Soil carbon stock surprises over three decades after liming

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Calcium availability can affect a range of plant, soil, and microbial processes that together can alter carbon storage in forest soils at decadal or longer timescales. A catchment-scale liming experiment initiated in 1989 in the Adirondack Mountains, New York, USA has yielded several surprising long-term responses. Contrary to expectations, twenty years after liming, surface forest floor carbon stocks in limed soils roughly doubled those in unlimed plots, even as liming had no effect on woody biomass production or plant litterfall. Initial indications of suppression of decomposition were supported by subsequent measurements of microbial community composition and function that showed that liming suppressed the abundance of the fungal decomposers associated with lignocellulose degradation, especially woody saprotrophs and the dominant ectomycorrhizal guilds.

New measurements in 2021 examined the long-term responses of fine root dynamics as well as changes in plant and soil carbon stocks. Liming suppressed fine root production across all surface soil horizons (Oe, Oa, 0-10 mineral), even as fine root biomass (live + dead) shifted upward, increasing in Oa horizons and decreasing in 0-10 horizons relative to controls soils. These changes in fine root biomass (live + dead) are best explained by suppressed decomposition rather than changes in fine root production.

Thirty-two years after liming, surface soil carbon stocks in limed soils continue to exceed those in unlimed soils, showing persistent enhancement over multiple decades. However, carbon inventories in both limed and unlimed soils declined by roughly 30% over the twelve years since they were last measured. Similar declines in other temperate forest sites have been attributed to increased soil heterotrophic activity in soils recovering from historic acid deposition. However, the parallel declines of soil C in both limed and unlimed plots suggest that other mechanisms may be more important, such as increased priming of decomposition by plants in need of other limiting nutrients, or warming temperatures.

Soil respiration (Rsoil) is the second largest terrestrial carbon flux, vastly exceeding fossil fuel emissions. It is composed of two separate fluxes: autotrophic respiration (Ra), driven by plant respiration, and heterotrophic respiration (Rh), which comes predominantly from microbial decomposition. Many studies have demonstrated that increasing nitrogen (N) availability can suppress Rsoil, but the mechanisms underpinning this response are difficult to discern, because each component flux can respond differently to changes in N availability, through its roles as a limiting nutrient and as an acidifying agent. As a limiting nutrient, increasing N availability could reduce plant belowground carbon allocation to roots (Ra) and microbial symbionts; however, supplying N to nutrient-limited soil microbes inhabiting carbon rich soil layers could offset this effect by increasing saprotroph biomass (Rh). Alternatively, as an acidifying agent, N may decrease soil decomposer biomass and increase belowground carbon allocation if acidification reduces availability of other nutrients. Here, we test these hypotheses by measuring respiration fluxes from fixed collars (Rsoil) and from lab-incubated soils separated by depth (Rh) in a replicated, ten-year N x pH manipulation (+N, +pH; +N, -pH; -pH; control) study in mixed temperate forests in central New York, USA.

Acidifying N additions led to large reductions in Rsoil (19%, 2.2 t C ha-1 yr-1), and decreased forest floor Rh (per unit soil mass). In contrast, acidification alone had no effect on Rsoil, but produced large increases in Rh in mineral soils. De-acidifying N additions did not significantly affect Rsoil or Rh, but effects trended towards suppression rather than enhancement. When considered per unit area, both Rh and Rsoil decreased sharply with increasing soil N availability, but showed little response to soil pH across all treatments. However, within acidification treatments, Rsoil and mineral soil Rh decreased with increasing acidity. We anticipated that acidification would impact Rsoil by reducing Rh and increasing Ra, but surprisingly found that acidification alone stimulated Rh in mineral soil, perhaps reflecting long-term accumulations of carbon in surface mineral soils. Overall, our findings suggest that increased N availability suppresses Rsoil through nitrogen’s role as a limiting nutrient for both plants and heterotrophic microbes and that N-driven acidification can contribute to this effect by suppressing microbial activity in surface soil layers.