Supplementary Materials

Role of nutrient enriched biochar in soil amendment and fertilizing maize growth: Exploring practical alternatives to recycle agricultural residuals and reduce chemical fertilizer demand

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Supplementary Text S1: Procedure for characterizsing the biochar

The biochar surface area was determined based on N_2 adsorption technique using the Brunauer, Emmett and Teller (BET) method. The biochar functional groups and structural chemical composition were be determined by FT-IR, SEM-EDS, and XRD techniques, respectively.

Supplementary Text S2: Procedure for determining P in the soil using the Olsen method

This method estimates the relative bioavailability of ortho-phosphate (PO_4-P) in soils by extraction with alkaline sodium bicarbonate (pH = 8.5) solution and determining the P concentration in the extract colorimetrically. A 2.5 g scoop of soil and 50 mL of 0.5 M sodium bicarbonate (pH = 8.5) solution wearе shaken together for 30 min. The mixture was then filtered through Whitman filter paper and the ortho-phosphate in the extract was determined colorimetrically at 630 nm on a Technicon Auto Analyser II) by reacting it with ammonium molybdate using ascorbic acid as the reducing agent. The results are reported as parts per million (ppm) phosphorus in the soil.

Supplementary Text S3: Calculation of carbon, nutrients (NH_4^+–N, PO_4–P and& K) and amount of biochar addition to the soil

There were two applied biochar rates ~~were two~~ i.e., at 10~~t/ha~~ and 20 t/ha. Since the trial pots had soil (6 kg), ~~so~~ the applicable biochar was administered on a wt/wt basis i.e., soil:-biochar. To work out the weight of each biochar for each replicated pot at the two application rates, the following parameters were considered;

1. Carbon content of the biochars. The carbon content of the biochars were~~;~~ 80%, 90%, and 56% for corn cobs, wood, and sewage sludge biochars, respectively.
2. Soil depth of biochar application. This was taken as 10 cm.
3. Soil density~~.~~ ~~:~~ This was determined as 1.4 g/cm^3
4. Land area unit. ~~-~~This was per hectare and equivalent to 10,000 m^2
5. Volume of the soil per ha. This ~~was~~ equated to 10,000 m^2*0.1 m (10 cm depth of char application) = 1000 m^3 soil/ha.
6. Mass of soil/ha = 1000 m^3*1.4 g/cm^3 = 1.4*10^6 kg soil/ha

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7. Mass of soil per pot was 6 kg

Calculation of the final rates

Rate 1: 10 t biochar/ha for any char

10,000 kg of char/soil density kg/m^3 = 10,000/1400 kg soil/ha = 7.14 g biochar/kg soil

Final weight of corn cobs char added to the soil = 7.14 *6 = 42 g biochar/per pot (at 10 t biochar/ha)

At Rate 2: 20 t biochar/ha

=20,000 kg char/soil density (kg/m^3) = 20,000/1400 = 14.3 g biochar per kg soil

Final weight added per pot at 20 ton/ha = 14.3 *6 = 85.71 g per pot.

Therefore, %wt/wt of char/soil is 0.7% and 1.4 % for 10 and 20 ton biochar-/ha rates, respectively.

To calculate the total carbon added at both biochar rates for corn cobs

If we let X_{10} and X_{20} be the amount carbon be at 10 t biochar-/ha,

Therefore; for corncobs whose fixed carbon was 80%, X_{C10} = 10 ton biochar-/ha * (fixed carbon in the char i.e., 80% for corn cobs)

Xc_{10} = 8 tons of carbon (amount of carbon added for corn cobs at a rate of 10 t/ha)

Xc_{20} = 20*0.8 = 16 ton of carbon added at 20 t biochar/ha rate.

Conversely for wWood biochar and sSewage biochar, the added carbon will bewas calculated the same way and it would was be 9.1 and 18.2 ton carbon/ha for wood, and 5.6 and 11.2 ton carbon for sewage sludge biochar, respectively.

Supplementary text S4: Calculation of adsorbed nutrients onto the biochar

The amount of nutrients (NH_4^+–N, K^+ and PO_4^{3-}) adsorbed onto the biochar were based on the differences between the initial and final concentrations in solutions and the weight of biochar and volume of digestate initially mixed with the biochar using Equations. (1) and (2).

$$\% \text{ sorption} = \frac{C_o - C_e}{C_e} * 100 \quad (1)$$

$$Q_e = \frac{(C_0 - C_e) * V}{W_B} \quad (2)$$

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wWhere ;

C_o and C_e (mg/L) are the initial and equilibrium K^+, NH_4^+–N and PO_4^{3-} concentrations in solution respectively, Q_e (mg/g) was the adsorbed amount of K^+, NH_4^+-N and PO_4^{3-}–P at equilibrium, V (L) was the volume of solution used, and W_b (g) the mass of biochar.

