This is a post-peer-review, pre-copyedit version of the supplementary information of an article published in Environmental geochemistry and health (Ed. Springer). The final authenticated version is available online at: DOI 10.1007/s10653-018-0224-7

Supplementary Information

Table S1

Characteristics of the steel slag and biochar used in the study.

Amendment	Physical property	Fe_2O_3 (%)	Fe (%)	S (%)	SiO_2 (%)	C (%)	N (%)	P (%)	K (%)	Mg (%)	Ca (%)
Steel slag	Granular form (2 mm)	4.8	-	-	40.7	0.7	0.01	0.01	0.5	0.36	24.9
Biochar	Granular form (2 mm)	-	0.2	0.6	-	56.6	1.4	1.0	1.8	1.0	0.5

Table S2

Summary of the RM-ANOVAs for GHG emissions of the various amendments.

Early paddy CO_2	*df*	*MS*	*F*	*P*
Steel slag	1, 4	54059.92	0.19	0.688
Time	13, 52	7524128.53	67.93	<0.001
Steel slag × Time	13, 52	104494.18	0.943	0.517
Biochar	1, 4	317787.73	0.53	0.506
Time	13, 52	7208353.39	59.72	<0.001
Biochar × Time	13, 52	59643.70	0.49	0.918
Steel slag+biochar	1, 4	1138345.45	7.46	0.052
Time	13, 52	6998406.21	70.89	<0.001
Steel slag+biochar × Time	13, 52	79509.02	0.85	0.652
Late paddy CO_2				
Steel slag	1, 4	585763.22	13.93	0.020
Time	15, 60	3029441.01	94.78	<0.001
Steel slag × Time	15, 60	109590.67	3.43	<0.001
Biochar	1, 4	2507948.12	14.75	0.018
Time	15, 60	2511364.61	96.83	<0.001
Biochar × Time	15, 60	134246.53	5.18	<0.001
Steel slag+biochar	1, 4	32918.24	7.87	0.048
Time	15, 60	2448082.17	53.77	<0.001
Steel slag+biochar × Time	15, 60	85507.06	1.88	0.044
Early paddy CH_4				
Steel slag	1, 4	2.021	1.312	0.316
Time	13, 52	73.84	34.66	<0.001
Steel slag × Time	13, 52	3.01	1.41	0.186
Biochar	1, 4	0.85	0.07	0.801
Time	13, 52	87.31	19.39	<0.001
Biochar × Time	13, 52	2.27	0.50	0.912
Steel slag+biochar	1, 4	21.14	32.57	0.005
Time	13, 52	54.93	27.52	<0.001

Steel slag+biochar × Time	13, 52	4.18	2.09	0.031
Late paddy CH_4				
Steel slag	1, 4	25.38	0.37	0.578
Time	15, 60	711.01	33.36	<0.001
Steel slag × Time	15, 60	64.49	3.03	0.001
Biochar	1, 4	221.51	1.07	0.359
Time	15, 60	537.83	10.23	<0.001
Biochar × Time	15, 60	70.97	1.35	0.203
Steel slag+biochar	1, 4	130.08	2.28	0.206
Time	15, 60	621.80	17.97	<0.001
Steel slag+biochar × Time	15, 60	68.66	1.98	0.032
Early paddy N_2O				
Steel slag	1, 4	5076.14	0.45	0.540
Time	13, 52	32448.60	2.85	0.004
Steel slag × Time	13, 52	2779.58	0.24	0.996
Biochar	1, 4	1538.32	0.12	0.747
Time	13, 52	39257.66	4.83	<0.001
Biochar × Time	13, 52	5510.67	0.68	0.775
Steel slag+biochar	1, 4	2737.72	0.24	0.648
Time	13, 52	19283.65	2.73	0.005
Steel slag+biochar × Time	13, 52	8281.25	1.17	0.324
Late paddy N_2O				
Steel slag	1, 4	11686.97	6.56	0.063
Time	15, 60	3818.05	1.47	0.146
Steel slag × Time	15, 60	3448.02	1.33	0.215
Biochar	1, 4	41878.19	11.01	0.029
Time	15, 60	9255.20	2.98	0.001
Biochar × Time	15, 60	4159.39	1.34	0.209
Steel slag+biochar	1, 4	22543.45	10.36	0.032
Time	15, 60	5042.87	2.05	0.026
Steel slag+biochar × Time	15, 60	2958.56	1.21	0.294

31

32

Table S3

Summary of the mixed models.

