SINGLE-IMPACT FICHE
SOIL AMENDMENT WITH BIOCHAR

IMPACT: GREENHOUSE GAS EMISSION

Data extracted in February 2021

Note to the reader: This fiche summarises the impact of soil amendment with biochar on GREENHOUSE GAS EMISSION (CH_4, N_2O, and all GHGs emission combined, taking into account only direct emissions from soils after amendment with biochar). It is based on 14 peer-reviewed synthesis research papers[1], each of them including from 5 to 129 individual studies.

1. WEIGHT OF THE EVIDENCE

- CONSISTENCY OF THE IMPACT:
  Soil amendment with biochar, compared to no-biochar-amendment, showed variable effects on greenhouse gas emissions, depending on the type of greenhouse gas emission (see **Table 1**).
  A consistent positive effect (decrease) was reported for N_2O emission in 6 out of 8 synthesis studies.
  However, biochar showed inconsistent results for CH_4 emissions and for CO_2 emissions (direct emissions from soil respiration). From 13 results, 7 showed no-effect, while 3 showed a positive effect and 3 a negative effect. The various effects were found to depend on the type of soil (soil pH, texture, organic carbon content, redox conditions, etc.) and biochar properties (feedstock precursor, pyrolysis temperature, pH, etc.).
  The global warming potential given by the combined effect of GHGs emissions (as CO_2-equivalents) from soil after soil after amendment with biochar was consistently reported as positive (decrease) in 3 out of 3 synthesis studies

  From the 14 reviewed synthesis papers, 7 include data collected in Europe, 1 in China and 6 do not specify geographical locations (see **Table 2**).

Table 1. Summary of effects. The numbers between parenthesis indicate the number of synthesis papers with a quality score of at least 50%. Details on quality criteria can be found in the next section.

Impact	Metric	Positive	Negative	No effect	Uncertain
Decrease GHG emissions*	CH_4*	2 (2)	2 (2)	3 (3)	0
	N_2O*	6 (6)	0	2 (2)	0
	All GHGs emission **	3 (3)	0	0	0

*Direct emissions from soils after amendment with biochar;
** combined effect of GHG emissions (as CO_2-equivalents) from soil after amendment with biochar (excluding emissions along biochar production/distribution chains and carbon sequestration in soil)

- QUALITY OF THE SYNTHESIS PAPERS: *The quality score summarises 16 criteria assessing the quality of three main aspects of the synthesis papers: 1) the literature search strategy and studies selection; 2) the statistical analysis; 3) the potential bias. Details on quality criteria can be found in the methodology section of this WIKI*.

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[1] Research synthesis papers include a formal meta-analysis or systematic reviews with some quantitative results Details can be found in the methodology section of the WIKI

2. IMPACTS

The main characteristics and results of the synthesis papers are summarized in **Table 2**. Summaries of the meta-analyses provide fuller information about the results reported in each synthesis paper, in particular about the modulation of effects by factors related to soil, climate and management practices.

Table 2. Main characteristics of the synthesis papers reporting impacts of soil amendment with biochar on greenhouse gas emission.

Reference	Population	Geographical scale	Num. papers	Intervention	Comparator	Metric	Conclusion	Quality score
Xu, WH; Whitman, WB; Gundale, MJ; Chien, CC; Chiu, CY 2021	not specified	Global	107	Soil amendment with biochar	No amendment	CO_2 emissions from soil	Soil respiration did not significantly change with biochar application.	69%
Gu, JX; Wu, YY; Tian, ZY; Xu, HH 2020	Greenhouse vegetables	China	5	Soil amendment with biochar	No amendment	N_2O emission, Yield-scaled N_2O emission	Biochar application decreased N_2O emission factor (per unit of N-input) and yield-scaled N_2O emissions from greenhouse vegetables. Area-scaled N_2O emission was not significantly changed.	75%
Zhang, Q; Xiao, J; Xue, JH; Zhang, L 2020	Not specified	Global	129	Soil amendment with biochar	No amendment	CH_4, CO_2, N_2O emissions and Global warming potentials from soil	Biochar application enhanced the soil CH_4 and CO_2 emissions but reduced the N_2O flux. However, the overall global warming potential (area-scaled) and greenhouse gas emission intensity (i.e. Yield-scaled) significantly decreased.	62%
Borchard, N; Schirrmann, M; Cayuela, ML; Kammann, C; Wrage-Monnig, N; Estavillo, JM; Fuertes-Mendizabal, T; Sigua, G; Spokas, K; Ippolito, JA; Novak, J 2019	Not specified	Global	88	Soil amendment with biochar	No amendment	N_2O emission	Biochar stimulates an overall N_2O emissions reduction of 38% with greater reductions immediately after application. Results support the notion of a dose-response relationship of biochar application on N_2O emission reduction, which hints towards the interesting possibility of using biochar as a carrier matrix for "carbon-fertilizers".	94%