Supplementary Table S1: Summary of anaerobic digestate slurry characteristics used in the study

Biological Parameter[b]	Symbol	Unit	Value
pH	___	___	8.0–8.3
Electro conductivity	(EC)	(µs/cm^3)	104–134
Soluble chemical oxygen demand	SCOD	(mg/L)	4500–5000
Biological oxygen demand	BOD_5	(mg/L)	430–510
Total solid	TS	(mg/L)	15–18
Ammoniac nitrogen	NH_4^+-N	(mg/L)	1390–1450
Nitrate nitrogen	NO_3^--N	(mg/L)	47–54
Nitrite nitrogen	NO_2^--N	(mg/L)	34–56
Ortho-phosphate	PO_4^{3-}-P	(mg/L)	15–20
Total organic carbon	TOC	(mg/L)	226.1 ± 10.9
Metal ions[b]			
Potassium	K	(mg/L)	1205.75 ± 9.81
Sodium	Na	(mg/L)	301.5 ± 1.00
Calcium	Ca	(mg/L)	48.7 ± 5.459
Magnesium	Mg	(mg/L)	39.45 ± 4.729
Ferrous Iron	Fe	(mg/L)	3.74 ± 0.694
Zinc	Zn	(mg/L)	0.583 ± 0.250
Copper	Cu	(mg/L)	0.296 ± 0.139
Strontium	Sr	(mg/L)	0.184 ± 0.005

[a]slurry was collected and analyzsed for a total period of 6 weeks and the analyzsed values were expressed as a range depicting the lower and upper limit concentrations.

[b]Sr, Ni, Al, Co, As, Mn, Ba, Cr, Se, Pb, Cd are not reported because their concentrations were < 0.1 (mg L^{-1})

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Supplementary Table S2: Percentage increase in soil nutrients and heavy metals over the control as influenced by different biochar treatments at 10 ~~ton~~ and 20 t/~~on per~~ ha application rates

Treatment	TOC[b]	TN[c]	TP[d]	Ca	K	Na	Mg	Fe	Cu	Zn	Cr	As
10 ton/ha biochar application rate												
[a]CB-N	59	14	50	37	58	25	18	72	-69	-61	-65	72
WB-N	111	50	37	-41	-37	-16	-67	-22	-89	-88	-93	87
CB-T	86	50	170	78	87	283	156	97	11	15	9	4
WB-T	137	450	259	52	62	258	133	12	-50	-23	-30	3
CB + NPK	57	709	240	52	119	26	71	76	-65	-18	-60	-87
WB + NPK	109	550	169	13	31	8	26	25	-68	-81	-94	-19
20 ton/ha biochar application rate												
CB-N	634	50	68	18	51	67	39	112	-59	-56	-53	-81
WB-N	862	36	40	-58	-88	17	-51	3	-83	-77	-72	-82
CB-T	744	141	358	131	342	325	133	132	55	5	6	-14
WB-T	916	441	414	98	373	192	58	46	-34	6	3	-77
CB + NPK	679	227	218	43	665	75	129	97	17	11	-49	-71
WB + NPK	857	132	115	8	465	10	79	34	-42	15	-82	-78
Soil + NPK	13	418	738	32	833	12	289	65	27	87	-5	3

[a]CB–N, WB–N; CB + NPK, WB + NPK; CB–T, WB–T and soil + NPK refer to unenriched corncobs, and wood biochar treatments; corncobs, and wood biochar added together with NPK; corn cobs, and wood biochar enriched with nutrients from anaerobic digestate and soil mixed with NPK fertilizer, respectively (see details Table 1).

[b]TOC represents total organic carbon

[c]TN represents Total Nitrogen was measured as ((TIN = NH_4^+–N, NO_3^-) + Total Organic Nitrogen)

[d]TP represents Total Phosphorus measured as (PO_4^{3-} + Organic P)

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Supplementary Table S3: Percentage increase over the control treatment (only soil) of nutrients uptake (mg.kg^{-1} dry matter) and heavy metal uptake (mg.g^{-1} dry matter) in plant tissues as influenced by different treatments.

	Treatment[a]	TN[b]	TP[c]	Ca	K	Mg	Cu	Zn	Cr	As	Fe
10 t/ha biochar application rate	CB-N	17.8	63.4	83.6	30.2	27.9	−68.8	−60.8	−64.9	−71.7	157.6
	WB-N	−9.4	24.4	−27.0	−39.5	−65.6	−89.2	−88.4	−93.0	−87.0	16.8
	CB-T	61.5	114.6	148.4	9.3	49.2	11.5	15.0	8.8	4.3	194.8
	WB-T	30.0	97.6	43.8	48.8	−6.6	−49.6	−22.5	−29.8	4.3	68.0
	CB + NPK	74.6	248.8	130.5	127.9	63.9	−65.0	−18.1	−59.6	−87.0	164.2
	WB + NPK	51.2	146.3	77.7	46.5	−6.6	−67.7	−81.2	−94.7	−93.5	87.7
20 t/ha biochar application rate	CB-N	35.2	119.5	107.8	76.7	63.9	−58.8	−55.6	−52.6	−80.4	112.0
	WB-N	−16.4	36.6	−10.2	−14.0	−29.5	−83.5	−77.1	−71.9	−82.6	2.7
	CB-T	131.0	195.1	208.2	197.7	123.0	55.0	5.1	7.0	−13.0	132.3
	WB-T	72.3	97.6	191.0	155.8	24.6	−33.8	5.8	3.5	−76.1	46.2
	CB + NPK	147.9	258.5	236.3	234.9	127.9	17.7	11.3	−49.1	−71.7	97.3
	WB + NPK	124.4	178.0	275.0	83.7	37.7	−86.5	15.0	−82.5	−78.3	33.5
	Soil + NPK	35.2	119.5	107.8	76.7	63.9	−58.8	−55.6	−52.6	−80.4	112.0

