

Variation in feedstock wood chemistry strongly influences biochar liming potential

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Supplementary Table S1. Biochar pH and acidic surface functional groups for 19 temperate tree species pyrolyzed at temperatures of 300, 400, 500, 600, and 700 °C.

Species	Pyrolysis Temp (°C)	pH	Carbon (%)	Nitrogen (%)	Acidic Surface Functional Groups Concentration (mmol/g)		
					Carboxylic	Lactonic	Phenolic
<i>Abies balsamea</i>	300	7.58	70.098	0.382	0.226 (± 0.007)	0.272 (± 0.004)	0.048 (± 0.004)
	400	7.66	72.837	0.387	0.208 (± 0.006)	0.250 (± 0.016)	0.040 (± 0.002)
	500	8.17	83.354	0.470	0.106 (± 0.006)	0.016 (± 0.002)	0.057 (± 0.002)
	600	8.19	85.005	0.590	0.088 (± 0.003)	0.013 (± 0.001)	0.085 (± 0.004)
	700	9.29	87.357	0.622	0.074 (± 0.003)	0.015 (± 0.002)	0.106 (± 0.001)
<i>Picea glauca</i>	300	7.19	67.994	0.301	0.396 (± 0.143)	0.223 (± 0.002)	0.055 (± 0.003)
	400	7.22	76.119	0.316	0.137 (± 0.102)	0.241 (± 0.024)	0.054 (± 0.003)
	500	8.18	83.292	0.440	0.163 (± 0.002)	0.216 (± 0.002)	0.065 (± 0.001)
	600	8.00	87.986	0.366	0.044 (± 0.003)	0.046 (± 0.003)	0.075 (± 0.003)
	700	9.62	91.143	0.501	0.037 (± 0.001)	0.020 (± 0.005)	0.165 (± 0.002)
<i>Picea mariana</i>	300	7.32	69.555	0.364	0.320 (± 0.013)	0.274 (± 0.016)	0.044 (± 0.003)
	400	7.45	74.456	0.225	0.248 (± 0.009)	0.166 (± 0.004)	0.058 (± 0.006)
	500	7.97	83.726	0.247	0.220 (± 0.005)	0.164 (± 0.005)	0.084 (± 0.004)
	600	8.22	88.896	0.326	0.073 (± 0.005)	0.085 (± 0.003)	0.078 (± 0.001)
	700	8.58	90.433	0.442	0.034 (± 0.001)	0.036 (± 0.005)	0.095 (± 0.003)
<i>Picea rubens</i>	300	6.73	65.652	0.190	0.255 (± 0.004)	0.232 (± 0.001)	0.045 (± 0.002)
	400	6.91	74.360	0.210	0.255 (± 0.004)	0.234 (± 0.003)	0.050 (± 0.003)
	500	7.96	82.872	0.278	0.133 (± 0.010)	0.206 (± 0.006)	0.052 (± 0.003)
	600	7.89	87.995	0.390	0.092 (± 0.002)	0.069 (± 0.003)	0.068 (± 0.008)
	700	8.69	90.085	0.644	0.046 (± 0.005)	0.035 (± 0.004)	0.421 (± 0.048)
<i>Pinus resinosa</i>	300	6.56	65.332	0.136	0.211 (± 0.012)	0.025 (± 0.003)	0.037 (± 0.003)
	400	7.72	75.227	0.173	0.105 (± 0.001)	0.016 (± 0.001)	0.059 (± 0.008)
	500	7.96	82.188	0.230	0.104 (± 0.003)	0.017 (± 0.003)	0.066 (± 0.003)
