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Sources and co-biomineralization of organic carbon and selenium in cold region Mollisols under climate change and agricultural perturbations

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Mollisols are inherently organic-rich soils that are extremely suitable for agricultural production. Although there are only four major Mollisol belts globally, they are a significant terrestrial organic carbon (OC) and selenium (Se) reservoir and host some of the most productive cold-region agroecosystems in the world [1]. A majority of the cold region Mollisols are seasonally frozen and very vulnerable to climate warming and agricultural perturbations, for instance, in the Mollisol regions of northeastern China [2]. The resulting enhanced soil respiration and biogeochemical cycles pose a growing risk of Mollisol OC and Se loss. The environmental conditions and underlying mechanisms that constrain co-evolution of OC and Se, however, remain poorly understood. By combining field investigations, customized mesocosm experiments, theoretical calculations, and kinetic modeling, we provide novel insights into how the unique cold region soil-forming environments drive the co-enrichment of OC and Se in cold region Mollisols and then how the freeze-thaw cycles impact the co-biomineralization of OC and Se, leading to underestimated soil gas emissions. The results indicate that, Mollisol OC originated from both C3 and C4 plants, but paleoclimate and redox shifts are critical factors driving variations in compositional and structural characteristics of OC and the bound Se. Under freeze-thaw cycles, increased emissions of CO_2, CH_4, and methylated Se from the Mollisol landscapes were observed. The mobilization and decomposition of biodegradable organic matter in Mollisol aggregates with different sizes are critical drivers [3]. Turnover of Mollisol OC and Se is further explained by microbial carbon use efficiency and metabolic energy requirements. These findings help inform appropriate Mollisol conservation strategies that enable sustainable resource utilization and agricultural development in cold region Mollisols.

[1] Li *et al.* (2022) *Environ. Sci. Technol.* **56**, 16494-16505. [2] Pi *et al.* (2025) *Environ. Sci. Technol.* doi: 10.1021/acs.est.5c05541. [3] Pi *et al.* (2024) *Environ. Int.* **188**, 108758.