[a]CB–N, WB–N; CB + NPK, WB + NPK; CB–T, WB–T and soil + NPK refer to unenriched corncobs, and wood biochar treatments; corncobs, and wood biochar added together with NPK; corn cobs, and wood biochar enriched with nutrients from anaerobic digestate and soil mixed with NPK fertilizer respectively (see details in Table 1).

[b]TN represents Total Nitrogen was measured as ((TIN = NH_4^+–N, NO_3^-) + Total Organic Nitrogen)

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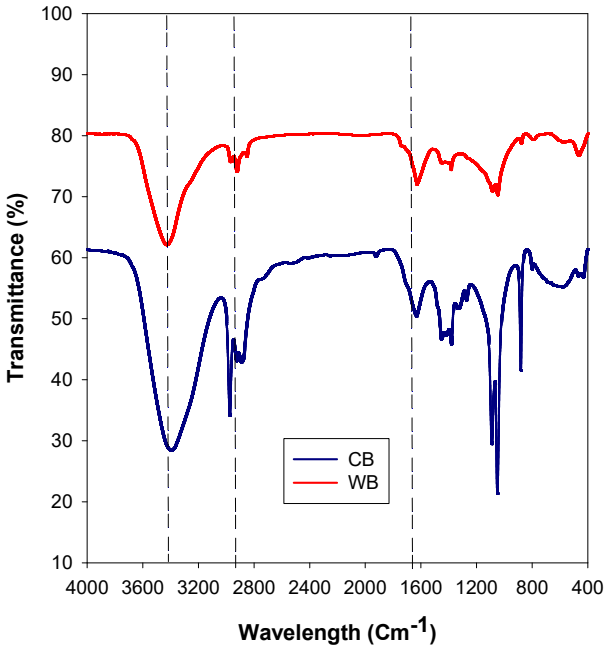

Supplementary Figure S1: FTIR diagram showing the peaks for corncobs biochar (CB) and Wood biochar (WB).

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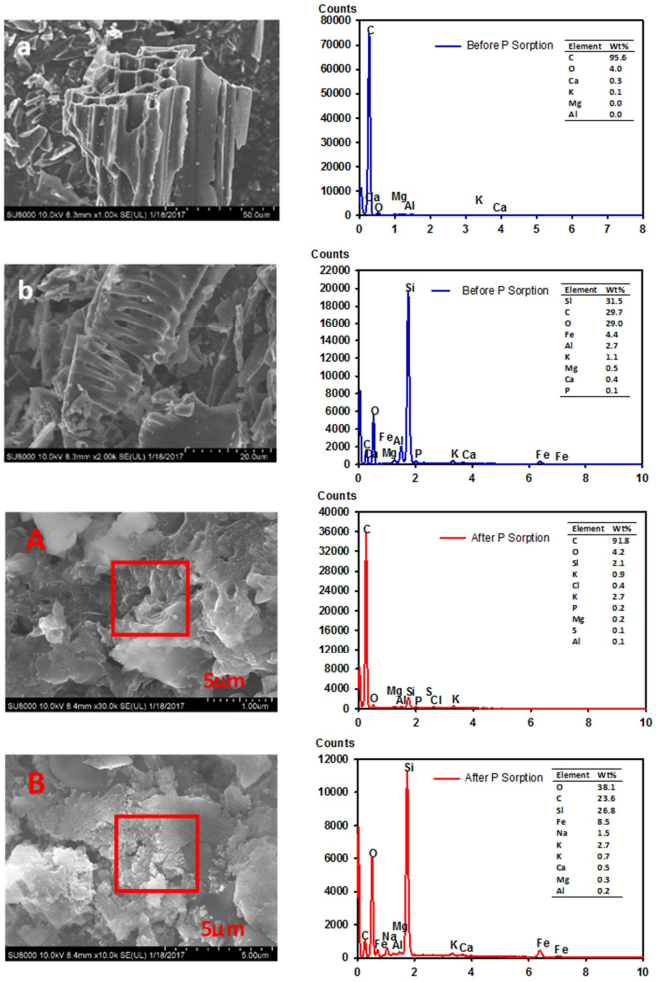

Supplementary Figure S2: Scanning Electronic Microscopy (SEM) and Energy-Dispersion X-ray Spectroscopy (EDS) images of biochar before and after Sorption (**a**) Wood biochar (WB) before sorption (**b**) Corn Cobs biochar (CB) before sorption, (**A**) Wood biochar (WB) after digestate nutrients enrichment (**B**) Corncobs (CB) after digestate nutrients enrichment.

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