**Supplementary information**

**Part 1: Supplementary tables and figures in this study.**

**Table S1** Thevariables involved in this text.

|  |  |  |
| --- | --- | --- |
|  | Name of variable | Unit |
| Target variables | CO2 emission | kg ha-1 |
| CH4 emission/uptake | kg ha-1 |
| N2O emission | kg ha-1 |
| Global Warming Potential (GWP) | kg CO2 equivalent ha-1 |
| GHG intensity (GHGI) | kg CO2 equivalent kg-1 |
| Grain yield | t ha-1 |
| Geoclimatic  factors | Coordinates (latitude and longitude) | ° |
| Mean annual temperature (MAT) | °C |
| Mean annual precipitation (MAP) | mm |
| Soil variables | Soil pH | - |
| Soil organic C (SOC) | g kg-1 |
| Soil dissolved organic C (DOC) | mg kg-1 |
| Soil microbial biomass C (MBC) | mg kg-1 |
| Soil total N (TN) | g kg-1 |
| Soil NH4+-N | mg kg-1 |
| Soil NO­3--N | mg kg-1 |
| Soil microbial biomass N (MBN) | mg kg-1 |
| Soil cation exchange capacity (CEC) | cmol(+) kg-1 |
| Soil bulk density (BD) | g cm-3 |
| Soil texture | - |
| amoA genes | 106 copy g-1 soil |
| nirS/nirK genes | 106 copy g-1 soil |
| nosZ genes | 106 copy g-1 soil |
| Biochar  treatment | Biochar pH | - |
| Biochar C content | g kg-1 |
| Biochar N content | g kg-1 |
| Biochar C: N | - |
| Biochar pyrolysis temperature | °C |
| Biochar feedstocks | - |
| Biochar application rate | t ha-1 |
| N treatment | N forms | Inorganic (IN); Organic (OF); IN+OF |
| N application rate | kg ha-1 |
| Experimental  scenarios | Experimental duration | Year (field) |
| Experimental method | Field; Incubation; Pot |
| Land-use | Paddy; Upland |

**Table S2** Classification criteria in this meta-analysis.

|  |  |  |
| --- | --- | --- |
|  | Factors | Levels |
| Soil texture | Coarse | Loamy sand; sandy clay loam; sandy loam |
| Medium | Silt; silt loam; silty clay loam; loam; clay loam |
| Fine | Sandy clay; silt clay; clay |
| Biochar  feedstock | Herbaceous | Grass; bamboo; stalks; straws |
| Lignocellulosic | Rice husk; Peanut shells |
| Biowaste | Green-waste; sludge; manure |
| Wood | Oak; willow; pine |

**Table S3** Publication bias was tested through fail safe numbers.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | CO2 | CH4-E | CH4-U | N2O | GWP | Yield | GHGI |
| B | Sig. | <0.0001 | <0.0001 | 0.9956 | <0.0001 | <0.0001 | <0.0001 | <0.05 |
| Fail-safe numbers (N) | 1378 | 11564 | 0 | 21064 | 1388 | 16595 | 4 |
| Number of observations (k) | 80 | 42 | 7 | 133 | 39 | 56 | 22 |
| N | Sig. | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| Fail-safe numbers (N) | 8486 | 5162 | 61 | 451857 | 25608 | 72253 | 1518 |
| Number of observations (k) | 74 | 29 | 10 | 116 | 31 | 37 | 16 |
| BN | Sig. | <0.0001 | <0.0001 | 0.9709 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| Fail-safe numbers (N) | 13884 | 45678 | 0 | 1083866 | 45147 | 362494 | 1989 |
| Number of observations (k) | 117 | 55 | 12 | 189 | 51 | 68 | 27 |

Note: If N>5k+10, indicates no publication bias. CH4-E and CH4-U represent CH4 emission and uptake, respectively.

