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Chemical characterization of organic inputs reveals archetypes relevant for fate of zinc and cadmium in agricultural systems

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With growing populations and the threat of global change, it is essential to develop circular food systems able to produce nutritious crops while relying on recycled resources. Organic inputs can increase circularity by allowing recycling of carbon and mineral nutrients, including the micronutrient zinc (Zn), from agriculture-derived products and waste. However, application of organic inputs may negatively affect soil functions if Zn accumulates above critical concentrations that can harm microbial communities. Organic inputs may also be a source of the toxic, non-essential element cadmium (Cd) that poses a food chain risk as it is readily transferred from soils to crops. As the composition of organic inputs is highly complex, there are multiple chemical properties that may affect Zn and Cd mobility versus accumulation in soil.

We performed a survey of 28 inputs of diverse origins, in which we i) characterized organic matter (OM) composition via pyrolysis-GC/MS, ii) determined bulk parameters (pH, element concentrations), and iii) evaluated speciation of water-soluble Zn and Cd. For speciation analysis, we employed the chemical equilibrium model WHAM VII (estimation of inorganic versus organic Zn and Cd) and size exclusion chromatography coupled to ICP-MS/MS (characterization of organic Zn and Cd forms in terms of size, aromaticity and elements). Cluster analysis demonstrated that datasets of OM composition, bulk chemical composition, and water-soluble Zn and Cd speciation reveal shared archetypes of organic inputs. In organic inputs enriched in rapidly degradable OM (e.g., green manures, lignified crop residues), water-soluble Zn and Cd were mainly bound to DOM, with Zn bound to lower-molecular-weight OM and Cd to higher-molecular-weight OM. Conversely, organic inputs characterized by more degraded and resistant OM (e.g., ruminant farmyard manures, industrial composts), contained higher proportions of water-soluble Zn and Cd present as inorganic species (free ions and inorganic complexes) or associated with higher-molecular-weight OM.

The identification of these archetypes allows constraint of the complex chemical composition of organic inputs, particularly regarding chemical properties likely to affect Zn and Cd (im)mobilization. This establishes a foundation for future experiments to better understand how organic inputs affect the fate of Zn and Cd in circular agricultural systems.