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Composting-derived organic coating on biochar enhances its affinity to nitrate

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Biochar is defined charcoal that is produced by the thermal treatment of biomass in the (partial) absence of oxygen (pyrolysis) for non-oxidative applications, especially in agriculture. Due to its high surface area and porous structure, it is suggested as a beneficial soil amendment to increase crop yields and to tailor biogeochemical cycles in agro-ecosystems to reduce both greenhouse gas emissions and nutrient leaching. While early research focused on single applications of large amounts of biochar ($>$10 t ha^{-1}), economic and ecological boundaries as well as practical considerations and recent findings shifted the focus towards low-dose ($\sim$1 t ha^{-1}) and potentially repeated applications of nutrient-enriched biochars, i.e. biochar-based fertilizers in the root-zone. Thus, biochar must be "loaded" with nutrients prior to its use as a root-zone amendment. Co-composting is suggested as a superior method, as co-composted biochar was shown to promote plant growth and showed the desired slow release of nutrients such as nitrate ("nitrate capture", Kammann et al., 2015 SR5:11080). However, the underlying mechanisms are not understood and nitrate capture has been quantified only for isolated biochars but not for e.g. biochar-amended composts without prior separation of the biochar.

In the present study, we used repeated extractions with 2 M KCl and found that up to 30% of the nitrate present in a biochar-amended compost is captured in biochar, although biochar was amended to the initial composting feedstock (manure) only at 4% (w/w). Additionally, we quantified nitrate capture by pristine biochar after soaking the biochar in NH_4NO_3 solution in the absence of any additional organic carbon and nitrate capture of separated co-composted biochar. Assuming pseudo-first order kinetics for biochar nitrate release, we found an increase of biochar's affinity to nitrate after co-composting. Spectro-microscopical investigations (scanning transmission electron microscopy with electron energy loss spectroscopy - STEM-EELS, scanning transmission X-ray microscopy STXM) revealed the formation of a nano-porous organic coating on co-composted biochar. This coating alters the interaction of biochar with water as evidenced by proton fast field cycling nuclear magnetic resonance (^{1}H FFC NMR) relaxometry and might explain its distinct characteristics.

Our findings offer a roadmap for future research to design sustainable slow-release nitrogen fertilizers based on biochar to reduce the environmental impact of agriculture. Further microscopic studies are necessary to understand the preconditions of the formation of organic coatings on biochar on a holistic basis to design biochar post-production treatments.