**Table S4** Correlation between predictors (climates, experimental conditions, biochar properties and the response ratios of soil properties) and soil GWP, yield and GHGI. N rate: N application rate; B rate: biochar application rate; B temp: biochar pyrolysis temperature; SOC: soil organic carbon.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | MAP | MAT | Duration | N rate | B rate | B temp | Biochar pH | Biochar C:N C:C:N gfhgfnGFHGF GFHNFGNH C:NCC:N | Soil pH | SOC | TN | NH4+ | NO3- |
| GWP | B | 0.10 | -0.13 | 0.07 | - | 0.07 | 0.02 | -0.21 | 0.15 | **-0.55\*** | -0.36 | 0.29 | 0.59 | -0.19 |
| N | **-0.80\*\*** | **-0.70\*\*** | 0.07 | -0.11 | - | - | - | - | -0.01 | -0.16 | -0.14 | 0.09 | -0.25 |
| BN | **-0.68\*\*** | **-0.61\*\*** | 0.22 | -0.22 | 0.08 | 0.11 | 0.24 | 0.07 | **-0.48\*** | **-0.67\*\*** | -0.16 | **-0.71\*** | -0.04 |
| Yield | B | -0.20 | -0.00 | -0.14 | - | -0.00 | **-0.49\*\*** | -0.01 | -0.20 | **-0.46\*\*** | 0.13 | **0.34\*** | 0.01 | **-0.58\*** |
| N | **-0.49\*\*** | **-0.61\*\*** | -0.21 | -0.06 | - | - | - | - | 0.09 | 0.14 | -0.40 | **-0.74\*** | -0.29 |
| BN | **-0.44\*\*** | **-0.59\*\*** | -0.11 | -0.09 | **-0.31\*\*** | **0.24\*** | **0.30\*** | **-0.35\*\*** | -0.06 | 0.18 | -0.04 | **-0.92\*\*** | -0.29 |
| GHGI | B | 0.17 | 0.00 | 0.16 | - | -0.37 | -0.25 | -0.05 | **-0.45\*** | -0.44 | -0.43 | 0.22 | - | - |
| N | **-0.73\*\*** | **-0.67\*\*** | -0.07 | -0.21 | - | - | - | - | -0.22 | -0.24 | -0.03 | - | - |
| BN | **-0.59\*\*** | **-0.54\*\*** | 0.06 | -0.18 | 0.10 | -0.31 | 0.25 | **-0.45\*** | -0.29 | **-0.69\*\*** | -0.11 | - | - |

**Fig. S1** Global distribution of the experimental sites selected for the meta-analysis.



**Fig. S2** Effects of biochar (B), nitrogen (N), and combined biochar and nitrogen (BN) additions on soil physical and chemical properties.

**Fig. S3** The responses of soil GWP, yield and GHGI to predictors under BN addition.

**Fig. S4** Model-averaged importance of the predictors of N or B addition effects on soil GHGs. The structural equation model (SEM) examining the indirect and direct effects of predictors on soil GHGs. MAP, mean annual precipitation; MAT, mean annual temperature; SOC: soil organic carbon; B temp: biochar pyrolysis temperature.﻿



