Supplementary Online Material

Corn growth and nitrogen nutrition after additions of biochars with varying properties to a temperate soil

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Table S1 ANOVA results of total biomass production of corn amended with biochars made from different feedstock and under different production conditions

Effects	df Effect	MS Effect	df Error	MS Error	F value	*P*
Feedstock (F)	7	109.3	128	1.58	69.2	0.0000
Pyrolysis temperature (PT)	3	7.8	128	1.58	5.0	0.0028
Application rate (AR)	3	133.7	128	1.58	84.6	0.0000
F × PT	21	8.3	128	1.58	5.2	0.0000
F × AR	21	29.8	128	1.58	18.9	0.0000
PT × AR	9	3.5	128	1.58	2.2	0.00235
F × PT × AR	63	5.1	128	1.58	3.2	0.0000

Table S2 Mean separation of main effects from ANOVA results of total biomass production of corn amended with biochars made from different feedstock and under different production conditions; values followed by the same letter are not significantly different at *P*<0.05

	Mean	
Poultry manure	16.8	A
Corn stover	15.4	B
Hazelnut shells	14.3	C
Dairy manure	14.2	C
Oak	13.8	CD
Paper waste	13.7	CD
Pine	13.5	D
Food waste	10.3	E

	Mean	
500°C	14.4	A
600°C	14.	AB
400°C	13.8	BC
300°C	13.7	C

	Mean	
0.5%	14.9	A
0.2%	14.8	A
2%	14.5	A
7%	11.8	B

Table S3 ANOVA results of total N uptake of corn amended with biochars made from different feedstock and under different production conditions

Effects	df Effect	MS Effect	df Error	MS Error	F value	*P*
Feedstock (F)	7	6803	128	523.8	12.99	0.0000
Pyrolysis temperature (PT)	3	2557	128	523.8	4.88	0.0030
Application rate (AR)	3	21241	128	523.8	40.56	0.0000
F × PT	21	1970	128	523.8	3.76	0.0000
F × AR	21	4507	128	523.8	8.60	0.0000
PT × AR	9	484	128	523.8	0.51	0.5065
F × PT × AR	63	874	128	523.8	0.01	0.0076

Table S4 Mean separation of main effects from ANOVA results of total N uptake of corn amended with biochars made from different feedstock and under different production conditions; values followed by the same letter are not significantly different at $P<0.05$

	Mean	
Poultry manure	173.2	A
Corn stover	140.7	B
Hazelnut shells	138.8	B
Paper waste	137.3	B
Oak	136.0	B
Pine	135.1	B
Dairy manure	132.2	BC
Food waste	123.3	C

	Mean	
300°C	147.1	A
500°C	142.0	AB
400°C	136.4	BC
600°C	132.7	C

	Mean	
0.2%	153.4	A
0.5%	149.5	AB
2%	142.3	B
7%	113.1	C

Table S5 ANOVA results of tissue N concentration of corn amended with biochars made from different feedstock and under different production conditions

Effects	df Effect	MS Effect	df Error	MS Error	F value	*P*
Feedstock (F)	7	17.57	128	2.37	7.43	0.0000
Pyrolysis temperature (PT)	3	17.96	128	2.37	7.59	0.0001
Application rate (AR)	3	9.43	128	2.37	0.01	0.0093
F × PT	21	4.48	128	2.37	0.02	0.0163
F × AR	21	2.01	128	2.37	0.66	0.6560
PT × AR	9	0.88	128	2.37	0.95	0.9460
F × PT × AR	63	2.14	128	2.37	0.66	0.6664

Table S6 Mean separation of main effects from ANOVA results of tissue N concentration of corn amended with biochars made from different feedstock and under different production conditions; values followed by the same letter are not significantly different at $P<0.05$

	Mean	
Food waste	11.57	A
Poultry manure	10.32	B
Pine	9.99	BC
Paper waste	9.99	BC
Oak	9.82	BCD
Hazelnut shells	9.75	BCD
Dairy manure	0.29	CD
Corn stover	9.16	D

