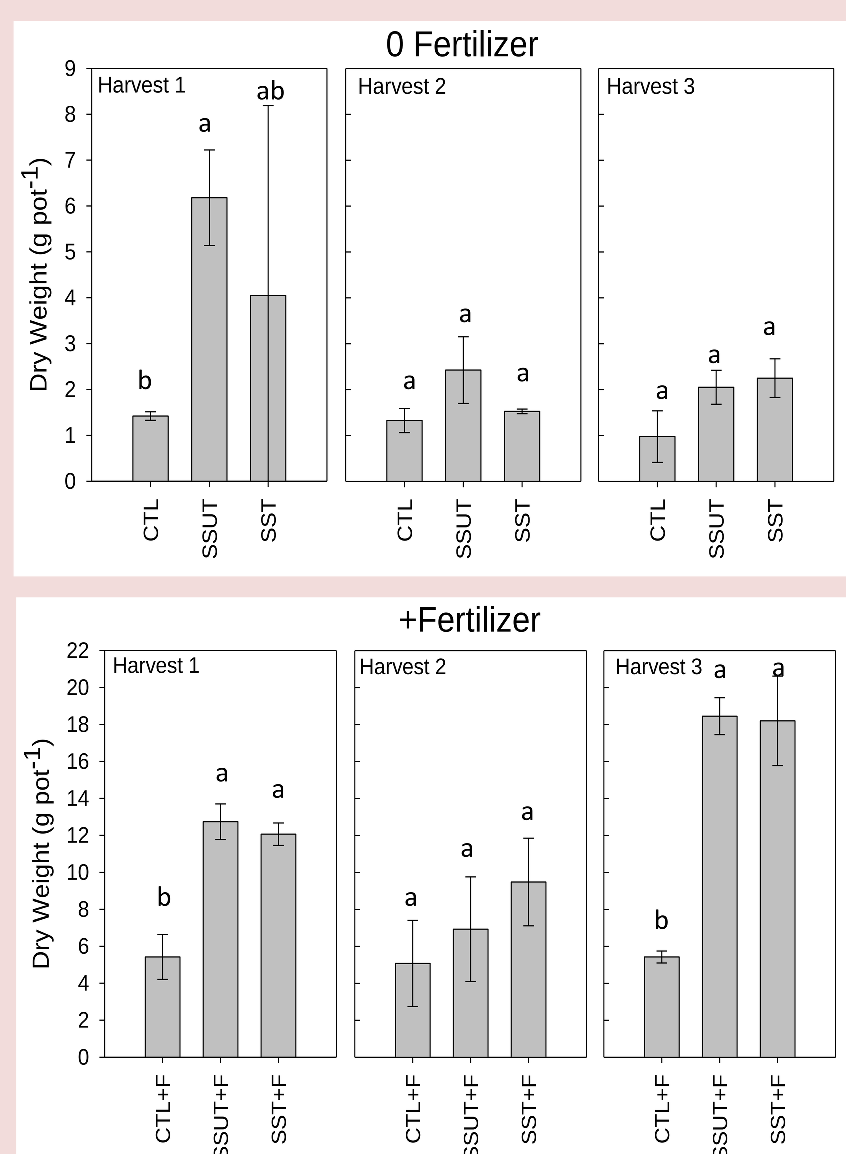

Figure 4. Corn growth response to SS biochar applications without fertilizer (top) and with fertilizer (bottom).

Table 4. Sewage sludge biochar effects on soil pH, extractable P and base cations following mixing (pre-plant) and after 3 harvests.

Treatment	pH	TC	TN	P	K	Ca	Mg
		------g kg^{-1}-----		-----mg kg^{-1}-----			
Pre-Plant							
CTL	6.23b	1.05c	0.21a	24.0b	285c	957b	251c
UT	6.07c	1.57b	0.18a	24.1b	434a	1137a	363b
T	6.59a	1.78a	0.21a	31.9a	375b	1092a	385a
Planting 3							
CTL	6.33a	1.32c	0.15c	6.48e	193ab	816b	226d
CTL+F	5.24d	1.42c	0.16c	16.5de	98.3bc	674c	151e
UT	5.89bc	1.85b	0.21b	24.4cd	160abc	916a	361b
UT+F	5.79c	2.65a	0.21b	58.8a	68.4c	850ab	272c
T	5.42d	1.71b	0.19b	38.1bc	205a	909a	396a
T+F	6.08a	2.88a	0.32a	52.4a	80.3c	911a	339a

Table 5. Sewage sludge biochar effects on corn tissue nutrient concentrations for crops 1 and 3.