Variable	Model	
	Treatment	Total model (R^2m=Fixed, R^2c=Fixed+ random)
Early paddy over time		
Salinity	F=89.0, P<0.0001	R^2m=0.30, R^2c=0.81
Soil water content	F=8176, P<0.0001	R^2m=0.57, R^2c=0.82
Soil temperature	F=0.80, P=0.50	R^2m=0.00023, R^2c=0.98
Soil pH	F=93.8, P<0.0001	R^2m=0.58, R^2c=0.65
CO_2 emissions	F=4.36, P=0.0059	R^2m=0.0059, R^2c=0.92
CH_4 emissions	F=4.01, P=0.0093	R^2m=0.016, R^2c=0.78
N_2O emissions	F=0.28, P=0.84	R^2m=0.0033, R^2c=0.34
Late paddy over time		
Salinity	F=43.9, P<0.0001	R^2m=0.16, R^2c=0.77
Soil water content	F=153, P<0.0001	R^2m=0.33, R^2c=0.86
Soil temperature	F=4.079, P=0.0082	R^2m=0.00013, R^2c=0.998
Soil pH	F=284, P<0.0001	R^2m=0.79, R^2c=0.83
CO_2 emissions	F=15.74, P<0.0001	R^2m=0.031, R^2c=0.87
CH_4 emissions	F=1.59, P=0.19	R^2m=0.0104, R^2c=0.58
N_2O emissions	F=5.34, P=0.0016	R^2m=0.057, R^2c=0.32
Total emissions early paddy		
CO_2 emissions	F=1.1038, P=0.42	R^2m=0.23, R^2c=0.24
CH_4 emissions	F=3.78, P=0.033	R^2m=0.33, R^2c=0.56
N_2O emissions	F=0.29, P=0.83	R^2m=0.064, R^2c=0.20
Total emissions early paddy		
CO_2 emissions	F=8.68, P=0.0133	R^2m=0.70, R^2c=0.71
CH_4 emissions	F=0.56, P=0.66	R^2m=0.13, R^2c=0.13
N_2O emissions	F=0.29, P=0.83	R^2m=0.064, R^2c=0.20
Total emissions early + late paddy		
CO_2 emissions	F=8.68, P=0.0133	R^2m=0.70, R^2c=0.71

CH_4 emissions	F=0.56, P=0.66	R^2m=0.13, R^2c=0.13
N_2O emissions	F=0.74, P=0.57	R^2m=0.17, R^2c=0.16
Total emissions by yield in early paddy (kg CO_2-eq mg^{-1} yield)		
CO_2 emissions	F=1.104, P=0.42	R^2m=0.23, R^2c=0.24
CH_4 emissions	F=2.80, P=0.13	R^2m=0.33, R^2c=0.56
N_2O emissions	F=0.33, P=0.80	R^2m=0.23, R^2c=0.70
Total emissions by yield in late paddy (kg CO_2-eq mg^{-1} yield)		
CO_2 emissions	F=8.68, P=0.013	R^2m=0.70, R^2c=0.71
CH_4 emissions	F=0.56, P=0.66	R^2m=0.13, R^2c=0.14
N_2O emissions	F=0.33, P=0.80	R^2m=0.07, R^2c=0.23
Total emissions by yield in early + late paddy (kg CO_2-eq mg^{-1} yield)		
CO_2 emissions	F=6.01, P=0.031	R^2m=0.62, R^2c=0.62
CH_4 emissions	F=0.74, P=0.57	R^2m=0.17, R^2c=0.18
N_2O emissions	F=0.33, P=0.80	R^2m=0.07, R^2c=0.23

Table S4

Summary of the RM-ANOVAs for the soil properties of the various amendments.