**Fig. S5** Relationships between the responses of soil NH4+-N or NO3--N and biochar application rate.



**Part 2: The 75 papers were extracted for the meta-analysis.**

1. Angst, T.E., Patterson, C.J., Reay, D.S., Anderson, P., Peshkur, T.A., Sohi, S.P., 2013. Biochar diminishes nitrous oxide and nitrate leaching from diverse nutrient sources. Journal of Environmental Quality 42, 672-682.
2. Augustenborg, C.A., Hepp, S., Kammann, C., Hagan, D., Schmidt, O., Müller, C., 2012. Biochar and earthworm effects on soil nitrous oxide and carbon dioxide emissions. Journal of Environmental Quality 41, 1203-1209.
3. Azeem, M., Hayat, R., Hussain, Q., Ahmed, M., Pan, G., Tahir, M.I., Imran, M., Irfan, M., Mehmood ul, H., 2019. Biochar improves soil quality and N2-fixation and reduces net ecosystem CO2 exchange in a dryland legume-cereal cropping system. Soil & Tillage Research 186, 172-182.
4. Barracosa, P., Cardoso, I., Marques, F., Pinto, A., Oliveira, J., Trindade, H., Rodrigues, P., Pereira, J.L.S., 2020. Effect of biochar on emission of greenhouse gases and productivity of cardoon crop (*Cynara cardunculus* L.). Journal of Soil Science and Plant Nutrition 20, 1524-1531.
5. Bruun, E., Müller‐Stöver, D., Ambus, P., Hauggaard‐Nielsen, H., 2011. Application of biochar to soil and N2O emissions: potential effects of blending fast‐pyrolysis biochar with anaerobically digested slurry. European Journal of Soil Science 62, 581-589.
6. Chen, J., Kim, H., Yoo, G., 2015. Effects of biochar addition on CO2 and N2O emissions following fertilizer application to a cultivated grassland soil. Plos One 10, e0126841.
7. Cheng, X., Liu, X., Meng, J., Lan, Y., Liu, Z., 2016. Effects of biochar on NH3 volatilization, N2O emission and nitrogen fertilizer use efficiency in brown soil. Journal of Agricultural Environmental Sciences 35, 801-807.
8. Clough, T.J., Bertram, J.E., Ray, J.L., Condron, L.M., Wells, N.S., 2010. Unweathered wood biochar impact on nitrous oxide emissions from a bovine-urine-amended pasture soil. Soil Science Society of America Journal 74, 852-860.
9. Edwards, J.D., Pittelkow, C.M., Kent, A.D., Yang, W.H., 2018. Dynamic biochar effects on soil nitrous oxide emissions and underlying microbial processes during the maize growing season. Soil Biology & Biochemistry 122, 81-90.
10. Feng, Z., Zhu, L., 2017. Impact of biochar on soil N2O emissions under different biochar-carbon/fertilizer-nitrogen ratios at a constant moisture condition on a silt loam soil. Science of the Total Environment 584, 776-782.
11. Fernandez, J.M., Nieto, M.A., Lopez-De-Sa, E.G., Gasco, G., Mendez, A., Plaza, C., 2014. Carbon dioxide emissions from semi-arid soils amended with biochar alone or combined with mineral and organic fertilizers. Science of the Total Environment 482-483, 1-7.
12. Fuertes-Mendizabal, T., Huerfano, X., Vega-Mas, I., Torralbo, F., Menendez, S., Ippolito, J.A., Kammann, C., Wrage-Moennig, N., Cayuela, M.L., Borchard, N., Spokes, K., Novak, J., Gonzalez-Moro, M.B., Gonzalez-Murua, C., Estavillo, J.M., 2019. Biochar reduces the efficiency of nitrification inhibitor 3,4-dimethylpyrazole phosphate (DMPP) mitigating N2O emissions. Scientific Reports 9, 1-16.
13. Fungo, B., Lehmann, J., Kalbitz, K., Tenywa, M., Thionģo, M., Neufeldt, H., 2017. Emissions intensity and carbon stocks of a tropical Ultisol after amendment with Tithonia green manure, urea and biochar. Field Crops Research 209, 179-188.