Treatment	N	P	K	Ca	Mg	Mn
	-----%-----					mg kg^{-1}
Crop 1						
Control+F	3.32a	0.19b	5.28ab	0.39a	0.28b	193a
Untreat+F	3.03a	0.29a	5.52a	0.37ab	0.37a	266a
Treat+F	2.07b	0.27a	4.84b	0.31b	0.30b	74.9b
Crop 3						
Control+F	2.37a	0.15b	3.45a	0.48a	0.41a	328a
Untreat+F	1.14b	0.20a	1.71b	0.25b	0.40a	146b
Treat+F	1.07b	0.22a	1.78b	0.29b	0.43a	69.1b

- Without fertilizer, the untreated sewage sludge biochar showed a significant increase in corn biomass compared with the control. The increased yield was correlated with increased P and Mg availability (Fig. 4, top).
- Combining SS biochar and fertilizer increased corn biomass by more than 2X in the 1st crop cycle and 3X in the 3rd crop cycle (Fig. 4, bottom). Increased corn growth was correlated with higher pH and increased P, K, Ca, and Mg availability in the SS biochar amended treatments (Table 4 & 5).
- SS biochar showed a significant reduction in tissue Mn concentration especially in the 3rd crop indicating a capacity to counteract the negative impacts of Mn toxicity in the acidified Wahiawa soil.
- Corn plants in biochar amended soils showed similar heavy metal tissue concentrations as the control.

Biochar and Manganese Detoxification

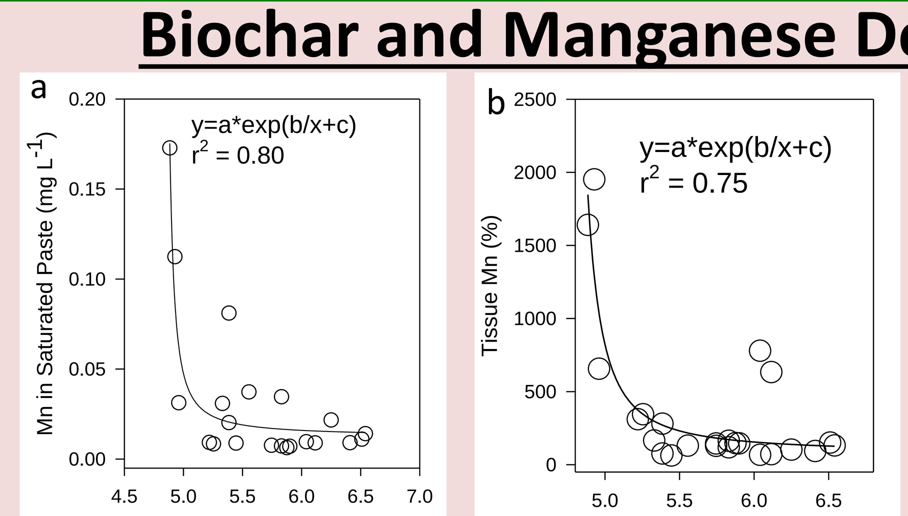

Figure 5. Biochar driven increases in pH reduce soil and tissue Mn concentrations.

- Maintenance of higher pH in biochar amended soils reduced soil solution Mn (Fig 5a) with significant reductions in Mn accumulation in corn tissue (Fig. 5b).
- Research is needed to explain detoxification mechanism

Summary

- Domestic sewage sludge biochar shows promise as a soil amendment providing an environmentally sound means of disposal.
- Biochar shows potential to improve soil fertility, increase plant nutrition and growth, and mitigate Mn toxicity in acid soils.
- Greenhouse results must be validated at the field scale.

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