

Table S1. The experimental design in our study.

Seasons	Treatment	Description	N (kg ha ⁻¹)	P (kg ha ⁻¹)	K (kg ha ⁻¹)	Biochar (kg ha ⁻¹)	DMPP (kg ha ⁻¹)
First	CK	No addition	0	0	0	0	0
	PK	Superphosphate and potassium sulfate	0	0.62	1.35	0	0
	NPK	Urea, superphosphate, and potassium sulfate	1.65	0.62	1.35	0	0
	NPK+DMPP	Urea, superphosphate, potassium sulfate, and 3,4-dimethylpyrazole phosphate	1.65	0.62	1.35	0	0.01
	NPK+BC10	Urea, superphosphate, potassium sulfate, and biochar	1.65	0.62	1.35	64.5	0
	NPK+BC30	Urea, superphosphate, potassium sulfate, and biochar	1.65	0.62	1.35	193	0
	NPK+BC10+DMPP	Urea, superphosphate, potassium sulfate, biochar, and 3,4-dimethylpyrazole phosphate	1.65	0.62	1.35	64.5	0.01
Second	NPK+BC30+DMPP	Urea, superphosphate, potassium sulfate, biochar, and 3,4-dimethylpyrazole phosphate	1.65	0.62	1.35	193	0.01
	CK	No addition	0	0	0	0	0
	PK	Superphosphate and potassium sulfate	0	0.58	1.28	0	0
	NPK	Urea, superphosphate, and potassium sulfate	1.57	0.58	1.28	0	0
	NPK+DMPP	Urea, superphosphate, potassium sulfate, and 3,4-dimethylpyrazole phosphate	1.57	0.58	1.28	0	0
	NPK+BC10	Urea, superphosphate, potassium sulfate, and biochar	1.57	0.58	1.28	64.5	0
	NPK+BC30	Urea, superphosphate, potassium sulfate, and biochar	1.57	0.58	1.28	193	0
	NPK+BC10+DMPP	Urea, superphosphate, potassium sulfate, biochar, and 3,4-dimethylpyrazole phosphate	1.57	0.58	1.28	64.5	0.01
	NPK+BC30+DMPP	Urea, superphosphate, potassium sulfate, biochar, and 3,4-dimethylpyrazole phosphate	1.57	0.58	1.28	193	0.01

DMPP, 3,4-dimethylpyrazole phosphate; CK, control.

Table S2. Analysis of variance (ANOVA) of the effects of fertilization treatments, seasons, and their interaction on plant properties, soil physicochemical properties, microbial functional gene abundances, gross N transformation rates, and N₂O emissions.

Paramenter ^a	Fertilizer		Season		Fertilizer × Season	
	F	<i>p</i>	F	<i>p</i>	F	<i>p</i>
Crop yield	12.9	<0.01	52.2	<0.01	5.83	<0.01
Aboveground yield	11.9	<0.01	49.3	<0.01	5.07	<0.01
Underground yield	61.2	<0.01	81.0	<0.01	9.15	<0.01
Crop N content	25.6	<0.01	63.7	<0.01	5.46	<0.01
Crop N uptake	20.3	<0.01	60.4	<0.01	2.91	0.02
Aboveground C content	65.8	<0.01	17.3	<0.01	3.93	<0.01
Aboveground N content	17.3	<0.01	27.0	<0.01	3.27	0.01
Aboveground C:N ratio	36.1	<0.01	41.3	<0.01	9.21	<0.01
Underground C content	10.4	<0.01	4.45	0.01	2.05	0.08
Underground N content	0.14	0.71	12.0	<0.01	6.26	<0.01
Underground C:N ratio	0.02	0.89	14.7	<0.01	6.14	<0.01
NUE	13.3	<0.01	62.4	<0.01	2.80	0.04
WHC	3.07	<0.01	26.2	<0.01	0.74	0.64
pH	24.8	<0.01	47.2	<0.01	2.53	0.04
SOC	52.1	<0.01	5.39	0.03	0.73	0.65
TN	1.80	0.12	6.16	0.02	0.48	0.84
C/N	28.3	<0.01	12.7	<0.01	1.15	0.36
NH ₄ ⁺	3.19	0.01	0.30	0.59	1.68	0.15
NO ₃ ⁻	4.91	<0.01	23.1	<0.01	5.02	<0.01
Inorganic N	6.28	<0.01	22.1	<0.01	5.19	<0.01
NO ₃ ⁻ /NH ₄ ⁺	2.36	<0.05	95.8	<0.01	2.66	0.03
AOA	18.8	<0.01	10.6	<0.01	10.6	<0.01
AOB	26.2	<0.01	65.3	<0.01	9.65	<0.01
GNM	10.7	<0.01	49.8	<0.01	3.38	<0.01
GN	61.2	<0.01	48.9	<0.01	5.69	<0.01
GAI	27.3	<0.01	12.7	<0.01	5.80	<0.01
GNI	27.2	<0.01	56.1	<0.01	2.39	0.04
GI	37.6	<0.01	13.1	<0.01	5.40	<0.01
GAI/GN	9.41	<0.01	21.7	<0.01	1.43	0.23
MRT NH ₄ ⁺	10.3	<0.01	41.7	<0.01	3.54	<0.01
MRT NO ₃ ⁻	8.46	<0.01	9.69	<0.01	2.70	0.03
N ₂ O emissions	10.3	<0.01	34.1	<0.01	49.3	<0.01
Yield-scaled N ₂ O emissions	65.5	<0.01	55.8	<0.01	29.5	<0.01
N ₂ O emission factor	35.4	<0.01	84.0	<0.01	12.8	<0.01