Early paddy	*df*	*MS*	*F*	*P*
pH				
Steel slag	1, 4	20.34	604.17	<0.001
Time	13, 52	0.47	46.97	<0.001
Steel slag × Time	13, 52	0.23	23.16	<0.001
Biochar	1, 4	3.64	357.20	<0.001
Time	13, 52	0.20	56.59	<0.001
Biochar × Time	13, 52	0.05	14.83	<0.001
Steel slag+biochar	1, 4	29.10	199.75	<0.001
Time	13, 52	0.32	3.10	0.002
Steel slag+biochar × Time	13, 52	0.42	4.05	<0.001
Salinity				
Steel slag	1, 4	0.94	54.35	0.002
Time	13, 52	0.11	31.69	<0.001
Steel slag × Time	13, 52	0.01	3.22	0.001
Biochar	1, 4	1.36	250.20	<0.001
Time	13, 52	0.15	42.15	<0.001
Biochar × Time	13, 52	0.02	6.37	<0.001
Steel slag+biochar	1, 4	2.34	46.89	0.002
Time	13, 52	0.15	23.88	<0.001
Steel slag+biochar × Time	13, 52	0.03	4.74	<0.001
Temperature				
Steel slag	1, 4	0.10	0.61	0.477
Time	13, 52	46.80	502.13	<0.001
Steel slag × Time	13, 52	0.32	3.40	0.001
Biochar	1, 4	468.60	0.98	0.379
Time	13, 52	612.11	1.28	0.257
Biochar × Time	13, 52	481.87	1.01	0.461

Steel slag+biochar	1, 4	0.27	1.01	0.373
Time	13, 52	49.07	524.01	<0.001
Steel slag+biochar × Time	13, 52	0.15	1.63	0.107
Water content				
Steel slag	1, 4	2413.93	121.08	<0.001
Time	13, 52	316.70	53.49	<0.001
Steel slag × Time	13, 52	13.16	2.22	0.021
Biochar	1, 4	15438.87	76.21	0.001
Time	13, 52	560.17	13.57	<0.001
Biochar × Time	13, 52	141.69	3.43	0.001
Steel slag+biochar	1, 4	24802.42	888.35	<0.001
Time	13, 52	549.07	27.81	<0.001
Steel slag+biochar × Time	13, 52	134.52	6.81	<0.001
Late paddy				
pH				
Steel slag	1, 4	37.23	965.30	<0.001
Time	15, 60	0.15	5.75	<0.001
Steel slag × Time	15, 60	0.16	5.84	<0.001
Biochar	1, 4	9.81	557.36	<0.001
Time	15, 60	0.13	8.28	<0.001
Biochar × Time	15, 60	0.16	10.44	<0.001
Steel slag+biochar	1, 4	40.68	2956.32	<0.001
Time	15, 60	0.11	2.80	0.002
Steel slag+biochar × Time	15, 60	0.13	3.25	0.001
Salinity				
Steel slag	1, 4	1.02	118.96	<0.001
Time	15, 60	0.17	21.76	<0.001
Steel slag × Time	15, 60	0.02	2.89	0.002
Biochar	1, 4	0.72	36.50	0.004
Time	15, 60	0.20	52.96	<0.001
Biochar × Time	15, 60	0.01	3.32	<0.001
Steel slag+biochar	1, 4	0.73	70.37	0.001
Time	15, 60	0.16	27.73	<0.001