	600	7.96	90.027	0.356	0.071 (± 0.002)	0.017 (± 0.002)	0.063 (± 0.004)
	700	8.42	91.166	0.461	0.075 (± 0.002)	0.013 (± 0.002)	0.116 (± 0.012)
<i>Pinus strobus</i>	300	7.01	62.726	0.099	0.205 (± 0.004)	0.034 (± 0.002)	0.043 (± 0.003)
	400	7.03	74.777	0.397	0.153 (± 0.002)	0.034 (± 0.004)	0.057 (± 0.005)
	500	7.77	82.387	0.252	0.144 (± 0.017)	0.024 (± 0.002)	0.073 (± 0.004)
	600	7.75	89.946	0.344	0.051 (± 0.012)	0.016 (± 0.002)	0.091 (± 0.003)
	700	9.25	85.861	0.493	0.064 (± 0.003)	0.014 (± 0.003)	0.443 (± 0.020)
<i>Pseudotsuga menziesii</i>	300	6.86	70.710	0.136	0.267 (± 0.018)	0.054 (± 0.002)	0.034 (± 0.003)
	400	7.17	75.870	0.126	0.253 (± 0.002)	0.044 (± 0.002)	0.054 (± 0.003)
	500	7.63	84.062	0.213	0.124 (± 0.003)	0.017 (± 0.001)	0.067 (± 0.002)
	600	8.01	90.107	0.353	N/A	N/A	N/A
	700	8.24	92.640	0.485	0.075 (± 0.002)	0.013 (± 0.001)	0.153 (± 0.002)
<i>Thuja occidentalis</i>	300	7.33	66.138	0.237	0.297 (± 0.001)	0.052 (± 0.002)	0.045 (± 0.002)
	400	7.37	73.171	0.258	0.294 (± 0.006)	0.046 (± 0.003)	0.051 (± 0.002)
	500	8.26	82.015	0.537	0.175 (± 0.001)	0.026 (± 0.002)	0.054 (± 0.001)
	600	8.56	87.984	0.373	0.135 (± 0.003)	0.025 (± 0.002)	0.067 (± 0.002)
	700	8.70	83.547	0.421	0.056 (± 0.001)	0.017 (± 0.006)	0.073 (± 0.006)
<i>Tsuga canadensis</i>	300	7.21	66.602	0.130	0.267 (± 0.003)	0.051 (± 0.002)	0.063 (± 0.003)
	400	6.68	74.811	0.154	0.249 (± 0.006)	0.056 (± 0.003)	0.086 (± 0.002)
	500	8.47	82.096	0.230	0.147 (± 0.006)	0.016 (± 0.001)	0.096 (± 0.004)
	600	8.66	89.304	0.307	0.085 (± 0.003)	0.012 (± 0.001)	0.125 (± 0.028)
	700	8.82	89.474	0.588	0.068 (± 0.002)	0.018 (± 0.009)	0.138 (± 0.001)
<i>Acer rubrum</i>	300	7.47	69.553	0.204	0.534 (± 0.035)	0.236 (± 0.002)	0.017 (± 0.002)
	400	7.51	76.778	0.256	N/A	N/A	N/A
	500	8.07	82.619	0.294	0.155 (± 0.002)	0.173 (± 0.004)	0.048 (± 0.001)
	600	8.35	86.804	0.368	N/A	N/A	N/A
	700	8.41	88.874	0.481	0.064 (± 0.005)	0.057 (± 0.003)	0.138 (± 0.002)
<i>Acer saccharum</i>	300	7.56	74.724	0.403	0.372 (± 0.015)	0.344 (± 0.037)	0.048 (± 0.002)
	400	7.72	N/A	N/A	N/A	N/A	N/A
	500	8.73	84.770	0.525	0.175 (± 0.001)	0.197 (± 0.002)	0.086 (± 0.002)
	600	8.91	N/A	N/A	N/A	N/A	N/A

