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Direct impacts of biochar on N_2O production during denitrification by a soil microbial community

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Biochar, i.e. biomass heated under O_2 limitation to 350-1000°C (pyrolysis), is suggested as a beneficial soil amendment to mitigate climate change and to maintain and restore the fertility of agro-ecosystems. Its stability enables long-term carbon sequestration and biochar effectively reduces soil-borne N_2O emissions. Biochar's ability to reduce N_2O emissions is well recognized through field and laboratory experiments as well as meta-analyses. However, the underlying mechanisms remain widely debated. Microbial nitrogen transformations, especially denitrification, the stepwise reduction of nitrate/nitrite via NO and N_2O to N_2, are considered to be a major source of N_2O emissions. Soil microcosm experiments showed lower N_2O emissions in the presence of biochar often correlate with a higher abundance and/or activity of N_2O reducing bacteria in the presence of biochar. However, it is still unknown whether these shifts in the microbial community and/or activity is cause or effect of reduced N_2O production.

Biochar has the potential to change the physico-chemical environment towards conditions that favor complete denitrification, i.e. decrease the $N_2O/(N_2O+N_2)$ product ratio. Specifically, biochar can increase soil pH, reduce the availability of nitrate and increase the entrapment of gases, including N_2O. These effects are known to decrease the $N_2O/(N_2O+N_2)$ ratio.

In addition to the observed effects in the physio-chemical environment, we hypothesized that biochar has a direct impact on the soil microbial community. For instance, it has been shown to provide a suitable habitat to microorganisms, or facilitate electron transfer between microbe and substrates by acting as an electron shuttle or as a temporary acceptor/donor of electrons.

To test this hypothesis, our experiment consisted of a microbial community extracted from soil and cultivated under anoxic conditions. It was introduced as an inoculum into three different treatments: biochar, quartz (control with a solid) and a solid-free control in the presence of a well-defined liquid medium. To maintain consistency with respect to geochemical parameters as well as to exclude any indirect effects of biochar, the concentration of substrates (nitrate, acetate) and the pH were kept identical in all three treatments. The biochar used was previously shown to reduce soil-borne N_2O emissions.

The results showed that biochar promoted nitrate reduction coupled to acetate consumption leading to a faster intermediate accumulation of nitrite compared to the non-biochar treatments. Additionally, N_2O intermediately accumulated in the biochar treatment. Gene copy numbers from quantitative polymerase chain reaction combined with optical density measurements suggested that microbes were attached to the biochar surface instead of being suspended in the liquid. This association of microbial cells with biochar's surface might result in expedited consumption of acetate and nitrate. Since similar effects were not observed in the treatment containing quartz, they were concluded to be specific to biochar.

These results can be put forth as the first evidence for a direct impact of biochar on microbial denitrification. Overall, our study highlights the need to take a detailed look at biochar's direct effect on the activity of the soil microbial community when designing biochars that target N_2O mitigation.