	Mean	
300°C	10.70	A
400°C	9.93	B
500°C	9.89	B
600°C	9.42	B

	Mean	
0.2%	10.44	A
0.5%	10.10	AB
2%	9.89	BC
7%	9.52	C

Table S7 Shoot-to-root ratios of corn with different biochars added in comparison to the control without biochar additions ($LSD_{0.05}$=1.25; N=2 for biochar amended soils; N=6 for control without biochar additions)

Biochar	Shoot-to-root ratios				
	Biochar application rates (w/w)				
	0.0%	0.2%	0.5%	2.0%	7.0%
Corn 300°C	2.77	1.77	3.06	3.51	2.38
Corn 400°C	2.77	2.06	3.38	3.81	3.01
Corn 500°C	2.77	2.30	2.10	2.83	3.29
Corn 600°C	2.77	2.23	2.00	2.98	4.46
Hazelnut 300°C	2.77	3.55	3.17	3.21	2.30
Hazelnut 400°C	2.77	2.23	3.24	2.31	3.35
Hazelnut 500°C	2.77	3.34	3.30	3.33	3.38
Hazelnut 600°C	2.77	2.35	4.12	2.86	3.13
Oak 300°C	2.77	2.21	2.60	3.23	2.16
Oak 400°C	2.77	1.97	3.15	3.71	2.07
Oak 500°C	2.77	3.11	3.40	3.42	3.73
Oak 600°C	2.77	2.97	2.15	2.63	2.70
Pine 300°C	2.77	2.07	4.19	3.56	3.09
Pine 400°C	2.77	3.45	2.83	3.66	2.39
Pine 500°C	2.77	2.75	3.05	2.06	3.36
Pine 600°C	2.77	2.90	2.52	3.18	3.36
Dairy Manure 300°C	2.77	3.33	3.55	4.10	4.11
Dairy Manure 400°C	2.77	2.81	2.27	3.37	3.71
Dairy Manure 500°C	2.77	2.51	3.85	3.74	4.14
Dairy Manure 600°C	2.77	2.73	4.63	4.01	2.80
Food Waste 300°C	2.77	2.15	2.64	4.86	2.60
Food Waste 400°C	2.77	2.97	3.20	3.57	2.94
Food Waste 500°C	2.77	3.14	3.51	2.30	3.41
Food Waste 600°C	2.77	3.41	3.20	2.49	2.06
Paper Waste 300°C	2.77	3.18	2.94	3.09	3.27
Paper Waste 400°C	2.77	3.72	2.96	3.51	2.94
Paper Waste 500°C	2.77	2.04	3.30	3.13	2.49
Paper Waste 600°C	2.77	4.05	3.84	2.70	3.02
Poultry 300°C	2.77	3.22	2.46	2.99	3.14
Poultry 400°C	2.77	2.72	2.99	3.49	3.18
Poultry 500°C	2.77	3.82	3.41	3.00	3.17
Poultry 600°C	2.77	2.16	2.85	3.00	3.11

Table S8 Description of biochar feedstocks, temperatures and production conditions for Fig. 4 in main manuscript (shown in the same order as in Fig. 4)

Label in Fig. 4	No. of reps	Feedstock	Production temp. (°C)	Thermal production condition	Reference
Poultry	3	Poultry manure	300-600	Fixed-bed gasification, 30-60 min contact time, 300 kg hr^{-1} capacity	Josh Frye, Lehmann and Joseph (2009)
Poultry	2	Poultry manure with sawdust	300	Slow pyrolysis	Main manuscript
Switchgrass	3	Total switchgrass ground	500	Fast pyrolysis, fluidized bed, 1 sec residence time, 0.2 sec contact time in bed, 5 kg hr^{-1} capacity	Boateng et al (2010)
Poultry	2	Poultry manure with sawdust	400	Slow pyrolysis	Main manuscript
Mixture	3	Poultry manure, sawdust, bentonite and kaolinite, crushed brick, cement kiln residue, blood and bone	240	Torrefaction, batch reactor, 8 hour residence time, 2 kg per batch	Stephen Joseph, Chee Chia (University of New South Wales)
Corn	3	Corn stover	515	Ablative-updraft pyrolysis, continuous feed, , 10 min contact time 19 kg hr^{-1} capacity	Das et al. (2009)

