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Influence of Enhanced Weathering and Copper on Nitrous Oxide Emissions

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In order to meet key climate pathways, we will need rapid and deep emissions cuts of all greenhouse gases, in addition to annual gigatonne-scale carbon dioxide removal (CDR). Nitrous oxide (N_2O) is a potent and long-lived greenhouse gas which is largely released from the application of N fertilizers in agriculture. Enhanced weathering (EW) is a CDR strategy that has been shown to simultaneously decrease N_2O emissions in agriculture by increasing the soil pH and causing more efficient denitrification. As the fine-grained feedstock weathers, EW releases micronutrients such as copper (Cu). Cu can be a limiting nutrient for crops, deficient in many soils (e.g., areas in Europe with sandy, calcareous, and organic-rich soils). As Cu is an important metal cofactor in multiple nitrogen cycling enzymes, EW-driven Cu release may have further consequences for the emissions of N_2O, but that prospect remains currently uninvestigated.

During a series of agricultural mesocosm experiments, we microdosed soils with cupric chloride to increase total Cu concentrations from background values of ~28 to 114 ppm over a range of soil pHs, and continuously measured N_2O fluxes to assess their response to the interacting effects of Cu and pH. We show that at higher pH, when N cycling is more efficient, Cu can further decrease N_2O emissions, whereas under acidic conditions, Cu is not as dominant of a force on N_2O fluxes. Using multi-omics approach, we analyze the changes in key N-cycle genes underpinning these responses. In line with our empirical data, the combined effect of high pH and high Cu resulted in the most favorable transcriptional program within the soil microbial community as enhanced expression of *nosZ*, converting N_2O to N_2, coincided with reduced expression of *norBC*, generating N_2O from NO. Independent from pH, Cu levels also changed the soil nitrifying community, with Cu-demanding ammonia oxidizing archaea (AOA) increased relative to metal-sensitive ammonia oxidizing bacteria (AOB) at high Cu. As AOB are generally linked to 2-fold greater N_2O emissions, their reduction can also contribute to the ability of Cu to ameliorate N_2O emissions. Together, our findings point to pH and Cu as important levers on N_2O fluxes.