# SINGLE-IMPACT FICHE
# SOIL AMENDMENT WITH BIOCHAR

## IMPACT: GHG EMISSIONS

Data extracted in February 2021
Fiche created in May 2024

**Note to the reader**: This fiche summarises the effects of Soil amendment with biochar on GHG EMISSIONS. It is based on 10 synthesis papers[1], including from 5 to 208 primary 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 (**Table 1**).

The table below shows the number of synthesis papers with statistical tests reporting i) a significant difference between the Intervention and the Comparator, that is to say, a significant statistical effect, which can be positive or negative; or ii) a non-statistically significant difference between the Intervention and the Comparator. In addition, we include, if any, the number of synthesis papers reporting relevant results but without statistical test of the effects. Details on the quality assessment of the synthesis papers can be found in the methodology section of this WIKI.

- 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 aggregated effect of GHGs emissions (expressed as $CO_2$-equivalents) from soil after soil after amendment with biochar was consistently reported as significant positive (decrease) in 2 out of 2 synthesis studies.
- One synthesis study reported a significant positive effect on yield-scaled aggregated GHG emission (as $CO_2$eq per ton of harvested crop).

Out of the 10 selected synthesis papers, 5 included studies conducted in Europe (see **Table 2**).

**Table 1**: Summary of effects. Number of synthesis papers reporting positive, negative or non-statistically significant effects on environmental and climate impacts. The number of synthesis papers reporting relevant results but without statistical test of the effects are also provided. When not all the synthesis papers reporting an effect are of high quality, the number of synthesis papers with a quality score of at least 50% is indicated in parentheses. The reference numbers of the synthesis papers reporting each of the effects are provided in **Table 3**. Some synthesis papers may report effects for more than one impact or more than one effect for the same impact.

| | | | | Statistically tested | | | Non-statistically tested |
|---|---|---|---|---|---|---|---|
| Impact | Metric | Intervention | Comparator | Significantly positive | Significantly negative | Non-significant | |
| Decrease ghg emissions | Aggregated soil GHG emission (as $CO_2$eq) | Soil amendment with biochar | No amendment | 2 | 0 | 0 | 0 |
| Decrease ghg emissions | $CH_4$ | Soil amendment with biochar | No amendment | 2 | 2 | 3 | 0 |
| Decrease ghg emissions | $N_2O$ | Soil amendment with biochar | No amendment | 6 | 0 | 2 | 0 |
| Decrease ghg emissions | Yield-scaled aggregated soil GHG emission (as $CO_2$eq) | Soil amendment with biochar | No amendment | 1 | 0 | 0 | 0 |

QUALITY OF THE SYNTHESIS PAPERS

The quality of each synthesis paper was assessed based on 16 criteria regarding three main aspects: 1) the literature search strategy and primary studies selection; 2) the statistical analysis conducted; and 3) the evaluation of potential bias. We assessed whether authors addressed and reported these criteria. Then, a quality score was calculated as the percentage of these 16 criteria properly addressed and reported in each synthesis paper. Details on quality criteria can be found in the methodology section of this WIKI.

## 2. IMPACTS

[1] Synthesis research papers include either meta-analysis or systematic reviews with quantitative results. Details can be found in the methodology section of the WIKI.

The main characteristics and results of the 10 synthesis papers are reported in **Table 2** with the terminology used in those papers, while **Table 3** shows the reference numbers of the synthesis papers reporting for each of the results shown in **Table 1**. Comprehensive 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, are provided in the **summaries of the synthesis papers** available in this WIKI.

**Table 2**: Main characteristics of the synthesis papers reporting effects on ghg emissions. The references are ordered chronologically with the most recent publication date first.

