Supplementary Materials

In accordance with Lu (1999) [69], soil texture was measured using pipette analysis, and soil moisture content was measured by drying 10 g soil at 105 ℃ for 24 h to a constant weight. Soil bulk density (BD) was measured by collecting undisturbed soil cores using a 100 cm^3 cutting ring from a depth of 0-20 cm after harvest. Soil pH and electric conductivity (EC) were measured in a 1:5 ratio of soil to deionized water with a pH meter (PHS-3C, Shanghai) and a Mettler Toledo instrument (FE30-K, Shanghai, China). The SOC content was determined by wet digestion with potassium dichromate, and total N was analyzed by the Kjeldahl method. The soil total P contents were determined by the molybdenum antimony colorimetric method after digestion with an H_2SO_4 + $HClO_4$ solution. Soil cation exchange capacity (CEC) was measured using hexamminecobalt trichloride and was expressed in cmol kg^{-1}. Soil dissolved organic C (DOC) and N (DON) contents were determined using a multi N/C 3100 analyzer (Jena TOC Analyzer, Germany). Briefly, DOC and DON were extracted by adding 25 mL H_2O to 5 g moist soil, shaking for 1 h followed by centrifuging at 4000 rpm for 20 min, and then the supernatant was filtered through a 0.45 μm membrane. Soil microbial biomass C (MBC) and N (MBN) were determined by using the chloroform fumigation extraction method (Shen, et al., 2021) [70]. Briefly, MBC and MBN were extracted with 0.50 M K_2SO_4 for 30 min (10 g soil with 50 mL solution) and subsequently measured on a multi N/C 3100 analyzer (Jena TOC Analyzer, Germany). The conversion coefficients of MBC and MBN are 0.45 and 0.54, respectively. The soil NH_4^+-N and NO_3^--N contents were measured on an ultraviolet spectrophotometer (HITACHI, UV-2900, Tokyo, Japan) using indophenol blue and two-wavelength ultraviolet spectrometry, respectively, following extraction by shaking for 1 h on a rotary shaker with 2 M KCl (soil: KCl = 1:5) solution. Available P was extracted with 0.5 M $NaHCO_3$ and quantified by the molybdenum blue method using an ultraviolet spectrophotometer. Available K was determined using the flame photometry method.

Table S1 Initial properties of the soil in our study (mean ± SD, n = 3).

pH	BD (g cm^{-3})	Clay (%)	Silt (%)	Sand (%)
7.95 ± 0.48	1.30 ± 0.35	30.5 ± 3.36	66.4 ± 7.30	3.10 ± 0.34
CEC (cmol kg^{-1})	SOC (g kg^{-1})	TN (g kg^{-1})	NO_3^--N (mg kg^{-1})	NH_4^+-N (mg kg^{-1})
25.3 ± 2.08	18.8 ± 2.27	2.30 ± 0.36	36.0 ± 14.4	51.2 ± 12.2

Note: BD: bulk density; Sand is 0.02-2 mm, silt is 0.002-0.02 mm and clay < 0.002 mm. CEC: cation exchange capacity; SOC: soil organic carbon; TN: total N.

Table S2 Main compounds and ingredient content of the chemical fertilizers applied.

Fertilizers	Main compounds	Main ingredient content
Urea	$(NH_2)_2CO$	46.0% N
Calcium magnesium phosphate	$Ca_3(PO_4)_2$ $CaSiO_3$ $MgSiO_3$	14.0% P_2O_5 45.0% CaO 20.0% SiO_2 12.0% MgO
Potassium chloride	KCl	63.2% K_2O

Table S3 Results of two-way ANOVA and repeated-measures ANOVA (F-values and significance) for cumulative N_2O and NO emissions. *** Significant at $p < 0.001$; ** Significant at $p < 0.01$; * Significant at $p < 0.05$.