Corn	2	Corn stover	600	Slow pyrolysis	Main manuscript
Corn	2	Corn stover	400	Slow pyrolysis	Main manuscript
Softwood	3	Mixture of softwood shavings	450-500	Fast pyrolysis, bubbling fluidized bed, <5 sec contact time	Dynamotive
Corn	2	Corn stover	500	Slow pyrolysis	Main manuscript
Poultry	2	Poultry manure with sawdust	600	Slow pyrolysis	Main manuscript
Paper	2	Paper mill waste	600	Slow pyrolysis	Main manuscript
Rice husk	3	Rice husks	800	Gasification, 200 kg hr^{-1} capacity	
Peanut	3	Peanut shells	480	Ablative-updraft pyrolysis, continuous feed, , 10 min contact time 19 kg hr^{-1} capacity	Das et al. (2009)
Mixture	3	Poultry manure, sawdust, bentonite and kaolinite, crushed brick, cement kiln residue, blood and bone	220	Torrefaction, batch reactor, 8 hour residence time, 2 kg	Stephen Joseph, Chee Chia (University of New South Wales)
Dairy	2	Dairy manure, screw-pressed and digested	400	Slow pyrolysis	Main manuscript
Poultry	2	Poultry manure with sawdust	500	Slow pyrolysis	Main manuscript
Dairy	2	Dairy manure, screw-pressed and digested	300	Slow pyrolysis	Main manuscript
Soybean	3	Soybean crop	500	Fast pyrolysis,	Boateng et al

		residue, stalks		fluidized bed, 1 sec residence time, 0.2 sec contact time in bed, 5 kg hr^{-1} capacity	(2010)
Grass	2	Summer yard waste, mainly grass	500	Slow pyrolysis	Main manuscript
Dairy	2	Dairy manure, screw-pressed and digested	500	Slow pyrolysis	Main manuscript
Hazelnut	2	Hazelnut shells	400	Slow pyrolysis	Main manuscript
Hazelnut	2	Hazelnut shells	500	Slow pyrolysis	Main manuscript
Dairy	2	Dairy manure, screw-pressed and digested	600	Slow pyrolysis	Main manuscript
Oak	2	Oak wood	600	Slow pyrolysis	Main manuscript
Wood	3	Unidentified wood	450-500	Fast pyrolysis, bubbling fluidized bed, <5 sec contact time	Dynamotive
Bush	3	Winter yard waste, mainly brush	500	Slow pyrolysis	Main manuscript
Dairy	2	Dairy manure digested, screw pressed solids	500	Slow pyrolysis	Main manuscript
Pine	3	Pine wood chips	500	Fast/intermediate pyrolysis, auger, 15-30 sec contact time, 30 kg hr^{-1} capacity	Sergio Capareda (Texas A&M University)
Pine	2	Pine wood	500	Slow pyrolysis	Main manuscript
Dairy	3	Composted dairy manure	500	Slow pyrolysis	Main manuscript