| Reference number | Population | Scale | Num. papers | Intervention | Comparator | Metric | Conclusion | Quality score |
|---|---|---|---|---|---|---|---|---|
| Ref9 | Greenhouse vegetables | China | 5 | Soil amendment with biochar | No amendment | 1) Area-scaled $N_2O$ emission (kgN /ha); 2) $N_2O$ emission factor (% of total N); 3) Yield-scaled $N_2O$ emission (kgN /ton crop harvested) | Applying biochar was capable of decreasing $N_2O$ 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% |
| Ref15 | Biochar obtained from crop residues or straw | Global | 129 | Soil amendment with biochar | No amendment | 1) $CH_4$ emission; 2) $N_2O$ emission; 3) $CO_2$eq emission | Biochar application enhanced the soil $CH_4$ and $CO_2$ emissions but reduced the $N_2O$ flux. However, with biochar application, the overall global warming potential (area-scaled) and greenhouse gas emission intensity (i.e. Yield-scaled) significantly decreased. | 62% |
| Ref17 | 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% |
| Ref19 | 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% |
| Ref21 | Rice-wheat/corn rotation systems | Global | 60 | Soil amendment with biochar | No amendment | 1) $CH_4$ emission; 2) $N_2O$ emission | Biochar application appeared to be a good strategy to mitigate global warming in fertilized soils over a long period on a global scale. | 88% |
| Ref22 | Rice cultivation | Global | 13 | Soil amendment with biochar | No amendment | 1) $CH_4$ emission; 2) $N_2O$ emission; 3) $CO_2$eq emission | Biochar have no significant effect on $CH_4$ and $N_2O$ emissions. However, the effect on the overall global warming potential (both area- and yield-scaled) was a significant decrease. | 88% |
| Ref23 | Column, pot and field experiments on rice (paddy soils) | Global | 40 | Soil amendment with biochar | No amendment | 1) $CH_4$ emission; 2) $N_2O$ emission | Biochar application significantly reduces $CO_2$ and $N_2O$ emissions in paddy soils, while having no significant effect on $CH_4$ emissions. | 56% |
| Ref25 | Paddy soils and upland soils | Global | 40 | Soil amendment with biochar | No amendment | $CH_4$ emission | Biochar application do not significantly change $CH_4$ fluxes, in average. However, there is substantial variation in the soil $CH_4$ flux response to biochar amendment. Interaction of soil properties tends to regulate the soil $CH_4$ emission/uptake response to biochar addition. | 69% |
| Ref26 | Paddy soils and upland soils | Global | 61 | Soil amendment with biochar | No amendment | 1) $CH_4$ emission; 2) $CH_4$ uptake | The evidence provided here demonstrates that biochar amendment benefits $CH_4$ mitigation for paddy soils, and a more beneficial effect can be achieved in upland soils acting as sources of $CH_4$. However, for upland soils acting as sinks of $CH_4$, a significant negative response of soil $CH_4$ uptake to biochar would instead potentially intensify global warming by increasing the source strength of atmospheric $CH_4$. Biochar's potential to mitigate $CH_4$ emissions from paddies and uplands would be largely offset by its induced decreases in $CH_4$ uptake of upland soils. | 94% |
| Ref27 | Not specified | Global | 208 | Soil amendment with biochar | No amendment | $N_2O$ emission | Biochar addition significantly decreases soil $N_2O$ emissions. However, $N_2O$ emissions due to biochar production in the absence of pyrolytic syngas purification could weaken or destroy the effectiveness of biochar in mitigating soil $N_2O$ emission. | 69% |

**Table 3**: Reference numbers of the synthesis papers reporting for each of the results shown in **Table 1**.

| | | | | Statistically tested | | | Non-statistically tested |
|---|---|---|---|---|---|---|---|
| Impact | Metric | Intervention | Comparator | Significantly positive | Significantly negative | Non-significant | |
| Decrease ghg emissions | Aggregated soil GHG emission (as $CO_2$eq) | Soil amendment with biochar | No amendment | Ref15 and Ref22 | | | |
| Decrease ghg emissions | $CH_4$ | Soil amendment with biochar | No amendment | Ref21 and Ref26 | Ref15 and Ref26 | Ref22, Ref23 and Ref25 | |
| Decrease ghg emissions | $N_2O$ | Soil amendment with biochar | No amendment | Ref9, Ref15, Ref17, Ref21, Ref23 and Ref27 | | Ref9 and Ref22 | |
| Decrease ghg emissions | Yield-scaled aggregated soil GHG emission (as $CO_2$eq) | Soil amendment with biochar | No amendment | Ref19 | | | |

## 3. FACTORS INFLUENCING THE EFFECTS ON GHG EMISSIONS

**Table 4**: List of factors reported to significantly affect the size and/or direction of the effects on ghg emissions, according to the synthesis papers reviewed.

| Factor | Reference number |
|---|---|
| Biochar application rate | Ref15, Ref17, Ref19, Ref23, Ref26 and Ref27 |

| Factor | Reference number |
|---|---|
| Biochar C/N | Ref21 |
| Biochar C/N ratio and pH | Ref26 |
| Biochar feedstock | Ref23 and Ref26 |
| Biochar incubation time in soil | Ref15 |
| Biochar pyrolysis temperature | Ref23 |
| Crop type | Ref17 |
| Cropping system | Ref19 |
| Fertilisation management | Ref17 |
| N-fertilisation | Ref26 |
| N fertilisation | Ref19 |
| N fertilisation rate | Ref21 |
| NA | Ref9, Ref9, Ref9, Ref9, Ref9, Ref9, Ref9, Ref9, Ref15, Ref15, Ref15, Ref15, Ref17, Ref17, Ref17, Ref19, Ref19, Ref19, Ref21, Ref21, Ref21, Ref22, Ref22, Ref22, Ref22, Ref22, Ref22, Ref22, Ref22, Ref23, Ref23, Ref23, Ref23, Ref23, Ref25, Ref25, Ref25, Ref25, Ref25, Ref27, Ref27, Ref27, Ref27, Ref27 |
| Scale of experiment | Ref26 |
| Soil C/N ratio | Ref21 |
| Soil flooding | Ref25 |
| Soil organic carbon | Ref25 and Ref27 |
| Soil organic matter content | Ref17 |
| Soil pH | Ref15, Ref19, Ref21 and Ref26 |
| Soil texture | Ref15, Ref19, Ref25, Ref26 and Ref27 |
| Soil type | Ref17 and Ref26 |
| Time scale | Ref21 |