Reference	Population	Geographical scale	Num. papers	Intervention	Comparator	Metric	Conclusion	Quality score
Liu, X; Mao, PN; Li, LH; Ma, J 2019	Not specified	Global	28	Soil amendment with biochar	No amendment	Yield-scaled global warming potential	Biochar application significantly reduced yield-scaled GHG intensity by 29%.	75%
Wu, Z; Zhang, X; Dong, YB; Li, B; Xiong, ZQ 2019	Rice-wheat/corn rotation systems	Global	60	Soil amendment with biochar	No amendment	N2O, CH4 emissions	Biochar application appeared to be a good strategy to mitigate global warming in fertilized soils over a long period on a global scale.	88%

3. KNOWLEDGE GAPS

Zhang et al., 2021	Although the short-term effect of biochar on soil GHG emissions and crop yield was analyzed, the sustainability of biochar for long-term application needs further research. Long-term trials, particularly under field conditions, are required to investigate the impact of biochar on reducing GHG intensity.
Borchard et al., 2019	Knowledge of biochar-induced effects on soil N2O emissions especially on grassland and perennial crops is incomplete.
Liu et al., 2019	Long-term field trials are required to examine the persistence of the impact of biochar on reducing yield-scaled GHGI in the future.
Wu et al, 2019	To elucidate the sustainable effect of biochar on soil GHG fluxes, field experiments performed on historically charcoal-rich soils should be broadened to a wider range of environmental and management factors.
Awad et al, 2018	The understanding of interactions between biochar and its dependent variables such as rice seedlings, iron reduction, soil quality and productivity, microbial communities and activities, and toxicity mitigation under varying redox conditions due to flooding and drainage in rice paddies should comprehensively be reinforced in the future.
Cong et al, 2018	These results are based on the mean CH4 flux, but not the cumulative CH4 uptake/emission in the experimental time for the flux change comparison among studies. This means that the effects of some environmental factors (soil temperature, moisture, etc.) are usually less consistent in field experiments compared to lab incubations and may therefore result in more substantial CH4 flux variation. Unfortunately, very few field studies have tested the effect of soil temperature and

	moisture trends on amended plots over large time scales; such studies are necessary to further our understanding of the response patterns and regulators of soil CH_4 flux identified as key factors in this study.
Ji et al, 2018	In this meta-analysis, the authors could not fully take environmental and management factors into consideration, such as the auxiliary data on other soil key properties (for example, soil total organic or microbial C) due to the lack of relevant information in the literature, which may have interactive effects with biochar on soil methanogenesis or CH_4 oxidation processes. To elucidate the sustainable effect of biochar on soil CH_4 fluxes, field experiments over a longer period across a wider range of environmental and management factors are needed in the future, instead of laboratory incubation or pot studies as included in the present quantitative analysis.
Liu et al, 2018	The biochar effects synthesized in the current paper are mainly derived from experiments characterized by single-dose designs and relatively short-term time scales (months to a few years). Biochar effects with respect to longer-term and repetitive additions require further evaluation with future more relevant experimental data.
Zhou et al, 2017	Short term lab or pot experiments may provide biased information for interpreting biochar's effect on soil and agricultural production. The meta-analysis here demonstrated the large uncertainty about the microbial response to biochar across the experiments with different lengths of duration. Yet, information from the existing studies mainly with short term lab incubations had limited our understanding of soil microbial response to biochar and the potential impact on carbon dynamics in agricultural soils.
Liu et al., 2016	The authors did not take into consideration the data on environmental and management conditions or the auxiliary data on other soil properties (e.g., soil inorganic C and N) due to lack of relevant information in studies included. The limited range of study durations did not allow us to examine the effect of biochar aging on soil CO_2 fluxes, SOC, and MBC in this meta-analysis. No studies ran more than 4 years, and only 21% of the observations included in this analysis showed results over a whole growing season with the presence of vegetation cover. To evaluate the effect of biochar on soil CO_2 fluxes and its effectiveness at enhancing soil C sequestration potential, therefore, field experiments with longer durations across a wider range of spatial and temporal scales are required.
Sagrilo et al, 2015	The studies used in our meta-analysis were predominantly from laboratory experiments (82%), compared to field (10%) and greenhouse experiments (8%). Moreover, laboratory experiments accounted for 90% of data points with PyC:SOC ratio >2. In fact, there was a significant difference in relative PyC addition rates between laboratory and field studies (Fisher's exact test, two-sided; $P = 0.001$). However, such ratios likely result in overestimation of the effect size. Furthermore, they are unrealistic representations of expected results under field conditions. It is necessary therefore that future research utilizes experimental designs with realistic

PyOM treatments rather than the large amounts often used in laboratory experiments.