Pine	3	Pine chips	700-750 for 1 min; 300-550 for 10 min	Updraft pyrolysis, 250 kg hr^{-1} capacity	BEC (2011)
Switchgrass	3	Switchgrass	500	Fast/intermediate pyrolysis, auger, 15-30 sec contact time, 30 kg hr^{-1} capacity	Sergio Capareda (Texas A&M University)
Hardwood	3	Mixed hardwood	450-500	Fast pyrolysis, bubbling fluidized bed, <5 sec contact time	Dynamotive
Kuikui	3	Kuikui and Macademia nut shells	400-500	Flash pyrolysis, 1.1 MPa pressure, batch reactor, appr. 0.5-2 hrs pyrolysis time, appr 1 kg capacity	Antal et al (2003)
Paper	2	Paper mill waste	300	Slow pyrolysis	Main manuscript
Pine	2	Pine wood	400	Slow pyrolysis	Main manuscript
Leaves	3	Yard waste collected in Fall, mainly leaves	500	Slow pyrolysis	Main manuscript
Oak	2	Oak wood	300	Slow pyrolysis	Main manuscript
Hazelnut	2	Hazelnut shells	300	Slow pyrolysis	Main manuscript
Paper	2	Paper mill waste	500	Slow pyrolysis	Main manuscript
Pine	2	Pine wood	300	Slow pyrolysis	Main manuscript
Corn	2	Corn stover	300	Slow pyrolysis	Main manuscript
Hazelnut	2	Hazelnut shells	600	Slow pyrolysis	Main manuscript
Oak	2	Oak wood	400	Slow pyrolysis	Main manuscript
Pine	2	Pine wood	600	Slow pyrolysis	Main manuscript
Control	6	No additions			
Paper	2	Paper mill waste	400	Slow pyrolysis	Main manuscript
Wood	2	Wood waste, mainly pallets	500	Slow pyrolysis	Main manuscript

Oak	2	Oak wood	500	Slow pyrolysis	Main manuscript
Food	2	Food waste	600	Slow pyrolysis	Main manuscript
Food	2	Food waste	500	Slow pyrolysis	Main manuscript
Coconut	3	Coconut shells	unknown	Batch carbonization, steam activation	PJAC, The Philippines, Product code: PJ2560-RSG
Food	2	Food waste	400	Slow pyrolysis	Main manuscript
Food	2	Food waste	300	Slow pyrolysis	Main manuscript

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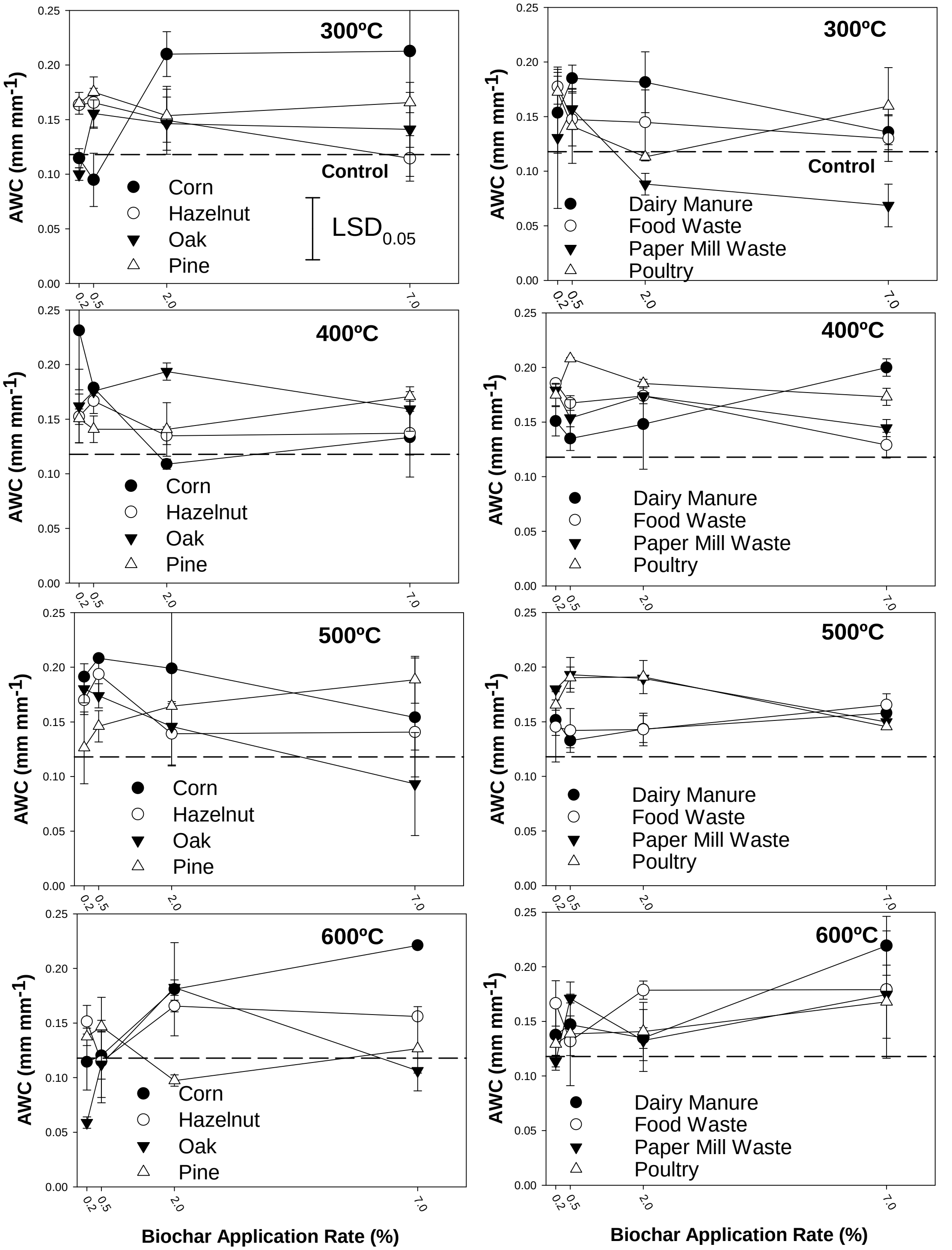

