FARMING PRACTICE
SOIL AMENDMENT WITH BIOCHAR

IMPACT: GHG EMISSIONS

Reference 17

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

Background and objective

Biochar can reduce both nitrous oxide (N_2O) emissions and nitrate (NO_3^-) leaching, but refining biochar's use for estimating these types of losses remains elusive. For example, biochar properties such as ash content and labile organic compounds may induce transient effects that alter N-based losses. The aim of this meta-analysis was to assess interactions between biochar-induced effects on N_2O emissions, regarding the duration of experiments as well as soil and land use properties.

Search strategy and selection criteria

A comprehensive survey of literature published between January 1, 2010 and May 31, 2016 was conducted, compiling 701 observations from 88 peer-reviewed publications accessed on the ISI Web of Knowledge. By using the term "biochar" in the "topic" field, 3328 publications appeared, but the number was reduced to 88 publications by abstract and full publication screenings. Studies were scrutinized using the following inclusion/exclusion quality criteria: They: 1) were conducted in soil (e.g., horticultural substrates were excluded); 2) included a minimum of three replicates per treatment; 3) followed a randomized design; 4) contained a "treatment" and a "control" such that the treatment was the same as the control in all aspects except for the inclusion of biochar; and 5) reported cumulative net N_2O emissions, cumulative NO_3^- leached and/or final NO_3^- concentrations in soil.

Data and analysis

The combined effect size over all available studies was estimated with a random effects model. The random effects model was chosen because we did not assume that the underlying true effect size is homogeneous over all included studies due to study conditions and environmental influences, and we further wanted to make generalizations beyond the observed studies (Hedges and Vevea, 1998). The random effects model was estimated with the DerSimonian-Laird estimator (DerSimonian and Laird, 2015). Each study was weighted by the inverse of its sampling error variance (inverse-variance-weighting), which ensures that studies with very small sample sizes do not have a severe influence on the estimates. The overall effect was estimated for cumulative N_2O emissions, final NO_3^- concentration, and cumulative NO_3^- leaching. For assessing the heterogeneity of the meta-analysis, the I^2 index was used. The I^2 index indicates the percentage of the total variability among the effect sizes that can be explained by the between-studies heterogeneity.

Number of papers	Population	Intervention	Comparator	Outcome	Quality score
88	Not specified	Soil amendment with biochar	No amendment	Metric: N_2O emission; Effect size: Logarithm of ratio of the considered metrics in the intervention to the considered metrics in the control	0.9375

Results

- Results showed a significant reduction of overall N_2O emissions by 38% ($P < 0.05$) caused by biochar applications, regardeless of biochar particle size, pH,C contents, N contents and soil texture, pH, SOC concentrations. According to the Failed Safe N-test, the significant N_2O reduction is robust against a possible positive publication bias because a huge number of non-significant observations would need to be furthermore included in the meta-analysis (>650.000) to turn the significant result into a non-significant result. However, biochar induced reductions of N_2O emissions were of transient nature with a tendency to be negligible within one year
- Biochars produced of wood and lignocellulosic biomass by gasification, slow pyrolysis, and their combination with steam at each heating temperature, reduced soil N_2O emissions ($P < 0.05$). On the other hand, N_2O emissions remained unaffected after application of i) biochars made of manure and biosolids ($P = 0.095$) and ii) biochar produced by fast pyrolysis (particle residence time a few seconds; Bruun et al. 2012) and iii) hydrochars produced via hydrothermal carbonization.
- In terms of land use, biochar can reduce rice paddy soil N_2O emissions (i.e. Anthrosols) by almost 40%; this may significantly mitigate climate change, as ~140 Mha are used as paddy fields globally.

Factors influencing effect sizes

- Soil organic matter content : In soils with SOC concentrations >24 g kg−1 and total N concentrations >3 g kg−1, the N_2O emission reduction was smallest and not significant.
- Soil type : Man-made soils (i.e. Anthrosols represented in this study exclusively by paddy soils), organic soils (i.e. Histosols), sandy soils (i.e. Arenosol), and soils typical for steppe and sub-humid temperate climate (i.e. Luvisol) showed reduced N_2O emissions after biochar applications
- Biochar application rate : Low biochar application rates of <10 Mg ha−1 did not affect N_2O emissions.
- Fertilisation management : N_2O emissions remained unaffected for soils managed by application of biochar in combination with organic fertilizers. Compared to unfertilized soils, the N_2O emission mitigation potential of biochars was larger for fertilized soils (reduction of −46% for mineral fertilizer [e.g. NH_4NO_3, $(NH_4)_2SO_4$, KNO], −34% for urea, −32% for mixtures of organic and mineral fertilizers, and −27% for unfertilized soils. For each N application rate, biochar induced a reduction of N_2O emissions.

- Crop type : Except for perennial crops (e.g. fruit trees), N_2O emissions at least tended to be reduced in all agronomic experiments (i.e. arable crops with −45% and horticultural cultures with −32%) that cultivated cereals (−31%, $P < 0.05$), maize (−31%, $P = 0.17$), rice (−40%, $P < 0.05$), vegetables (−30%, $P = 0.07$), and other crops (−35%, $P = 0.18$). For biochar applications to grassland N_2O emissions were not affected.

Conclusion

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".