Parameter	Year	N	Biochar	N × Year	N × Biochar	N × Biochar × Year	Biochar × Year	N × Biochar × Year
N_2O	2018-2020	1373***	21.44***	44.36***	9.096**	50.96***	4.518**	5.130**
	2018	2474***	97.42***		63.26***			
	2019	223.7***	8.825**		4.170*			
	2020	660.2***	0.530		0.293			
NO	2018-2020	946.9***	11.42**	40.82***	8.737**	30.73***	0.165	0.226
	2018	623.2***	5.694*		4.562*			
	2019	872.3***	16.09***		12.65**			
	2020	246.7***	2.842		2.036			

Table S4 Results of two-way ANOVA and repeated-measures ANOVA (F-values and significance) for vegetable yield and quality and soil fertility index (SFI). *** Significant at $p < 0.001$; ** Significant at $p < 0.01$; * Significant at $p < 0.05$.

Parameter	Year	N	Biochar	Year	N × Biochar	N × Year	Biochar × Year	N × Biochar × Year
Yield	2018-2020	262.6***	4.056*	0.922	0.316	7.891**	0.538	0.819
	2018	127.1***	2.626		0.534			
	2019	66.46***	2.261		0.127			
	2020	127.8***	0.664		1.211			
Nitrate	2018-2020	94.60***	2.081	3.245	1.870	0.975	1.066	0.175
	2018	49.21***	0.522		1.599			
	2019	33.36***	0.909		1.327			
	2020	36.15***	2.243		0.192			
Vitamin C	2018-2020	17.03**	0.329	3.897*	0.963	0.068	0.148	0.146
	2018	7.113*	0.477		1.154			
	2019	8.000*	0.432		0.150			
	2020	1.580	0.005		0.071			
Soluble sugar	2018-2020	1.001	0.241	1.083	0.082	5.935**	0.316	0.262
	2018	6.930*	0.202		0.084			
	2019	2.597	0.171		0.080			
	2020	5.945*	0.731		0.689			
Soluble protein	2018-2020	16.25**	0.388	2.365	0.244	0.355	0.136	0.012
	2018	13.87**	0.285		0.322			
	2019	3.388	0.173		0.093			
	2020	5.513*	0.239		0.041			
SFI	2018-2020	177.8***	3.782	34.53***	21.83***	26.77***	0.828	0.508
	2018	170.6***	0.113		10.51**			
	2019	46.30***	1.801		5.723*			
	2020	9.359**	4.232*		7.620**			

Table S5 Soil physicochemical properties after vegetable harvest in 2018, 2019 and 2020 (mean ± SD, n = 3).

