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Effects of biochar-based composite amendments on nitrogen migration and enzymatic activities in high-nitrogen soils

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Electronic Supplementary Material (ESM)

The authors are fully responsible for both the content and the formal aspects of the electronic supplementary material. No editorial adjustments were made.

Table S1. Cabbage and other soil physical and chemical properties

Treatments	pH	EC（uS/cm）	Soil organic matter (g/kg)	water content (%)	Nitrogen concentration in cabbage (%)
CK	6.56±0.03	461.33±3.06	25.44±3.35	35.32±2.74	2.58±0.003
CSB1	7.11±0.03***	505.00±2.65***	26.95±1.41	39.78±1.95	2.98±0.003**
CSB2	7.17±0.01***	526.33±3.06***	25.69±0.68	39.93±6.28	3.01±0.012**
CSB3	7.22±0.01***	546.00±4.36***	33.79±0.82***	42.07±3.47	3.08±0.003***
CSB4	7.27±0.01***	513.33±1.53***	26.83±3.21	44.86±1.88**	3.66±0.003***
CSB5	7.31±0.01***	564.33±3.06***	26.67±2.08	39.61±1.39	4.28±0.009***
CSB6	7.23±0.01***	551.67±0.58***	35.87±1.82***	42.24±4.19	2.86±0.003***
RHB1	6.84±0.04***	426.67±0.58***	27.75±4.16	37.58±3.08	2.71±0.003
RHB2	6.94±0.03***	447.33±4.73	26.00±1.54	42.03±2.44	2.73±0.005
RHB3	7.01±0.01***	455.33±4.04*	25.85±0.54	39.72±1.65	2.63±0.007
RHB4	7.06±0.01***	464.67±2.52	31.28±1.76**	42.89±2.39	2.95±0.005
RHB5	7.11±0.01***	485.67±3.06***	27.28±1.11	42.12±0.52	2.97±0.007*
RHB6	7.15±0.01***	493.67±2.08***	29.44±0.82	42.24±4.19	2.86±0.008
BB1	7.06±0.01***	464.67±2.52***	27.54±0.25	37.31±3.97	2.35±0.53
BB2	7.11±0.01***	485.67±3.51***	30.69±0.29*	39.88±1.31	2.72±0.003
BB3	7.15±0.01***	493.67±2.08	28.14±0.89	40.11±4.04	2.86±0.005
BB4	6.95±0.03***	474.33±0.58***	26.67±1.37	37.83±2.95	2.93±0.005
BB5	7.04±0.02***	483.67±3.06***	28.55±1.89	37.83±4.91	2.95±0.004*
BB6	6.74±0.01***	467.00±1.00	27.47±0.70	35.63±3.27	2.86±0.004**
Concentration	***	***	ns	ns	***
Types	***	***	ns	**	***
Ratios	***	***	***	ns	***
Concentration *Types	***	***	**	ns	***
Concentration *Ratios	***	***	ns	*	ns
Types*Ratios	***	***	***	ns	**
Concentration *Types*Ratios	***	***	ns	ns	***

All indices were subjected to Dunnett's ANOVA, and three-way ANOVA was applied to evaluate main and interactive effects. ns, no significant difference; *, $P<0.05$; **, $P<0.01$; ***, $P<0.001$.

Table S2. Three-ways ANOVA of the effects of biochar type, ratio, and application rate on soil total nitrogen content

Source	*SS*	*df*	*Mean Square*	*F*	*p*	*Partial* η^2
Concentration	0.008	1	0.008	0.862	0.359	0.023
Types	0.983	2	0.492	51.976	<0.001	0.743
Ratios	0.353	2	0.177	18.68	<0.001	0.509
Concentration *Types	0.003	2	0.001	0.158	0.855	0.009
Concentration *Ratios	0.016	2	0.008	0.862	0.431	0.046
Types*Ratios	0.013	4	0.003	0.349	0.843	0.037
Concentration *Types*Ratios	0.019	4	0.005	0.492	0.742	0.052
Error	0.341	36	0.009			
Total	41.729	54				

Table S3. Three-ways ANOVA of the effects of biochar type, ratio, and application rate on soil nitrate nitrogen content