	700	9.47	84.954	0.418	0.075 (± 0.016)	0.078 (± 0.005)	0.146 (± 0.002)
<i>Betula alleganiensis</i>	300	6.85	67.853	0.357	0.367 (± 0.024)	0.146 (± 0.003)	0.037 (± 0.002)
	400	6.95	71.851	0.389	0.306 (± 0.038)	0.263 (± 0.001)	0.057 (± 0.002)
	500	8.32	80.838	0.420	0.145 (± 0.003)	0.013 (± 0.001)	0.055 (± 0.003)
	600	8.54	86.485	0.473	0.078 (± 0.002)	0.020 (± 0.002)	0.071 (± 0.005)
	700	9.76	86.233	0.561	0.082 (± 0.002)	0.019 (± 0.006)	0.165 (± 0.002)
<i>Betula papyrifera</i>	300	7.42	68.723	0.333	0.438 (± 0.020)	0.165 (± 0.003)	0.055 (± 0.003)
	400	7.54	68.690	0.272	0.467 (± 0.005)	0.268 (± 0.002)	0.077 (± 0.002)
	500	8.33	81.255	0.411	0.278 (± 0.027)	0.145 (± 0.003)	0.088 (± 0.001)
	600	8.32	83.364	0.449	0.164 (± 0.019)	0.075 (± 0.002)	0.098 (± 0.002)
	700	9.14	84.214	0.398	0.086 (± 0.004)	0.040 (± 0.005)	0.156 (± 0.004)
<i>Fagus grandifolia</i>	300	7.52	61.978	0.173	0.497 (± 0.022)	0.196 (± 0.003)	0.035 (± 0.002)
	400	7.67	64.826	0.366	0.242 (± 0.001)	0.250 (± 0.008)	0.045 (± 0.002)
	500	8.22	79.902	0.287	0.156 (± 0.002)	0.125 (± 0.002)	0.054 (± 0.003)
	600	7.96	83.475	0.309	0.065 (± 0.004)	0.065 (± 0.002)	0.174 (± 0.004)
	700	9.52	87.210	0.620	0.084 (± 0.001)	0.083 (± 0.005)	0.194 (± 0.002)
<i>Fraxinus americana</i>	300	7.54	67.754	0.454	0.494 (± 0.001)	0.278 (± 0.001)	0.048 (± 0.001)
	400	7.79	N/A	N/A	N/A	N/A	N/A
	500	8.59	80.287	0.552	0.175 (± 0.001)	0.155 (± 0.004)	0.104 (± 0.001)
	600	8.61	87.376	0.621	N/A	N/A	N/A
	700	8.70	86.377	0.530	0.088 (± 0.003)	0.029 (± 0.001)	0.245 (± 0.004)
<i>Ostrya virginiana</i>	300	7.09	65.744	0.501	0.547 (± 0.004)	0.433 (± 0.002)	0.098 (± 0.001)
	400	7.22	71.000	0.557	0.523 (± 0.000)	0.332 (± 0.002)	0.135 (± 0.002)
	500	8.53	80.139	0.659	0.218 (± 0.025)	0.224 (± 0.015)	0.244 (± 0.003)
	600	8.92	82.931	0.716	0.164 (± 0.001)	0.124 (± 0.002)	0.396 (± 0.034)
	700	9.31	84.034	0.653	0.086 (± 0.003)	0.025 (± 0.003)	0.326 (± 0.012)
<i>Prunus serotina</i>	300	7.33	66.591	0.497	0.375 (± 0.001)	0.375 (± 0.002)	0.050 (± 0.004)
	400	7.54	74.062	0.563	0.344 (± 0.003)	0.296 (± 0.003)	0.047 (± 0.002)
	500	8.19	79.562	0.619	0.144 (± 0.002)	0.168 (± 0.001)	0.047 (± 0.003)
	600	8.22	84.427	0.721	0.096 (± 0.003)	0.049 (± 0.002)	0.148 (± 0.011)
	700	9.23	87.895	0.777	0.065 (± 0.001)	0.067 (± 0.001)	0.183 (± 0.003)
<i>Quercus rubra</i>	300	7.25	67.540	0.381	0.458 (± 0.015)	0.244 (± 0.004)	0.037 (± 0.002)
	400	7.34	73.016	0.421	0.427 (± 0.022)	0.254 (± 0.003)	0.045 (± 0.002)
	500	8.5	81.376	0.486	0.361 (± 0.007)	0.120 (± 0.009)	0.056 (± 0.002)
	600	8.61	84.691	0.548	0.208 (± 0.009)	0.056 (± 0.002)	0.073 (± 0.002)
	700	8.94	86.470	0.594	0.145 (± 0.002)	0.034 (± 0.004)	0.097 (± 0.003)
<i>Tilia americana</i>	300	8.85	68.482	0.546	0.580 (± 0.036)	0.426 (± 0.016)	0.045 (± 0.001)
	400	8.84	70.127	0.818	0.464 (± 0.029)	0.323 (± 0.007)	0.052 (± 0.003)
	500	9.25	80.513	0.646	0.029 (± 0.007)	0.217 (± 0.000)	0.069 (± 0.005)
	600	9.32	82.809	0.651	0.034 (± 0.004)	0.216 (± 0.002)	0.125 (± 0.003)
	700	10.38	86.304	0.775	0.023 (± 0.002)	0.021 (± 0.001)	0.145 (± 0.002)