Parameter	Year	N0C0	N0C1	N0C2	N1C0	N1C1	N1C2
CEC	2018	24.2 ± 0.14Ac	20.2 ± 0.52Cb	21.9 ± 0.81BCb	23.2 ± 0.38ABb	20.6 ± 0.54Cb	21.7 ± 1.24BCb
(cmol kg^{-1})	2019	26.3 ± 0.60Ab	22.6 ± 1.69Bab	24.5 ± 1.19ABa	26.3 ± 0.79Aa	24.4 ± 1.04ABa	23.7 ± 0.74ABb
	2020	28.0 ± 0.90Aa	23.5 ± 0.81Da	24.9 ± 0.25CDa	27.5 ± 0.79ABa	23.7 ± 0.50Da	26.2 ± 0.21BCa
pH	2018	8.21 ± 0.02Aa	8.24 ± 0.10Aa	8.10 ± 0.24Aa	7.70 ± 0.01Bb	7.91 ± 0.04ABb	8.02 ± 0.17ABa
	2019	8.14 ± 0.06Aa	8.12 ± 0.11Aa	8.03 ± 0.12Aa	7.59 ± 0.02Bc	7.97 ± 0.08Aab	7.98 ± 0.10Aa
	2020	7.96 ± 0.03Cb	8.12 ± 0.01Ba	8.23 ± 0.03Aa	7.79 ± 0.04Da	8.06 ± 0.02Ba	8.21 ± 0.03Aa
EC	2018	185 ± 4.30Db	173 ± 1.75Db	189 ± 16.2Db	346 ± 31.5Cb	541 ± 19.5Ab	440 ± 22.0Bb
(us cm^{-1})	2019	230 ± 6.51Da	313 ± 22.6Ca	346 ± 21.7Ca	477 ± 5.51Ba	712 ± 14.2Aa	743 ± 50.3Aa
	2020	108 ± 7.73BCc	131 ± 5.41Bc	104 ± 5.08BCc	102 ± 3.03Cc	205 ± 21.4Ac	104 ± 7.53BCc
SOC	2018	17.7 ± 0.35Cb	21.2 ± 1.07ABab	22.2 ± 1.02Aab	18.7 ± 0.12BCa	20.4 ± 1.01ABa	22.5 ± 1.42Aa
(g kg^{-1})	2019	16.5 ± 0.12Dc	21.6 ± 0.22Ba	23.2 ± 0.28Aa	18.6 ± 0.14Ca	20.7 ± 0.18Ba	22.8 ± 0.84Aa
	2020	18.6 ± 0.44Ba	20.0 ± 0.20ABb	21.2 ± 0.62Ab	18.8 ± 0.55Ba	20.0 ± 0.78ABa	21.1 ± 0.96Aa
TN	2018	2.03 ± 0.08Bb	1.92 ± 0.08Ba	1.98 ± 0.08Ba	2.33 ± 0.04Aa	2.15 ± 0.08ABa	2.30 ± 0.16Aa
(g kg^{-1})	2019	2.21 ± 0.03Ba	1.87 ± 0.03Ca	1.95 ± 0.04Ca	2.30 ± 0.05ABab	2.29 ± 0.03Ba	2.41 ± 0.06Aa
	2020	2.11 ± 0.05Bab	1.80 ± 0.05Ca	1.87 ± 0.09Ca	2.22 ± 0.03ABb	2.20 ± 0.06ABa	2.36 ± 0.09Aa
TP	2018	0.66 ± 0.03Ca	0.78 ± 0.04Ba	0.84 ± 0.02Aa	0.76 ± 0.01Ba	0.76 ± 0.02Ba	0.84 ± 0.01Aa
(mg kg^{-1})	2019	0.67 ± 0.03Aa	0.68 ± 0.02Ab	0.73 ± 0.09Aa	0.73 ± 0.07Aa	0.73 ± 0.05Aa	0.76 ± 0.12Aa
	2020	0.66 ± 0.13Aa	0.67 ± 0.03Ab	0.70 ± 0.07Aa	0.71 ± 0.06Aa	0.70 ± 0.09Aa	0.80 ± 0.03Aa
NH_4^+-N	2018	48.7 ± 1.63Ba	52.2 ± 7.84ABa	54.9 ± 4.68ABa	61.5 ± 1.90Aa	54.1 ± 0.82ABa	48.3 ± 2.91Ba
(mg kg^{-1})	2019	7.26 ± 0.78Ab	7.57 ± 1.05Ab	7.59 ± 0.96Ab	5.69 ± 0.31Ab	9.07 ± 3.15Ab	19.4 ± 12.3Ab
	2020	6.88 ± 0.90ABb	7.84 ± 1.60Ab	6.30 ± 0.93ABb	5.77 ± 1.09ABb	4.69 ± 0.67Bb	5.37 ± 0.68ABb
NO_3^--N	2018	68.8 ± 7.67Ba	40.2 ± 0.29Ba	40.8 ± 2.00Ba	376 ± 55.6Aa	433 ± 17.5Aa	413 ± 38.2Ab
(mg kg^{-1})	2019	7.38 ± 0.47Db	17.0 ± 4.19Db	13.3 ± 1.27Db	73.0 ± 5.12Cb	276 ± 12.5Bb	488 ± 30.1Aa
	2020	16.5 ± 3.99Cb	14.4 ± 2.41Cb	7.83 ± 0.38Cc	18.3 ± 2.81Cb	106 ± 1.38Ac	34.6 ± 10.9Bc
Available P	2018	112 ± 1.22Ba	127 ± 2.97Aa	122 ± 6.10ABa	117 ± 2.08ABb	118 ± 7.26ABa	117 ± 1.37ABa