Steel slag+biochar × Time	15, 60	0.02	3.50	<0.001
Temperature				
Steel slag	1, 4	0.18	1.15	0.34
Time	15, 60	85.67	2445.63	<0.001
Steel slag × Time	15, 60	0.06	1.56	0.11
Biochar	1, 4	0.11	0.70	0.451
Time	15, 60	84.47	2214.68	<0.001
Biochar × Time	15, 60	0.03	0.82	0.650
Steel slag+biochar	1, 4	0.30	1.97	0.234
Time	15, 60	84.32	2354.94	<0.001
Steel slag+biochar × Time	15, 60	0.06	1.68	0.080
Water content				
Steel slag	1, 4	2579.85	109.89	<0.001
Time	15, 60	750.25	105.44	<0.001
Steel slag × Time	15, 60	52.96	7.44	<0.001
Biochar	1, 4	7246.42	138.92	<0.001
Time	15, 60	565.37	87.96	<0.001
Biochar × Time	15, 60	53.73	8.36	<0.001
Steel slag+biochar	1, 4	8752.77	308.18	<0.001
Time	15, 60	451.36	31.66	<0.001
Steel slag+biochar × Time	15, 60	39.68	2.78	0.003

Table S5

Correlations between the soil properties and the GHG emissions.

Early paddy						
CO_2	CH_4	N_2O	pH	Salinity	Temperature	Water content
Control (n=42)	-0.148	0.435**	-0.209	-0.510**	0.776**	-0.610**
Steel slag (n=42)	-0.163	0.122	-0.251	-0.220	0.755**	-0.449**
Biochar (n=42)	-0.213	0.201	-0.484**	-0.354*	0.750**	-0.617**
Steel slag+biochar (n=42)	-0.219	0.454**	-0.043	-0.319*	0.727**	-0.601**
Total (n=168)	-0.172*	0.275**	-0.158*	-0.310**	0.749**	-0.416**
CH_4	CO_2	N_2O	pH	Salinity	Temperature	Water content
Control (n=42)	-0.148	-0.190	0.627**	0.560**	-0.005	0.530**
Steel slag (n=42)	-0.163	-0.127	0.489**	0.614**	-0.035	0.660**
Biochar (n=42)	-0.213	0.046	0.505**	0.587**	-0.160	0.230
Steel slag+biochar (n=42)	-0.219	-0.260*	-0.163	0.614**	0.004	0.265*
Total (n=168)	-0.172*	-0.101	0.086	0.420**	-0.055	0.172*
N_2O	CO_2	CH_4	pH	Salinity	Temperature	Water content
Control (n=42)	0.435**	-0.190	-0.134	-0.325*	0.205	-0.279*
Steel slag (n=42)	0.122	-0.127	-0.103	0.026	0.049	-0.221
Biochar (n=42)	0.201	0.046	0.136	-0.015	-0.079	0.062
Steel slag+biochar (n=42)	0.454**	-0.260*	0.021	-0.058	0.111	-0.295*
Total (n=168)	0.275**	-0.101	-0.058	-0.087	0.075	-0.098
Late paddy						
CO_2	CH_4	N_2O	pH	Salinity	Temperature	Water content
Control (n=48)	-0.483**	-0.006	-0.318*	-0.235	-0.205	-0.293*
Steel slag (n=48)	-0.400**	-0.171	0.240	0.011	-0.357**	-0.327*
Biochar (n=48)	-0.026	-0.124	0.170	0.102	-0.211	-0.159
Steel slag+biochar (n=48)	-0.229	0.032	0.141	0.017	-0.175	-0.144
Total (n=192)	-0.271**	-0.028	-0.052	-0.085	-0.237**	-0.294**
CH_4	CO_2	N_2O	pH	Salinity	Temperature	Water content
Control (n=48)	-0.483**	-0.119	0.159	0.813**	0.736**	0.828**