Source	*SS*	*df*	*Mean Square*	*F*	*p*	*Partial* η^2
Concentration	86.324	1	86.324	1.618	0.212	0.043
Types	6783.514	2	3391.757	63.573	<0.001	0.779
Ratios	2982.955	2	1491.477	27.956	<0.001	0.608
Concentration *Types	495.488	2	247.744	4.644	0.016	0.205
Concentration *Ratios	17.633	2	8.816	0.165	0.848	0.009
Types*Ratios	295.128	4	73.782	1.383	0.259	0.133
Concentration *Types*Ratios	268.692	4	67.173	1.259	0.304	0.123
Error	1920.665	36	53.352			
Total	469875.303	54				

Table S4. Simple effect analysis of the interaction between concentration and material on soil nitrate nitrogen content

Concentration level	comparison object	Standard Deviation	Standard Error of the Mean	*p*
2.5%	CSBvsRHB	11.52	3.443	0.006
	CSBvsBB	22.69	3.443	<0.001
	RHBvsBB	11.17	3.443	0.008
5%	CSBvsRHB	26.344	3.443	<0.001
	CSBvsBB	30.679	3.443	<0.001
	RHBvsBB	4.334	3.443	0.649
Types level				
CSB	2.5%vs5%	10.133	3.443	0.006
RHB	2.5%vs5%	4.692	3.443	0.181
BB	2.5%vs5%	2.144	3.443	0.537

Table S5. Three-ways ANOVA of the effects of biochar material, ratio and application rate on soil ammonium nitrogen content

Source	*SS*	*df*	*Mean Square*	*F*	*p*	*Partial* η^2
Concentration	62.93	1	62.93	30.035	<0.001	0.455
Types	694.12	2	347.06	165.646	<0.001	0.902
Ratios	57.21	2	28.605	13.653	<0.001	0.431
Concentration *Types	131.421	2	65.711	31.362	<0.001	0.635
Concentration *Ratios	0.44	2	0.22	0.105	0.901	0.006
Types*Ratios	11.519	4	2.88	1.374	0.262	0.132
Concentration *Types*Ratios	4.634	4	1.159	0.553	0.698	0.058
Error	75.427	36	2.095			
Total	25104.212	54				

Table S6. Simple effect analysis of the interaction between concentration and material on soil ammonium nitrogen content

Concentration level	comparison object	Standard Deviation	Standard Error of the Mean	*p*
	CSBvsRHB	1.742	0.682	0.045
2.5%	CSBvsBB	5.549	0.682	<0.001
	RHBvsBB	3.807	0.682	0.045
	CSBvsRHB	8.585	0.682	<0.001
5%	CSBvsBB	11.918	0.682	<0.001
	RHBvsBB	3.333	0.682	<0.001
Types level				
CSB	2.5%vs5%	6.563	0.682	<0.001
RHB	2.5%vs5%	0.280	0.682	0.684
BB	2.5%vs5%	0.194	0.682	0.778

Table S7. Three-ways ANOVA of the effects of biochar concentration, material type and ratio on soil urease activity

Source	*SS*	*df*	*Mean Square*	*F*	*p*	*Partial* η^2
Concentration	7611.757	1	7611.757	666.586	<0.001	0.949
Types	13381.939	2	6690.97	585.949	<0.001	0.97
Ratios	4370.17	2	2185.085	191.355	<0.001	0.914
Concentration *Types	674.251	2	337.125	29.523	<0.001	0.621
Concentration *Ratios	160.954	2	80.477	7.048	0.003	0.281
Types*Ratios	342.841	4	85.71	7.506	<0.001	0.455
Concentration *Types*Ratios	297.201	4	74.3	6.507	<0.001	0.42
Error	411.085	36	11.419			
Total	4218486.31	54				

Table S8. Analysis of interaction effects under fixed ratio

Ratios	Source	*SS*	*df*	*Mean Square*	*F*	*p*	*Partial* η^2
1:1:1	Concentration	1601.025	1	1601.025	73.716	<0.001	0.86
	Types	6303.15	2	3151.575	145.108	<0.001	0.96
	Concentration *Types	455.683	2	227.841	10.491	0.002	0.636
	Error	260.625	12	21.719			
	Total	1290327.718	18				
2:1:1	Concentration	3094.222	1	3094.222	388.227	<0.001	0.97
	Types	4307.843	2	2153.921	270.249	<0.001	0.978
	Concentration *Types	127.022	2	63.511	7.969	0.006	0.57
	Error	95.642	12	7.97			
	Total	1421334.643	18				
3:1:1	Concentration	3077.463	1	3077.463	673.674	<0.001	0.982
	Types	3113.788	2	1556.894	340.813	<0.001	0.983
	Concentration *Types	388.747	2	194.374	42.55	<0.001	0.876
	Error	54.818	12	4.568			
	Total	1506823.949	18				