(mg kg^{-1})	2019	96.2 ± 28.16Ba	141 ± 19.2Aa	92.0 ± 10.2Bb	123 ± 3.21ABa	126 ± 13.7ABa	96.7 ± 10.1ABb
	2020	87.4 ± 2.97Aa	86.5 ± 2.32Ab	56.8 ± 0.87BCc	52.4 ± 0.56Cc	59.9 ± 3.65Bb	50.3 ± 2.69Cc
Available K	2018	330 ± 25.5Ca	353 ± 6.60BCa	231 ± 8.37Eb	443 ± 5.87Aa	273 ± 2.80Da	374 ± 8.98Ba
(mg kg^{-1})	2019	293 ± 4.75Ca	333 ± 10.0Bb	253 ± 11.5Db	358 ± 1.54Ab	290 ± 8.17Ca	348 ± 7.39ABb
	2020	322 ± 13.2BCa	364 ± 3.50Aa	284 ± 7.19Ca	357 ± 8.24ABb	309 ± 29.3Ca	303 ± 8.82Cc
DOC	2018	146 ± 1.61Ab	177 ± 25.0Ab	163 ± 9.25Ab	144 ± 2.75Ab	184 ± 39.1Aa	148 ± 3.14Ab
(mg kg^{-1})	2019	201 ± 4.97Ba	220 ± 4.75Aa	188 ± 1.40Ca	160 ± 6.21Dab	161 ± 2.57Da	134 ± 2.15Eb
	2020	161 ± 13.6ABb	178 ± 1.51Ab	188 ± 1.66Aa	184 ± 19.8Aa	138 ± 3.24Ba	174 ± 14.1Aa
DON	2018	81.5 ± 1.34Ca	60.4 ± 6.96Ca	63.4 ± 2.26Ca	335 ± 36.1Aa	325 ± 17.7ABa	285 ± 8.75Ba
(mg kg^{-1})	2019	43.0 ± 0.23Bb	43.8 ± 2.45Bb	41.2 ± 0.74Bb	265 ± 1.08Ab	279 ± 2.29Ab	259 ± 35.5Aa
	2020	37.3 ± 2.23Cc	40.4 ± 3.36BCb	41.8 ± 0.88BCb	45.3 ± 6.26BCc	105 ± 14.1Ac	57.5 ± 1.40Bb
MBC	2018	216 ± 8.94Ab	206 ± 59.9Ab	236 ± 10.9Ab	198 ± 9.70Aa	191 ± 13.2Aa	224 ± 22.1Ab
(mg kg^{-1})	2019	167 ± 25.1BCa	216 ± 7.24ABCab	228 ± 34.8Ab	161 ± 12.2Cb	176 ± 22.1ABCa	220 ± 14.8ABb
	2020	265 ± 15.3Ba	301 ± 6.41Ba	297 ± 16.7Ba	217 ± 8.65Ca	217 ± 22.1Ca	342 ± 13.7Aa
MBN	2018	32.1 ± 3.72Ca	43.6 ± 5.00BCa	43.6 ± 2.15BCa	52.1 ± 3.72ABa	66.3 ± 7.37Aa	51.2 ± 7.31Ba
(mg kg^{-1})	2019	28.7 ± 4.67Ca	29.7 ± 6.25BCa	20.13 ± 4.91Cb	43.2 ± 3.93ABa	50.6 ± 6.14Aab	55.5 ± 4.22Aa
	2020	23.3 ± 5.17Aa	24.7 ± 12.2Aa	28.6 ± 10.4Aab	43.0 ± 7.64Aa	35.7 ± 14.9Ab	39.9 ± 17.2Aa