## 4. KNOWLEDGE GAPS

**Table 5**: Knowledge gap(s) reported by the authors of the synthesis papers included in this review.

| Ref Num | Gap |
|---|---|
| Ref15 | 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. |
| Ref17 | Knowledge of biochar-induced effects on soil $N_2O$ emissions especially on grassland and perennial crops is incomplete. |
| Ref19 | Long-term field trials are required to examine the persistence of the impact of biochar on reducing yield-scaled GHGI in the future. |
| Ref21 | 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. |
| Ref23 | The understanding ofinteractions 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 com- prehensively be reinforced in the future. |
| Ref25 | 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 $CH_4$ 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. |
| Ref26 | 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. |
| Ref27 | 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. |

## 5. SYNTHESIS PAPERS INCLUDED IN THE REVIEW

**Table 6**: List of synthesis papers included in this review. More details can be found in the summaries of the meta-analyses.

| Ref Num | Author(s) | Year | Title | Journal | DOI |
|---|---|---|---|---|---|
| Ref9 | Gu, JX; Wu, YY; Tian, ZY; Xu, HH | 2020 | Nitrogen use efficiency, crop water productivity and nitrous oxide emissions from Chinese greenhouse vegetables: A meta-analysis | Sci Total Environ. 743:140696. | 10.1016/j.scitotenv.2020.140696 |
| Ref15 | Zhang, Q; Xiao, J; Xue, JH; Zhang, L | 2020 | Quantifying the Effects of Biochar Application on Greenhouse Gas Emissions from Agricultural Soils: A Global Meta-Analysis | Sustainability 12:3436. . | 10.3390/su12083436 |
| Ref17 | 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 | Biochar, soil and land-use interactions that reduce nitrate leaching and N2O emissions: A meta-analysis | Sci. Total Environ. 2354–64. | 10.1016/j.scitotenv.2018.10.060 |
| Ref19 | Liu, X; Mao, PN; Li, LH; Ma, J | 2019 | Impact of biochar application on yield-scaled greenhouse gas intensity: A meta-analysis | Sci. Total Environ. p. 969–76. | 10.1016/j.scitotenv.2018.11.396 |
| Ref21 | Wu, Z; Zhang, X; Dong, YB; Li, B; Xiong, ZQ | 2019 | Biochar amendment reduced greenhouse gas intensities in the rice-wheat rotation system: six-year field observation and meta-analysis | Agric For Meteorol. 278:107625. | 10.1016/j.agrformet.2019.107625 |
| Ref22 | Zhao, X; Pu, C; Ma, ST; Liu, SL; Xue, JF; Wang, X; Wang, YQ; Li, SS; Lal, R; Chen, F; Zhang, HL | 2019 | Management-induced greenhouse gases emission mitigation in global rice production | Sci Total Environ. 649:1299–306. | 10.1016/j.scitotenv.2018.08.392 |
| Ref23 | Awad, YM; Wang, JY; Igalavithana, AD; Tsang, DCW; Kim, KH; Lee, SS; Ok, YS | 2018 | Biochar Effects on Rice Paddy: Meta-analysis | Adv. Agron. 148 | 10.1016/bs.agron.2017.11.005 |
| Ref25 | Cong, WW; Meng, J; Ying, SC | 2018 | Impact of soil properties on the soil methane flux response to biochar addition: a meta-analysis | Agric For Meteorol. 278:107625. | 10.1039/c8em00278a |
| Ref26 | Ji, C; Jin, YG; Li, C; Chen, J; Kong, DL; Yu, K; Liu, SW; Zou, JW | 2018 | Variation in Soil Methane Release or Uptake Responses to Biochar Amendment: A Separate Meta-analysis | Agric For Meteorol. 278:107625. | 10.1007/s10021-018-0248-y |
| Ref27 | Liu, Q; Zhang, YH; Liu, BJ; Amonette, JE; Lin, ZB; Liu, G; Ambus, P; Xie, ZB | 2018 | How does biochar influence soil N cycle? A meta-analysis | Plant Soil 426:211–25 | 10.1007/s11104-018-3619-4 |