14. Fungo, B., Lehmann, J., Kalbitz, K., Thiongo, M., Tenywa, M., Okeyo, I., Neufeldt, H., 2019. Ammonia and nitrous oxide emissions from a field Ultisol amended with tithonia green manure, urea, and biochar. Biology and Fertility of Soils 55, 135-148.
15. Gao, J., Zhao, Y., Zhang, W., Sui, Y., Jin, D., Xin, W., Yi, J., He, D., 2019. Biochar prepared at different pyrolysis temperatures affects urea-nitrogen immobilization and N2O emissions in paddy fields. Peerj 7, e7027.
16. Grutzmacher, P., Puga, A.P., Silveira Bibar, M.P., Coscione, A.R., Packer, A.P., de Andrade, C.A., 2018. Carbon stability and mitigation of fertilizer induced N2O emissions in soil amended with biochar. Science of the Total Environment 625, 1459-1466.
17. Hangs, R.D., Ahmed, H.P., Schoenau, J.J., 2016. Influence of willow biochar amendment on soil nitrogen availability and greenhouse gas production in two fertilized temperate prairie soils. Bioenergy Research 9, 157-171.
18. Hawthorne, I., Johnson, M.S., Jassal, R.S., Black, T.A., Grant, N.J., Smukler, S.M., 2017. Application of biochar and nitrogen influences fluxes of CO2, CH4 and N2O in a forest soil. Journal of Environmental Management 192, 203-214.
19. He, L., Zhao, X., Wang, S., Xing, G., 2016. The effects of rice-straw biochar addition on nitrification activity and nitrous oxide emissions in two Oxisols. Soil and Tillage Research 164, 52-62.
20. Horak, J., Kondrlova, E., Igaz, D., Simansky, V., Felber, R., Lukac, M., Balashov, E.V., Buchkina, N.P., Rizhiya, E.Y., Jankowski, M., 2017. Biochar and biochar with N-fertilizer affect soil N2O emission in Haplic Luvisol. Biologia 72, 995-1001.
21. Huang, H., Xiao, Q., Shen, Y., Li, S., 2014. Effect of biochar on nitrous oxide Emissions from dryland spring corn field on the Loess Plateau. Journal of Agro-Environment Science 33, 2063-2070.
22. Ji, C., Li, S., Geng, Y., Miao, Y., Ding, Y., Liu, S., Zou, J., 2020. Differential responses of soil N2O to biochar depend on the predominant microbial pathway. Applied Soil Ecology 145, 103348.
23. Jiang, M., Zhilong, H., Sun, Y., Zhou, W., 2018. The effect of wheat-straw derived biochar on the soil pH and emissions of CO2 and CH4 from tea garden soil. Journal of Agro-Environment Science 01, 196-204.
24. Jiang, X., Haddix, M.L., Cotrufo, M.F., 2016. Interactions between biochar and soil organic carbon decomposition: Effects of nitrogen and low molecular weight carbon compound addition. Soil Biology & Biochemistry 100, 92-101.
25. Kang, S.W., Kim, S.H., Park, J.H., Seo, D.C., Ok, Y.S., Cho, J.S., 2018. Effect of biochar derived from barley straw on soil physicochemical properties, crop growth, and nitrous oxide emission in an upland field in South Korea. Environmental Science and Pollution Research 25, 25813-25821.
26. Lan, Z., Chen, C., Rezaei Rashti, M., Yang, H., Zhang, D., 2018. High pyrolysis temperature biochars reduce nitrogen availability and nitrous oxide emissions from an acid soil. GCB Bioenergy 10, 930-945.
27. Lan, Z.M., Chen, C.R., Rashti, M.R., Yang, H., Zhang, D.K., 2019. Linking feedstock and application rate of biochars to N2O emission in a sandy loam soil: Potential mechanisms. Geoderma 337, 880-892.
28. Li, B., Bi, Z., Xiong, Z., 2017a. Dynamic responses of nitrous oxide emission and nitrogen use efficiency to nitrogen and biochar amendment in an intensified vegetable field in southeastern China. Global Change Biology Bioenergy 9, 400-413.
29. Li, B., Fan, C., Zhang, H., Chen, Z., Sun, L., Xiong, Z., 2015a. Combined effects of nitrogen fertilization and biochar on the net global warming potential, greenhouse gas intensity and net ecosystem economic budget in intensive vegetable agriculture in southeastern China. Atmospheric Environment 100, 10-19.
