

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 (CH₄, CO₂, N₂O, and overall Global warming potential, taking into account only direct emissions from soils after amendment with biochar). It is based on 14 peer-reviewed synthesis research papers¹, 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 N₂O emission in 6 out of 8 synthesis studies.

However, biochar showed inconsistent results for CH₄ emissions and for CO₂ 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 combined effect of CH₄, CO₂ and N₂O emissions (as CO₂-equivalents) from 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 effect with the higher score is marked in bold and the cell coloured. 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 |
| | CO ₂ * | 1 (1) | 1 (1) | 4 (4) | 0 |
| | N ₂ O* | 6 (6) | 0 | 2 (2) | 0 |
| | CH ₄ + CO ₂ + N ₂ O ** | 3 (3) | 0 | 0 | 0 |

*Direct emissions from soils after amendment with biochar;

** combined effect of CH₄, N₂O and CO₂ emission (as CO₂-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 this document* →.

¹ Research synthesis papers include a formal meta-analysis or systematic reviews with some quantitative results

As shown in the “Quality score” in **Table 2**, the quality level ranges from 62% to 94%. The least frequently satisfied quality criteria were “Number of studies at each step”, “Individual effect sizes”, “Dataset available” and “Publication bias analysed”.

2. IMPACTS

The main characteristics and results of the synthesis papers are summarized in **Table 2**. Detailed results of each synthesis study are reported in the summary reports [→](#).

Table 2. Main characteristics of the synthesis papers reporting impacts of soil amendment with biochar on greenhouse gas emission. The references are ordered chronologically with the most recent publication date first.

| Reference | Population | Geographic 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 ₂ O emission, Yield-scaled N ₂ O emission | Biochar application decreased N ₂ O emission factor (per unit of N-input) and yield-scaled N ₂ O emissions from greenhouse vegetables. Area-scaled N ₂ O 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 ₂ O emissions and Global warming potentials from soil | Biochar application enhanced the soil CH ₄ and CO ₂ emissions but reduced the N ₂ O 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, | Not specified | Global | 88 | Soil amendment with biochar | No amendment | N ₂ O emission | Biochar stimulates an overall N ₂ O emissions reduction of 38% with greater reductions immediately after application. Results support the notion of a dose-response relationship of biochar application on N ₂ O emission reduction, which hints towards the interesting possibility of using biochar as a carrier | 94% |

| Reference | Population | Geographic scale | Num. papers | Intervention | Comparator | Metric | Conclusion | Quality score |
|--|----------------------------------|------------------|-------------|-----------------------------|--------------|---|---|---------------|
| JA; Novak, J 2019 | | | | | | | matrix for "carbon-fertilizers". | |
| 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 | N ₂ O, CH ₄ 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

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|------------------------------|--|
| 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 N ₂ O 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 CH ₄ flux, but not the cumulative CH ₄ 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 CH₄ 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 CH₄ oxidation processes. To elucidate the sustainable effect of biochar on soil CH₄ 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 CO₂ 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 CO₂ 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.

4. SYSTEMATIC REVIEW SEARCH STRATEGY

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|--------------------|---|
| Keywords | <p>TOPIC: (biochar OR charcoal OR "black carbon") AND TOPIC: (soil OR agriculture OR farming) AND TOPIC: ("meta-analy*" OR "systematic* review*" OR "evidence map" OR "global synthesis" OR "evidence synthesis" OR "research synthesis")</p> <p>or</p> <p>TITLE-ABS-KEY: (biochar OR charcoal OR "black carbon") AND TITLE-ABS-KEY: (soil OR agriculture OR farming) AND TITLE-ABS-KEY: ("meta-analy*" OR "systematic* review*" OR "evidence map" OR "global synthesis" OR "evidence synthesis" OR "research synthesis")</p> |
| Search dates | No time restrictions |
| Databases | Web of Science and Scopus, run in February 2021 |
| Selection criteria | <p>The main criteria that led to the exclusion of a synthesis paper were if the paper: 1) does not deal with agronomic application of biochar; 2) does not synthesize pairwise comparisons on the agronomic effect of biochar; 3) the control of the pairwise comparison is not no-biochar; 4) deals with soil application of mineral- or organic-enriched biochar; 5) does not report results with the same fertilisation conditions between intervention and control; 6) is either a simple review, a non-quantitative systematic review, a meta-regressions looking only at factors influences, without mean effect sizes; 7) deals with other than agricultural soils in cropping systems, e.g. forest restoration; 8) is not written in English. Synthesis papers that passed the relevance criteria were subject to critical appraisal carried out on paper-by-paper basis.</p> <p>The search returned 130 synthesis papers potentially relevant for the practice object of our fiche. Searches for other farming practices added another 2 potentially relevant synthesis papers. From the 132 potentially relevant synthesis papers, 57 were excluded after reading the title and abstract, and 34 after reading the full text according to the above-mentioned criteria. Because of the high number of studies available, we only considered the most recent meta-analyses dealing with the impact of soil amendment with biochar on GHG emissions, published since 2015. Finally, 41 synthesis papers were selected for soil amendment with biochar, from which 14 were relevant for this impact.</p> |