Fig. S1 Available water capacity (AWC) of soil amended with different biochars (symbols) in comparison to the control (dashed horizontal line) without biochar additions (means and standard errors; N=2 for biochar amended soils; N=6 for control without biochar additions; temperature refers to pyrolysis temperature; LSD is the least significant difference)

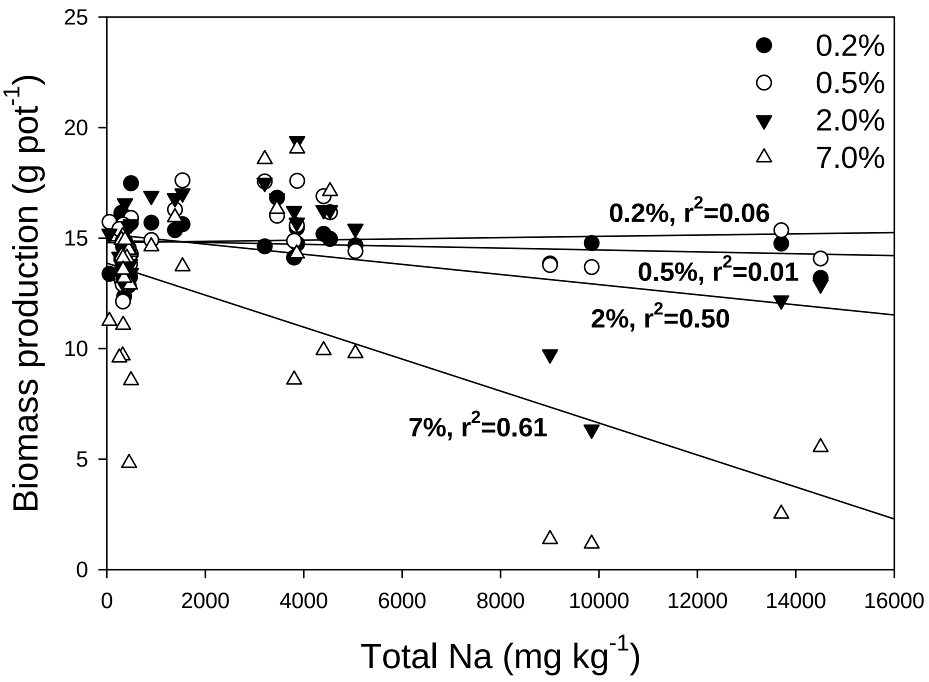

Fig. S2 Corn biomass production as a function of the total Na content of the biochar and the biochar application rate (N=32 for each correlation)