30. Li, B., Zhang, M., Xiong, Z., 2014. Effects of nitrogen fertilizer and biochar on net global warming potential of intensively managed vegetable fields. China Sciencepaper 9, 1057-1062.
31. Li, L., Zhou, Z.Q., Pan, X.J., Bo, L.I., Xiong, Z.Q., 2015b. Combined effects of nitrogen fertilization and biochar incorporation on methane and nitrous oxide emissions from paddy fields in rice-wheat annual rotation system. Journal of Plant Nutrition and Fertilizer 21, 1095-1103.
32. Li, S., Chen, C., Duan, P., Xu, X., Xiong, Z., 2018. Effects of biochar application N2O emissions and abundance of nitrogen related genes in an acidic vegetable soil. Journal of Plant Nutrition and Fertilizers 24, 414-423.
33. Li, S., Liang, C., Shangguan, Z., 2017b. Effects of apple branch biochar on soil C mineralization and nutrient cycling under two levels of N. Science of the Total Environment 607, 109-119.
34. Li, S., Wang, S., Fan, M., Wu, Y., Shangguan, Z., 2020. Interactions between biochar and nitrogen impact soil carbon mineralization and the microbial community. Soil & Tillage Research 196.
35. Li, X., Zhang, H., Shen, Y., Li, S., 2016. Effect of biochar and fertilizer on CO2 and CH4 emission from spring maize dryland. Acta Botanica Boreali-Occidentalia Sinica 36, 1216-1224.
36. Lin, Y., Ding, W., Liu, D., He, T., Yoo, G., Yuan, J., Chen, Z., Fan, J., 2017. Wheat straw-derived biochar amendment stimulated N2O emissions from rice paddy soils by regulating the *amoA* genes of ammonia-oxidizing bacteria. Soil Biology and Biochemistry 113, 89-98.
37. Liu, X., Zhou, J., Chi, Z., Zheng, J., Li, L., Zhang, X., Zheng, J., Cheng, K., Bian, R., Pan, G., 2019. Biochar provided limited benefits for rice yield and greenhouse gas mitigation six years following an amendment in a fertile rice paddy. Catena 179, 20-28.
38. Liu, X.Y., Qu, J.J., Li, L.Q., Zhang, A.F., Zheng, J., Zheng, J.W., Pan, G.X., 2012. Can biochar amendment be an ecological engineering technology to depress N2O emission in rice paddies?—A cross site field experiment from South China. Ecological Engineering 42, 168-173.
39. Lu, H., Wang, Y., Liu, Y., Wang, Y., He, L., Zhong, Z., Yang, S., 2018. Effects of water-Wwashed biochar on soil properties, greenhouse gas emissions, and rice yield. Clean-Soil Air Water 46, 1700143.
40. Lu, W., Ding, W., Zhang, J., Li, Y., Luo, J., Bolan, N., Xie, Z., 2014. Biochar suppressed the decomposition of organic carbon in a cultivated sandy loam soil: A negative priming effect. Soil Biology & Biochemistry 76, 12-21.
41. Maestrini, B., Herrmann, A.M., Nannipieri, P., Schmidt, M.W.I., Abiven, S., 2014. Ryegrass-derived pyrogenic organic matter changes organic carbon and nitrogen mineralization in a temperate forest soil. Soil Biology & Biochemistry 69, 291-301.
42. Niu, Y., Chen, Z., Mueller, C., Zaman, M.M., Kim, D., Yu, H., Ding, W., 2017. Yield-scaled N2O emissions were effectively reduced by biochar amendment of sandy loam soil under maize - wheat rotation in the North China Plain. Atmospheric Environment 170, 58-70.
43. Oladele, S., Adeyemo, A., Adegaiye, A., Awodun, M., 2019. Effects of biochar amendment and nitrogen fertilization on soil microbial biomass pools in an Alfisol under rain-fed rice cultivation. Biochar 1, 163-176.
44. Rizhiya, E.Y., Horak, J., Simansky, V., Buchkina, N.P., 2020. Nitrogen enriched biochar-compost mixture as a soil amendment to the Haplic Luvisol: effect on greenhouse gas emission. Biologia 75, 873-884.