(Note: Numbers in brackets refer to standard deviation of three replicates.)

Supplementary Table S2. Soil + Biochar pH over the course of 18 incubation days for 19 temperate tree species pyrolyzed at temperatures of 300, 400, 500, 600, and 700 °C.

Species	Pyrolysis Temp (°C)	Soil + biochar incubation pH					
		Day 1	Day 3	Day 5	Day 8	Day 11	Day 18
<i>Abies balsamea</i>	300	5.47	5.51	5.63	6.13	6.42	7.21
	400	5.47	5.46	5.51	6.37	6.35	7.40
	500	5.30	5.36	5.65	6.33	6.59	7.43
	600	5.38	5.39	5.71	6.71	6.81	7.50
	700	5.97	5.80	5.81	6.41	6.85	7.55
<i>Picea glauca</i>	300	5.38	5.52	5.62	6.02	6.19	6.99
	400	5.21	5.39	5.61	6.12	5.82	7.17
	500	5.55	5.57	5.66	6.32	6.52	7.29
	600	5.54	5.46	5.86	6.31	6.58	7.35
	700	5.39	5.46	5.73	6.49	6.77	7.52
<i>Picea mariana</i>	300	5.27	4.86	5.44	6.13	6.31	6.79
	400	5.51	5.60	5.50	6.20	6.37	7.30
	500	5.36	5.38	5.63	6.40	6.55	7.45
	600	5.68	5.66	5.73	6.31	6.62	7.61
	700	5.50	5.14	5.78	6.66	6.71	7.55
<i>Picea rubens</i>	300	5.16	5.23	5.39	5.98	6.14	7.18
	400	5.71	5.69	5.60	6.32	6.37	7.36
	500	5.53	5.30	5.67	6.42	6.56	7.40
	600	5.55	5.29	5.89	6.49	6.57	7.49
	700	5.70	5.53	5.84	6.51	6.65	7.60
<i>Pinus resinosa</i>	300	5.27	5.45	5.38	6.08	6.16	7.42
	400	5.19	5.30	5.57	6.20	6.35	7.45
	500	5.37	5.51	5.86	6.36	6.42	7.52
	600	5.31	5.42	6.04	6.34	6.57	7.53
	700	5.41	5.54	6.35	6.69	6.74	7.58
<i>Pinus strobus</i>	300	4.93	5.17	5.44	6.11	6.37	7.34
	400	5.28	5.38	5.53	6.20	6.45	7.43
	500	5.06	5.53	5.71	6.24	6.50	7.56
	600	5.27	5.61	5.73	6.47	6.53	7.61
	700	5.48	5.41	5.73	6.47	6.57	7.68
<i>Pseudotsuga menziesii</i>	300	5.00	5.22	5.51	6.23	6.49	7.25
	400	4.95	5.23	5.44	6.34	6.52	7.25
	500	5.57	5.51	5.64	6.47	6.58	7.47
	600	5.02	5.20	5.70	6.42	6.61	7.55
	700	5.47	5.50	5.83	6.65	6.66	7.56
<i>Thuja occidentalis</i>	300	5.30	5.31	5.48	6.20	6.36	7.39
	400	5.37	5.40	5.66	6.30	6.40	7.50
	500	5.80	5.68	5.78	6.40	6.51	7.49
	600	5.44	5.57	5.77	6.46	6.49	7.56
	700	5.71	5.66	5.83	6.53	6.49	7.60
<i>Tsuga canadensis</i>	300	5.27	5.34	5.54	6.25	6.41	7.36
	400	5.20	5.12	5.61	6.34	6.40	7.36
	500	5.75	5.73	5.73	6.44	6.49	7.40
	600	5.51	5.50	5.74	6.43	6.51	7.44
	700	5.56	5.56	5.82	6.47	6.27	7.52
<i>Acer rubrum</i>	300	4.63	4.70	5.41	6.28	6.55	7.41
	400	NA	NA	NA	NA	NA	NA
	500	5.54	5.31	5.58	6.46	6.71	7.43
	600	NA	NA	NA	NA	NA	NA
	700	5.37	5.30	5.71	6.65	6.79	7.64
<i>Acer saccharum</i>	300	5.05	4.99	5.50	6.25	6.42	7.38
	400	NA	NA	NA	NA	NA	NA
	500	5.29	5.38	5.64	6.53	6.57	7.57
	600	NA	NA	NA	NA	NA	NA
	700	5.59	5.59	5.85	6.46	6.60	7.58
<i>Betula alleghaniensis</i>	300	5.01	5.03	5.53	6.35	6.36	6.80
	400	4.97	5.17	5.71	6.49	6.41	7.27
	500	5.09	5.19	5.56	6.53	6.42	7.54
	600	5.18	5.27	5.63	6.44	6.47	7.53
	700	5.68	5.56	5.72	6.24	6.51	8.05
<i>Betula papyrifera</i>	300	5.13	5.23	5.38	6.40	6.39	7.22
	400	5.28	5.30	5.68	6.42	6.44	7.40
	500	5.05	5.26	5.68	6.52	6.52	7.52