Steel slag (n=48)	-0.400**	-0.130	-0.302*	0.609**	0.624**	0.727**
Biochar (n=48)	-0.026	-0.082	-0.106	0.596**	0.421**	0.594**
Steel slag+biochar (n=48)	-0.229	-0.037	-0.330*	0.407**	0.512**	0.380**
Total (n=192)	-0.271**	-0.063	-0.119*	0.535**	0.575**	0.466**
N_2O	CO_2	CH_4	pH	Salinity	Temperature	Water content
Control (n=48)	-0.006	-0.119	0.176	-0.258*	-0.206	-0.274*
Steel slag (n=48)	-0.171	-0.130	-0.009	-0.165	-0.175	-0.169
Biochar (n=48)	-0.124	-0.082	-0.156	-0.227	-0.305*	-0.186
Steel slag+biochar (n=48)	0.032	-0.037	-0.145	-0.150	-0.341**	-0.217
Total (n=192)	-0.028	-0.063	-0.159*	-0.260**	-0.249**	-0.290**

*, significant at the 0.05 level; **, significant at the 0.01 level.

Table S6

Test statistics for squared Mahalanobis distances among the plots receiving the fertilization treatments, with soil pH, temperature, salinity and water content and CO_2, CH_4 and N_2O emissions during the sampling period as independent continuous variables and with sampling time as the categorical independent variable for the late paddy crop. Mah, squared Mahalanobis distance.

	Steel slag	Biochar	Steel+biochar
Control	Mah=41.2 *F*=39.9 *P*<0.0001	Mah=28.0 *F*=27.1 *P*<0.0001	Mah=60.0 *F*=58.2 *P*<0.0001
Steel slag		Mah=9.44 *F*=9.15 *P*<0.0001	Mah=5.09 *F*=4.93 *P*<0.0001
Biochar			Mah=10.2 *F*=9.92 *P*<0.0001

Table S7

Test statistics for squared Mahalanobis distances among the plots receiving the fertilization treatments, with soil pH, temperature, salinity and water content and CO_2, CH_4 and N_2O emissions during the sampling period as independent continuous variables and with sampling time as the categorical independent variable for the early paddy crop. Mah, squared Mahalanobis distance.

	Steel slag	Biochar	Steel+biochar
Control	Mah=10.3 *F*=10.2 *P*<0.0001	Mah=15.9 *F*=15.7 *P*<0.0001	Mah=32.8 *F*=32.3 *P*<0.0001
Steel slag		Mah=10.9 *F*=10.7 *P*<0.0001	Mah=11.9 *F*=11.7 *P*<0.0001
Biochar			Mah=6.55 *F*=6.45 *P*<0.0001

Table S8

Statistical significance of the independent variables in the general discriminant analysis, with fertilization treatment as the dependent categorical grouping variable for the late paddy crop.

Variable	Value	F	*P*
Salinity	0.864	8.77	<0.0001
Temperature	0.986	0.796	0.50
Water content	0.458	65.8	<0.0001
pH	0.258	160.1	<0.0001
CO_2 emission	0.961	2.27	0.082
CH_4 emission	0.943	3.37	0.020
N_2O emission	0.969	1.81	0.15

Table S9

Statistical significance of the independent variables in the general discriminant analysis, with fertilization treatment as the dependent categorical grouping variable for the early paddy crop.

Variable	Wilks' Lambda	F	*P*
Salinity	0.706	15.3	<0.0001
Temperature	0.958	2.15	0.096
Water content	0.273	130	<0.0001
pH	0.429	64.8	<0.0001
CO_2 emission	0.985	0.753	0.522
CH_4 emission	0.943	2.95	0.035
N_2O emission	0.996	0.199	0.897