45. Rizhiya, E.Y., Mukhina, I.M., Vertebniy, V.E., Horak, J., Kononchuk, P.Y., Khomyakov, Y.V., 2017. Soil enzymatic activity and nitrous oxide emission from light-textured spodosol amended with biochar. Agricultural Biology 52, 464-470.
46. Rogovska, Natalia, Laird, David, Cruse, Richard, Fleming, Pierce, Parkin, Tim, 2011. Impact of biochar on manure carbon stabilization and greenhouse gas emissions. Soil Science Society of America Journal 75, 871-879.
47. Sánchez-García, M., Roig, A., Sánchez-Monedero, M.A., Cayuela, M.L., 2014. Biochar increases soil N2O emissions produced by nitrification-mediated pathways. Frontiers in Environmental Science 2, 25.
48. Sánchez-García, M., Sánchez-Monedero, M.A., Cayuela, M.L., 2020. N2O emissions during *Brassica oleracea* cultivation: Interaction of biochar with mineral and organic fertilization. European Journal of Agronomy 115.
49. Shaukat, M., Samoy-Pascual, K., Maas, E.D.V.L., Ahmad, A., 2019. Simultaneous effects of biochar and nitrogen fertilization on nitrous oxide and methane emissions from paddy rice. Journal of Environmental Management 248, 109242.
50. Sherman, L., Coleman, M.D., 2020. Forest soil respiration and exoenzyme activity in western North America following thinning, residue removal for biofuel production, and compensatory soil amendments. GCB Bioenergy 12, 223-236.
51. Sigua, G.C., Novak, J.M., Watts, D.W., Szoegi, A.A., Shumaker, P.D., 2016. Impact of switchgrass biochars with supplemental nitrogen on carbon-nitrogen mineralization in highly weathered Coastal Plain Ultisols. Chemosphere 145, 135-141.
52. Sistani, K.R., Simmons, J.R., Jn-Baptiste, M., Novak, J.M., 2019. Poultry litter, biochar, and fertilizer effect on corn yield, nutrient uptake, N2O and CO2 emissions. Environments 6, 55.
53. Sui, Y., Gao, J., Liu, C., Zhang, W., Yu, L., Li, S., Meng, J., Xu, Z., Liang, T., 2016. Interactive effects of straw-derived biochar and N fertilization on soil C storage and rice productivity in rice paddies of Northeast China. Science of the Total Environment 544, 203-210.
54. Sun, L., Deng, J., Fan, C., Li, J., Liu, Y., 2020. Combined effects of nitrogen fertilizer and biochar on greenhouse gas emissions and net ecosystem economic budget from a coastal saline rice field in southeastern China. Environmental Science and Pollution Research 27, 17013-17022.
55. Sun, L., Li, L., Chen, Z., Wang, J., Xiong, Z., 2014. Combined effects of nitrogen deposition and biochar application on emissions of N2O, CO2 and NH3 from agricultural and forest soils. Soil Science & Plant Nutrition 60, 254-265.
56. Sun, Z., Sänger, A., Rebensburg, P., Lentzsch, P., Wirth, S., Kaupenjohann, M., Meyer-Aurich, A., 2017. Contrasting effects of biochar on N2O emission and N uptake at different N fertilizer levels on a temperate sandy loam. Science of the Total Environment 578, 557-565.
57. Troy, S.M., Lawlor, P.G., O'Flynn, C.J., Healy, M.G., 2013. Impact of biochar addition to soil on greenhouse gas emissions following pig manure application. Soil Biology and Biochemistry 60, 173-181.
58. Wang, H., Yi, H., Zhang, X., Su, W., Li, X., Zhang, Y., Gao, X., 2020. Biochar mitigates greenhouse gas emissions from an acidic tea soil. Polish Journal of Environmental Studies 29, 323-330.
59. Wang, J., Pan, X., Liu, Y., Zhang, X., Xiong, Z., 2012. Effects of biochar amendment in two soils on greenhouse gas emissions and crop production. Plant and Soil 360, 287-298.