	600	5.26	5.51	5.81	6.56	6.52	7.68
	700	5.37	5.47	5.83	6.56	6.57	7.60
<i>Fagus grandifolia</i>	300	5.09	5.18	5.59	6.12	6.31	7.30
	400	5.58	5.59	5.58	6.28	6.36	7.38
	500	4.91	5.71	5.70	6.41	6.42	7.56
	600	5.24	5.64	5.79	6.49	6.52	7.66
	700	5.82	5.82	5.84	6.54	6.60	7.69
<i>Fraxinus americana</i>	300	5.13	5.30	5.49	6.35	6.34	7.24
	400	NA	NA	NA	NA	NA	NA
	500	5.70	5.71	5.72	6.54	6.36	7.34
	600	NA	NA	NA	NA	NA	NA
	700	5.45	5.60	5.70	6.67	6.52	7.31
<i>Ostrya virginiana</i>	300	5.20	5.22	5.44	6.23	6.27	6.84
	400	4.90	5.29	5.45	6.11	6.37	7.22
	500	4.66	5.12	5.63	6.38	6.45	7.28
	600	5.16	5.26	5.61	6.43	6.48	7.36
	700	5.49	5.42	5.70	6.61	6.53	7.45
<i>Prunus serotina</i>	300	4.93	4.94	5.13	6.17	6.26	6.94
	400	5.43	5.24	5.41	6.26	6.34	6.84
	500	5.60	5.58	5.62	6.37	6.39	7.14
	600	5.52	5.60	5.60	6.49	6.43	7.31
	700	5.52	5.86	6.09	6.53	6.47	7.47
<i>Quercus rubra</i>	300	5.08	5.17	5.53	6.28	6.41	7.28
	400	5.29	5.45	5.52	6.37	6.46	7.35
	500	5.21	5.35	5.66	6.41	6.50	7.50
	600	5.63	5.47	6.05	6.46	6.55	7.57
	700	5.37	5.49	5.94	6.52	6.58	7.63
<i>Tilia americana</i>	300	5.31	5.31	5.48	6.28	6.41	7.25
	400	5.57	5.57	5.54	6.31	6.44	7.38
	500	5.61	5.61	5.85	6.40	6.53	7.47
	600	5.62	5.62	6.05	5.49	6.49	7.59
	700	5.50	5.50	6.04	6.53	6.58	7.60

Supplementary Table S3. Comparison of non-linear models predicting pH as a function of char chemistry in 84 slow pyrolysis wood biochars.

Equation	AIC	ΔAIC
Models with acidic functional groups and base metals:		
$\text{pH} = \phi + \alpha(1 - \exp(-\beta \cdot \text{ctpr} - \gamma \cdot \text{Ca} - \varepsilon \cdot \text{K}))$	115.3495	0
$\text{pH} = \phi + \alpha(1 - \exp(-\beta \cdot \text{ctpr} - \gamma \cdot \text{Ca} - \delta \cdot \text{Mg} - \varepsilon \cdot \text{K}))$	116.1872	0.8377
$\text{pH} = \phi + \alpha(1 - \exp(-\beta \cdot \text{ctpr} - \gamma \cdot \text{Ca} - \varepsilon \cdot \text{K}))$	116.9567	1.6072
$\text{pH} = \phi + \alpha(1 - \exp(-\beta \cdot \text{ctpr} - \gamma \cdot (\text{Ca} + \text{Mg} + \text{K})))$	123.1562	7.8067
$\text{pH} = \phi + \alpha(1 - \exp(-\beta \cdot \text{ctpr} - \gamma \gamma \cdot \text{Ca}))$	130.4285	15.079
$\text{pH} = \phi + \alpha(1 - \exp(-\beta \cdot \text{ctpr} - \gamma \cdot \text{Ca} - \delta \cdot \text{Mg}))$	132.1304	16.7809
Models with acidic functional groups only:		
$\text{pH} = \phi + \alpha(1 - \exp(-\beta \cdot \text{ctpr}))$	141.2979	25.9484
$\text{pH} = \phi + \alpha(1 - \exp(-\beta \cdot \text{ctpr} - \gamma \cdot \text{lactonic}))$	142.2560	26.9065
$\text{pH} = \phi + \alpha(1 - \exp(-\beta \cdot 1/\text{carboxylic} - \gamma \cdot \text{phenolic}))$	151.9256	36.5761
$\text{pH} = \phi + \alpha(1 - \exp(-\beta \cdot \text{ctplr}))$	160.1787	44.8292
$\text{pH} = \phi + \alpha(1 - \exp(-\beta \cdot 1/\text{carboxylic}))$	162.1772	46.8277
Models with base metals only:		

