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Nitrate retention by biochar: mechanistic insights by 15N tracing

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Pyrogenic carbon (biochar) offers considerable potential for carbon capture and soil storage (CCSS) compared to other less recalcitrant soil-C additives. Moreover recent meta-analysis demonstrates that it can significantly reduce agricultural N2O emissions. However to “harvest” environmental benefits it is necessary to develop economic incentives for using biochar in soils. Nitrate retention, in particular in poor sandy soils, may provide such an incentive.

We explored the potential of biochar to protect mineral N against leaching or loss as N2O, and to deliver it for plant growth using various approaches, (1) observational: results obtained in two larger-scale agricultural field studies (I + II, with poor sandy soil and loess soil respectively) plus one macrocosm N leaching study with Vitis vinifera in poor sandy soil; and (2) mechanistic laboratory studies with untreated and composting- or field-aged biochars in sandy soil using 15N labelled mineral N species.

The results suggest a strong role of biochar in retaining mineral nitrogen mostly in the form of nitrate rather than ammonium (as could be expected). In the field study I (sandy soil) with biochar application rates of 15 and 30 t ha-1 (n=4 per treatment) significant nitrate retention was observed after the second winter in the top soil (0-15 cm) where the biochar had been incorporated, while the subsoil nitrate concentrations (30 – 60 and 60 – 90 cm) were significantly reduced. Biochar particles extracted from the top soil by forceps showed a significant enrichment with nitrate; but only a fraction was extractable with conventional standard methods. In field study II (loess) 30 t ha-1 biochar were combined with the factor mineral N fertilization (0 – 200 kg N ha-1 in 5 steps; n=3 per treatment). Here strong growth improvements were observed with maize or wheat in the first and second year after biochar application only in the no- or low- (50 kg N ha-1)fertilized treatments, but growth improvements were low or absent when the N fertilization was in excess of the plant demand. In the macrocosm study with Vitis vinifera (cf. Riesling) pure biochar, pure compost, or biochar-compost mixtures were applied at 30 and 60 t ha-1 to the first 30 cm layer of a poor sandy soil. Vine containers were constantly drip irrigated over the vegetation period to allow leachate collection. Pure biochar reduced nitrate leaching by roughly 60% compared to pure control soil, but the combination of biochar and compost was most effective, reducing nitrate leaching to virtually zero.

The subsequent 15N labelling-tracing studies revealed that the untreated as well as aged (co-composted) biochars strongly sorbed mineral N, particularly nitrate. For example in a soil mixture of 196 g soil with 4 g biochar (2%), up to 60% of the labelled nitrate-15N was be retrieved by washing the biochar particles out from the soil with distilled water roughly 50 hours after 15N application. Moreover, the co-composted biochar which was already nitrate- and organic-C-preloaded was more effective in sorbing mineral N; in addition it still reduced N2O emissions significantly, although it carried dissolved organic carbon and nitrate as prerequisites for denitrification. In parallel to the field experimental results (site II), the lab study results also showed that at least part of the sorbed N must have been plant available. However the plants did only access it (for significantly improved growth with the N-preloaded biochar) when the easily extractable mineral N pool had a-priori been depleted.

Our results therefore encourage further investigations into strategies that combine nutrient-rich agricultural waste streams with biochar post-treatment as a way forward to achieve environmental benefits, improve the efficiency of agricultural N use and deliver economic benefits.