60. Wang, J., Zhang, M., Xiong, Z., Liu, P., Pan, G., 2011. Effects of biochar addition on N2O and CO2 emissions from two paddy soils. Biology and Fertility of Soils 47, 887-896.
61. Wang, Y.B., Jun, W.U., Li, J.H., Cai, L.Q., Zhang, J., Zhang, R.Z., 2019. Effect of organic materials on N2O emission under different N-fertilizer levels in dryland of the Loess Plateau of central Gansu Province. Agricultural Research in the Arid Areas 37, 108-115.
62. Wei, X., Sun, N., Zhang, X., Zhang, S., Wang, D., Shen, H., 2016. Characteristics of CO2 emissions and changes in carbon fractions after application of biochar under various fertilization regimes in vegetable soil. Scientia Agricultura Sinica 49, 3578-3587.
63. Wu, Z., Zhang, X., Dong, Y., Li, B., Xiong, Z., 2019. Biochar amendment reduced greenhouse gas intensities in the rice-wheat rotation system: six-year field observation and meta-analysis. Agricultural and Forest Meteorology 278, 107625.
64. Xiao, Y., Che, Y., Zhang, F., Li, Y., Liu, M., 2018. Effects of biochar, N fertilizer, and crop residues on greenhouse gas emissions from acidic soils. Clean-Soil Air Water 46, 1700346.
65. Xu, X., Wu, Z., Dong, Y., Zhou, Z., Xiong, Z., 2016. Effects of nitrogen and biochar amendment on soil methane concentration profiles and diffusion in a rice-wheat annual rotation system. Scientific Reports 6, 1-13.
66. Yong, W., Rujie, L., Xing, L., Shuixiu, H., Qingyin, S., 2021. Effects of biochar and nitrogen incorporation on greenhouse gas emissions in double rice-cropping system. China Rice 27, 20-26.
67. Zhang, A., Cui, L., Pan, G., Li, L., Hussain, Q., Zhang, X., Zheng, J., Crowley, D., 2010. Effect of biochar amendment on yield and methane and nitrous oxide emissions from a rice paddy from Tai Lake plain, China. Agriculture, ecosystems & environment 139, 469-475.
68. Zhang, A., Liu, Y., Pan, G., Hussain, Q., Li, L., Zheng, J., Zhang, X., 2012a. Effect of biochar amendment on maize yield and greenhouse gas emissions from a soil organic carbon poor calcareous loamy soil from Central China Plain. Plant and Soil 351, 263-275.
69. Zhang, B., Liu, X., Pan, G., Zheng, J., Zhang, X., 2012b. Changes in soil properties, yield and trace gas emission from a paddy after biochar amendment in two consecutive rice growing cycles. Scientia Agricultura Sinica 45, 4844-4853.
70. Zhang, J., Li, Q., Wu, J., Song, X., 2019a. Effects of nitrogen deposition and biochar amendment on soil respiration in a *Torreya grandis* orchard. Geoderma 355, 113918.
71. Zhang, X., Sun, Y., Zhang, S., Yue, K., Cao, H., Lin, S., 2019b. Effects of biochar on N2O emission from four typical soils in the North China Plain. Environmental Science 40, 5173-5181.
72. Zhang, Y., Lin, F., Wang, X., Zou, J., Liu, S., 2016. Annual accounting of net greenhouse gas balance response to biochar addition in a coastal saline bioenergy cropping system in China. Soil and Tillage Research 158, 39-48.
73. Zhao, R., Coles, N., Wu, J., 2015. Soil carbon mineralization following biochar addition associated with external nitrogen. Chilean Journal of Agricultural Research 75, 465-471.
74. Zheng, J., Stewart, C.E., Cotrufo, M.F., Biochar and nitrogen fertilizer alters soil nitrogen dynamics and greenhouse gas fluxes from two temperate soils. Journal of Environmental Quality 41, 1361.
75. Zhou, Z., Xu, X., Bi, Z., Li, L., Li, B., Xiong, Z., 2016. Soil concentration profiles and diffusion and emission of nitrous oxide influenced by the application of biochar in a rice-wheat annual rotation system. Environmental Science and Pollution Research 23, 7949-7961.