Table S9. Three-ways ANOVA of the effects of biochar concentration, material type and ratio on soil leucine aminopeptidase activity

Source	*SS*	*df*	*Mean Square*	*F*	*p*	*Partial* η^2
Concentration	5222.178	1	5222.178	112.799	<0.001	0.758
Types	11613.93	2	5806.965	125.43	<0.001	0.875
Ratios	3676.95	2	1838.475	39.711	<0.001	0.688
Concentration *Types	2707.205	2	1353.602	29.238	<0.001	0.619
Concentration *Ratios	311.908	2	155.954	3.369	0.046	0.158
Types*Ratios	863.61	4	215.903	4.663	0.004	0.341
Concentration *Types*Ratios	637.028	4	159.257	3.44	0.018	0.277
Error	1666.667	36	46.296			
Total	2676229.013	54				

Table S10. Analysis of interaction effects under fixed ratio

Ratios	Source	*SS*	*df*	*Mean Square*	*F*	*p*	*Partial* η^2
1:1:1	Concentration	809.222	1	809.222	9.959	0.008	0.454
	Types	2691.241	2	1345.62	16.561	<0.001	0.734
	Concentration *Types	453.164	2	226.582	2.789	0.101	0.317
	Error	975.03	12	81.252			
	Total	802208.323	18				
2:1:1	Concentration	2834.093	1	2834.093	98.063	<0.001	0.891
	Types	3408.971	2	1704.485	58.977	<0.001	0.908
	Concentration *Types	931.761	2	465.881	16.12	<0.001	0.729
	Error	346.809	12	28.901			
	Total	908867.658	18				
3:1:1	Concentration	1890.772	1	1890.772	65.799	<0.001	0.846
	Types	6377.329	2	3188.664	110.966	<0.001	0.949
	Concentration *Types	1959.308	2	979.654	34.092	<0.001	0.85
	Error	344.828	12	28.736			
	Total	965153.032	18				

Table S11. Three-ways ANOVA of the effects of biochar concentration, material type and ratio on soil peroxidase activity

Source	*SS*	*df*	*Mean Square*	*F*	*p*	*Partial* η^2
Concentration	189991.877	1	189991.877	2272.209	<0.001	0.984
Types	115711.138	2	57855.569	691.924	<0.001	0.975
Ratios	145573.238	2	72786.619	870.492	<0.001	0.98
Concentration *Types	668.112	2	334.056	3.995	0.027	0.182
Concentration *Ratios	451000.916	2	225500.458	2696.874	<0.001	0.993
Types*Ratios	1801.116	4	450.279	5.385	0.002	0.374
Concentration *Types*Ratios	8799.923	4	2199.981	26.311	<0.001	0.745
Error	3010.158	36	83.616			
Total	12722075.24	54				

Table S12. Analysis of interaction effects under fixed ratio

Ratios	Source	*SS*	*df*	*Mean Square*	*F*	*p*	*Partial* η^2
1:1:1	Concentration	11050.641	1	11050.641	75.836	<0.001	0.863
	Types	32949.379	2	16474.689	113.058	<0.001	0.95
	Concentration *Types	711.138	2	355.569	2.44	0.129	0.289
	Error	1748.619	12	145.718			
	Total	3047266.344	18				
2:1:1	Concentration	625119.648	1	625119.648	13629.035	<0.001	0.999
	Types	35452.161	2	17726.081	386.469	<0.001	0.985
	Concentration *Types	4038.71	2	2019.355	44.027	<0.001	0.88
	Error	550.401	12	45.867			
	Total	5812271.915	18				
3:1:1	Concentration	4822.504	1	4822.504	81.377	<0.001	0.871
	Types	49110.713	2	24555.357	414.356	<0.001	0.986
	Concentration *Types	4718.187	2	2359.094	39.808	<0.001	0.869
	Error	711.138	12	59.261			
	Total	3862536.981	18				