$\text{pH} = \phi + \alpha (1 - \exp(-\gamma \cdot \text{Ca} - \delta \cdot \text{Mg} - \varepsilon \cdot \text{K}))$	184.0708	68.7213
$\text{pH} = \phi + \alpha (1 - \exp(-\varepsilon \cdot \text{K}))$	185.1190	69.7695
$\text{pH} = \phi + \alpha (1 - \exp(-\gamma \cdot (\text{Ca} + \text{Mg})))$	189.0413	73.6918
$\text{pH} = \phi + \alpha (1 - \exp(-\gamma \cdot \text{Ca}))$	189.9004	74.5509

Note: ctp_r = carboxylic to phenolic ratio; ctpl_r = carboxylic to (phenolic plus lactonic) ratio.

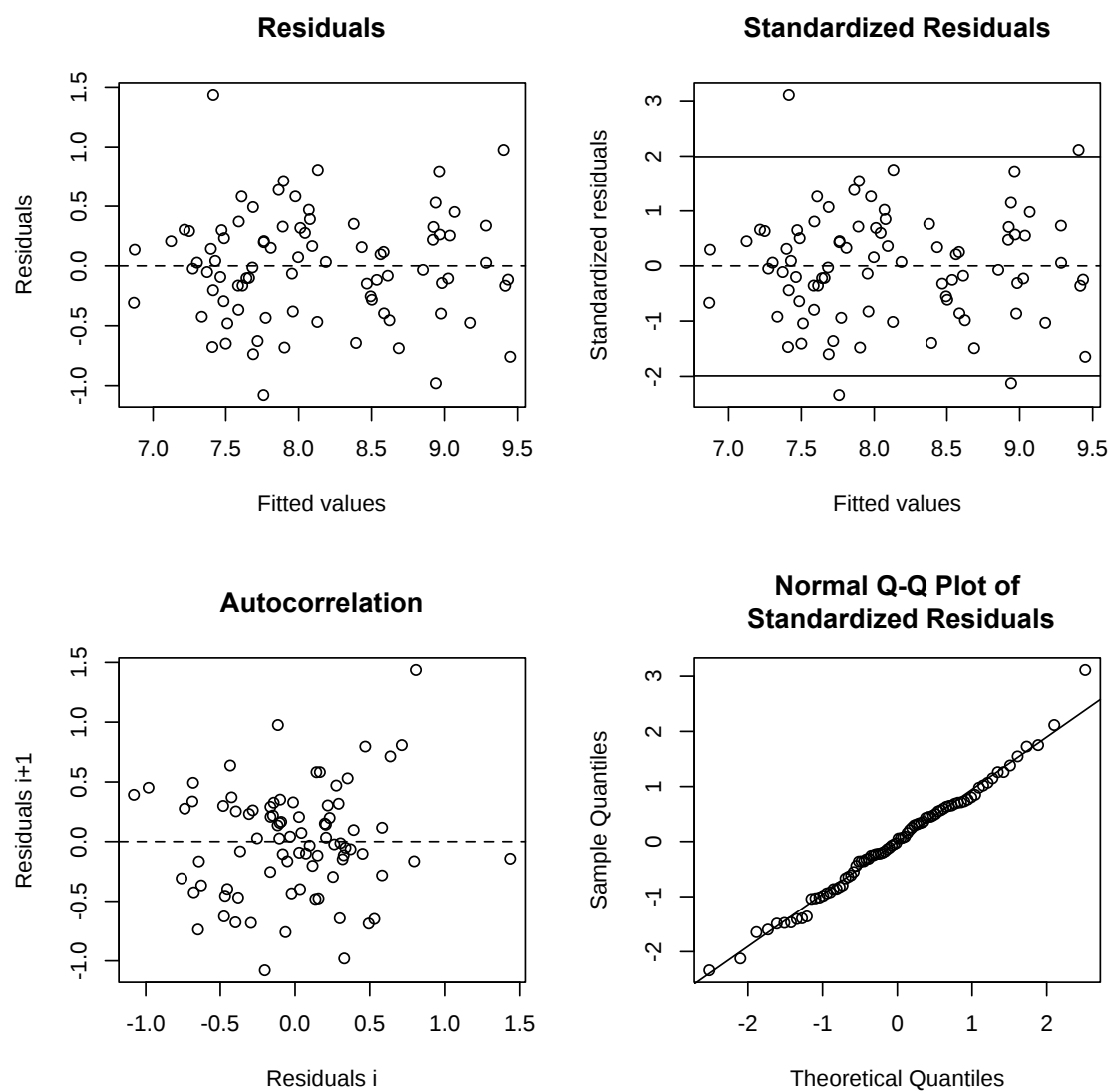


Fig. S1. Residuals plots for the lowest AIC model predicting pH as a function of char chemistry in 84 slow pyrolysis wood chars.

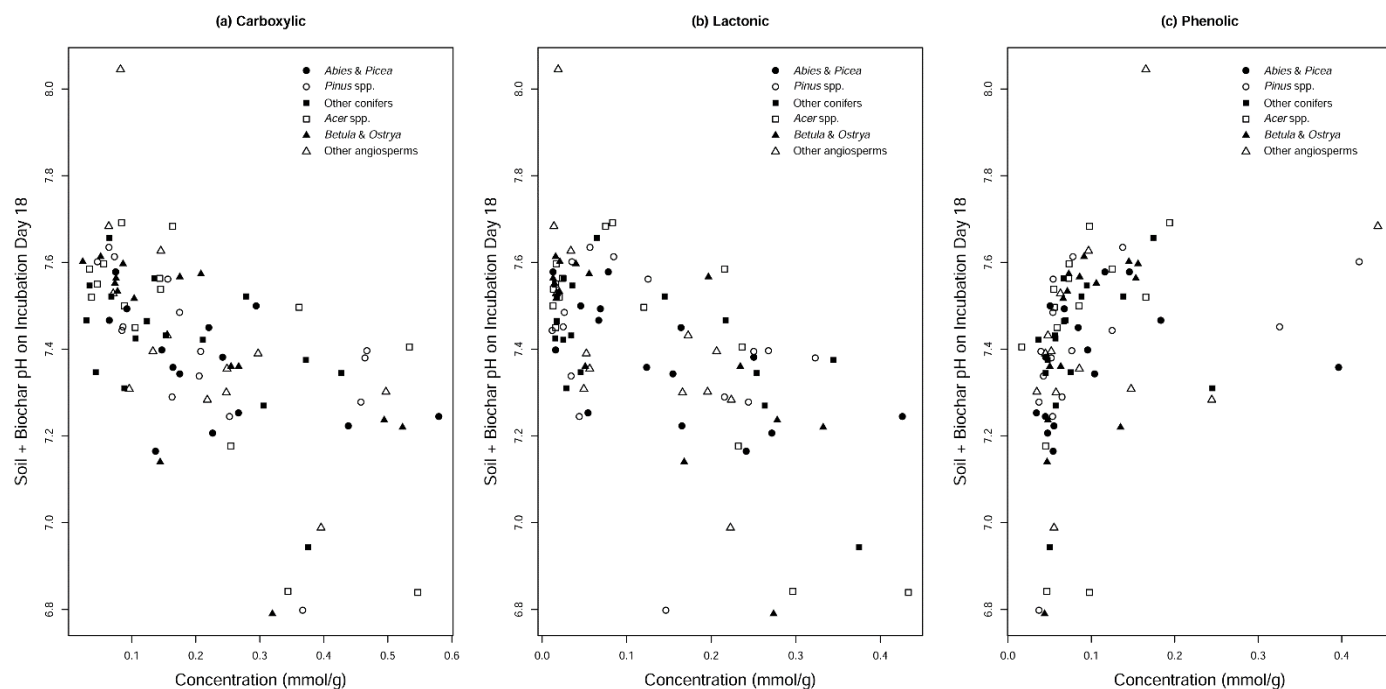


Fig. S2. Liming potential of biochar as a function of carboxylic, lactonic and phenolic surface functional groups in 19 temperate tree species (grouped by six species): conifer species ($n = 9$) and angiosperm species ($n = 10$).