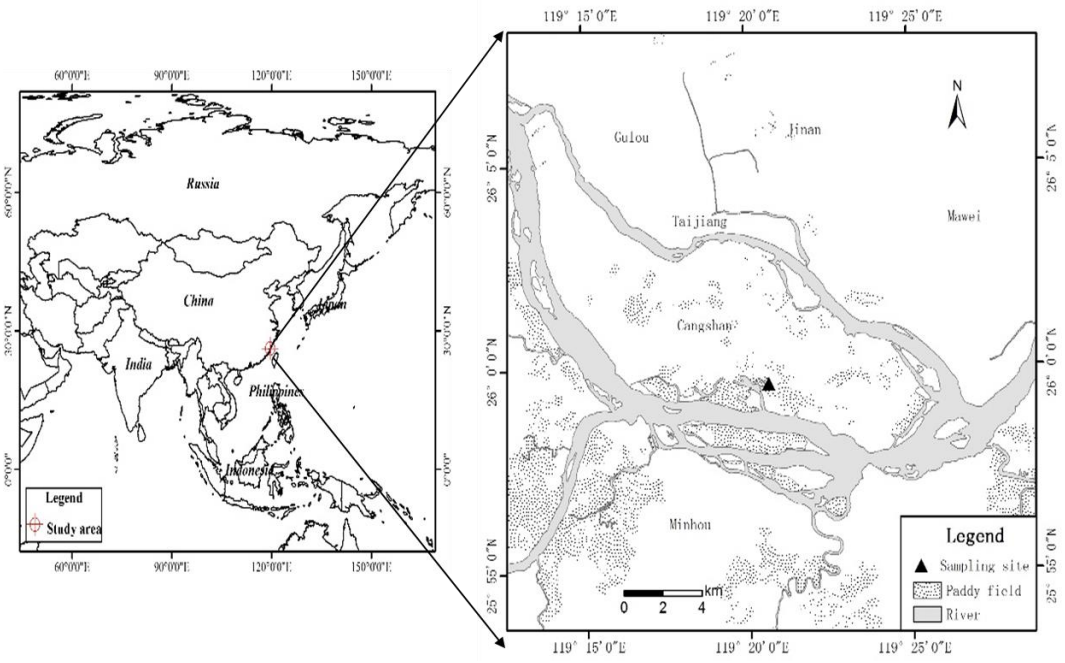

Fig. S1 The locations of the study area and sampling sites (▲) in Fujian Province, southeastern China.

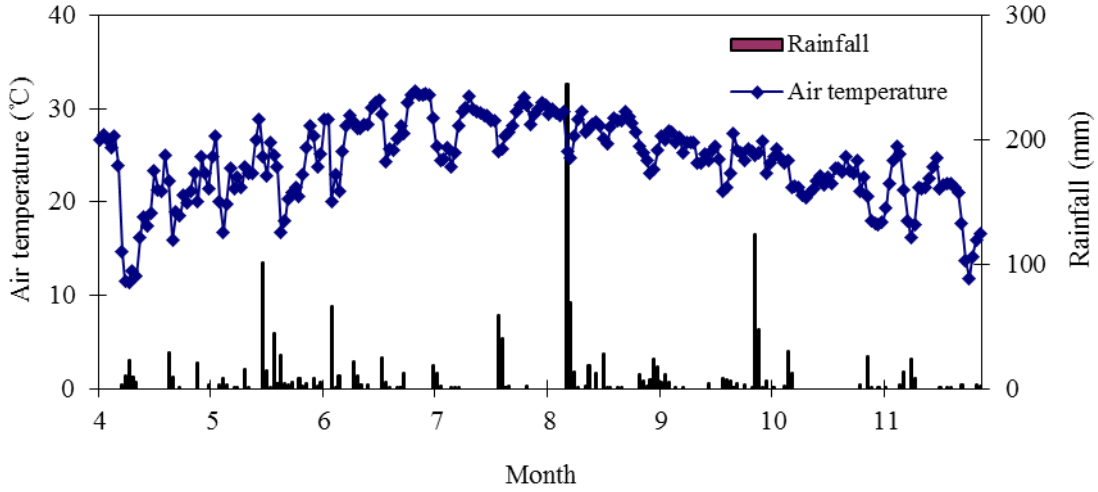

Fig. S2. Temporal variation of air temperature and rainfall in the study area.