^aNUE, N use efficiency; WHC, water holding capacity; SOC, soil organic C; TN, total N; C/N, soil organic C/total N; GNM, gross N mineralization; GN, gross nitrification; GAI, gross NH₄⁺ immobilization; GNI, gross NO₃⁻ immobilization; MRT NH₄⁺, mean residence time of NH₄⁺; MRT NO₃⁻, mean residence time of NO₃⁻.

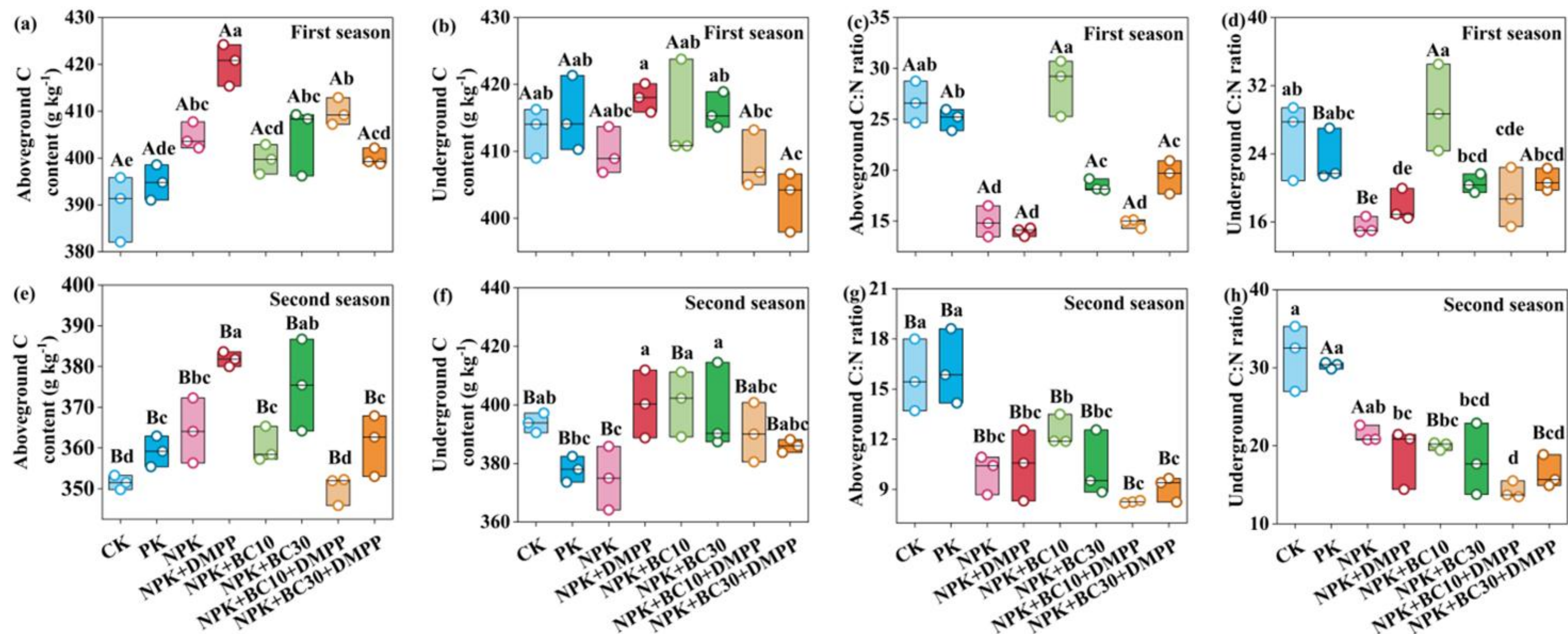


Figure S1. Changes in (a, e) aboveground C content, (b, f) underground C content, (c, g) aboveground C:N ratio, and (d, h) underground C:N ratio after fertilizer application during the first and second seasons. Different lowercase letters indicate significant differences among fertilization treatments, while different uppercase letters indicate significant differences between growing seasons, and the absence of letters indicates no significant differences. The values represent the average $\pm$ standard deviation ($n=3$).