Note: N0 or N1 refers to N fertilizer application rates of 0 or 240 kg N ha^{-1}, respectively. C0, C1 and C2 refer to biochar incorporation rates of 0, 20 and 40 t ha^{-1}, respectively. CEC: cation exchange capacity; EC: electrical conductivity; SOC: soil organic carbon; TN: total N; TP: total P; DOC: dissolved soil organic carbon; DON: dissolved soil organic nitrogen; MBC: microbial biomass carbon; MBN: microbial biomass nitrogen. Capital letters indicate significant differences among treatments for each cropping year at $p < 0.05$. Lowercase letters indicate significant differences among cropping years for each treatment at $p < 0.05$.

Table S6 Results of two-way ANOVA (F-values and significance) for soil properties. *** Significant at $p < 0.001$; ** Significant at $p < 0.01$; * Significant at $p < 0.05$.

Parameter	Year	N	Biochar	N × Biochar
CEC	2018	0.586	33.77***	1.583
	2019	0.332	11.54**	2.327
	2020	1.410	62.27***	2.722
pH	2018	25.64***	1.553	4.162*
	2019	34.65***	6.776*	12.74**
	2020	42.49***	270.7***	13.67**
EC	2018	850.6***	35.56***	44.94***
	2019	861.5***	99.12***	18.06***
	2020	21.94**	75.26***	27.62***
SOC	2018	0.109	30.31***	1.446
	2019	1.492	308.6***	26.84***
	2020	0.002	22.81***	0.118
TN	2018	43.20***	3.937*	0.373
	2019	279.4***	28.16***	37.69***
	2020	109.0***	8.655**	12.89**
TP	2018	5.434*	46.61***	9.538**
	2019	1.643	0.730	0.052
	2020	2.756	1.330	0.394
NH_4^+-N	2018	1.979	1.129	8.742**
	2019	2.525	2.910	2.698
	2020	12.75**	0.400	2.168
NO_3^--N	2018	701.6***	0.381	3.650
	2019	1730***	360.1***	340.6***
	2020	288.7***	134.6***	128.7***
Available P	2018	2.027	5.532*	3.977*
	2019	0.541	8.943**	2.438
	2020	388.1***	110.8***	53.47***
Available K	2018	103.9***	85.31***	148.9***
	2019	107.1***	15.30***	126.4***
	2020	0.005	19.14***	16.64***
DOC	2018	0.142	5.435*	0.499
	2019	718.6***	79.49***	7.335**
	2020	3.613	6.416*	11.28**
DON	2018	938.0***	6.012*	2.638
	2019	1075***	0.887	0.550
	2020	90.74***	36.76***	32.71***
MBC	2018	1.355	2.075	0.017
	2019	3.168	11.72**	1.180
	2020	16.83**	46.40***	30.37***
MBN	2018	45.91***	9.094**	3.555
	2019	96.20***	1.029	6.656*
	2020	6.128*	0.182	0.252

Note: CEC: cation exchange capacity; EC: electrical conductivity; SOC: soil organic carbon; TN: total N; TP: total P; DOC: dissolved soil organic carbon; DON: dissolved soil organic nitrogen; MBC: microbial biomass carbon; MBN: microbial biomass nitrogen.

Table S7 Pearson correlation coefficients among selected soil indicators. ** Significant at $p < 0.01$; * Significant at $p < 0.05$.

	PH	TP	NO_3^--N	Available K	DOC	DON
PH	1.000					
TP	-0.011	1.000				
NO_3^--N	-0.341*	0.327*	1.000			
Available K	-0.387**	-0.043	0.298*	1.000		
DOC	0.240	-0.256	-0.473**	-0.286*	1.000	
DON	-0.570**	0.299*	0.888**	0.349**	-0.434**	1.000

Note: TP: total P; DOC: dissolved soil organic carbon; DON: dissolved soil organic nitrogen.

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