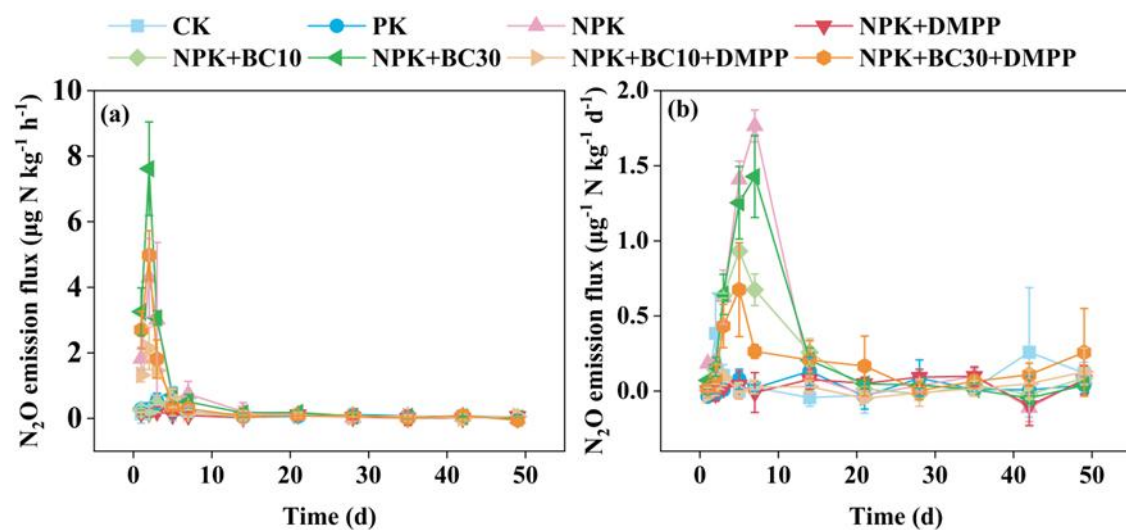


Figure S2. Changes in soil N_2O emission flux after fertilizer application during the first and second seasons. The values represent the average $\pm$ standard deviation ($n=3$).

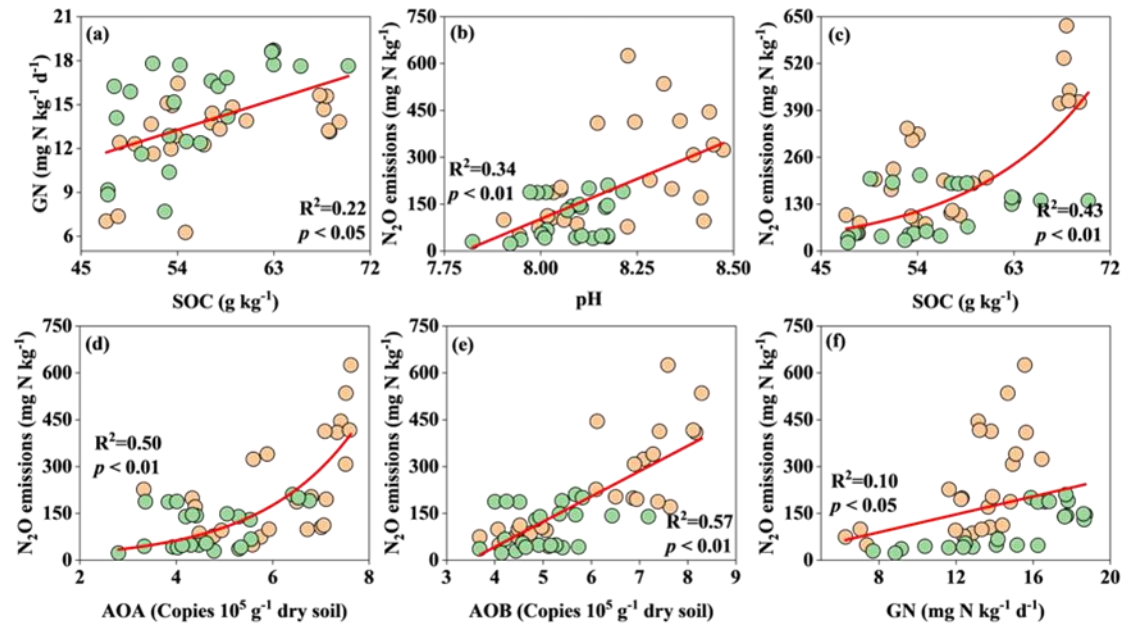


Figure S3. Relationships between (a) soil organic C (SOC) and gross nitrification rate (GN); N₂O emissions and (b) pH, (c) SOC, (d) AOA, (e) AOB, and GN rate.