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Chemical speciation governs zinc mobility and plant availability in neutral soils

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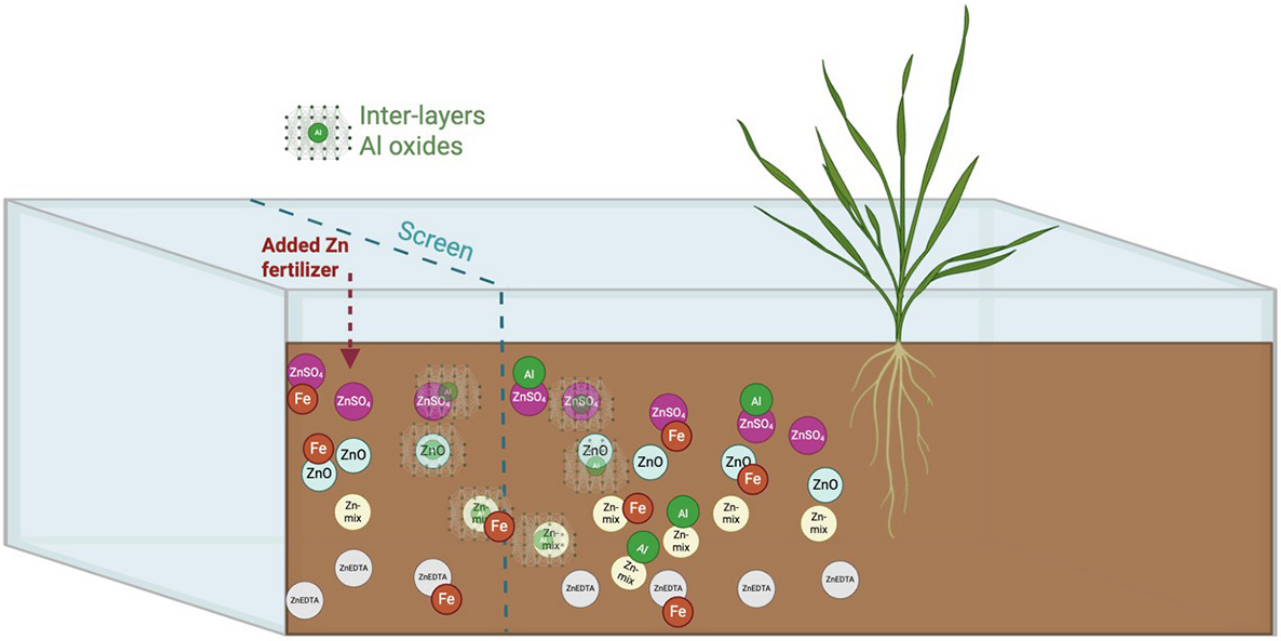


Illustration showing how different Zn fertilizers behave in neutral soil. Zinc sulfate and chelated Zn move farther from the application point and remain more available in the soil solution, whereas Zn oxide and mixed formulations quickly associate with soil minerals, such as iron and aluminum oxides, limiting zinc movement and availability to plants. Illustration courtesy of Sevendeep K. Chahal, Kansas State University.

Zinc (Zn) deficiency limits crop productivity worldwide, particularly in neutral and alkaline soils where applied Zn rapidly reacts with soil minerals, becoming unavailable to plants. Fertilizer effectiveness depends not only on Zn application rate, but also on its chemical form and the reactions it undergoes after application.

Although Zn sulfate ($ZnSO_4$), Zn oxide (ZnO), and chelated Zn (Zn-EDTA) are widely used, their reaction pathways and resulting Zn species in neutral soils remain poorly understood. In particular, the formation of mineral-associated Zn species can reduce Zn mobility and limit plant uptake, yet direct spectroscopic evidence linking fertilizer source to Zn speciation and phytoavailability has been limited.

A team of researchers at Kansas State University evaluated $ZnSO_4$, ZnO, Zn-EDTA, and a mixed Zn formulation (Zn mix, a new Zn product with 60% ZnO, 36% $ZnSO_4 \cdot 7H_2O$, and 4% Zn-EDTA by weight) using soil incubation and greenhouse experiments with wheat grown in a neutral silt loam soil. Zinc mobility was assessed through diffusion measurements, water-extractable Zn, and soil solution Zn concentrations from the point of application while synchrotron-based X-ray absorption spectroscopy identified fertilizer-derived soil Zn species. They found that Zn from ZnO and Zn mix remained concentrated near the application point with more than 80% retained in the initial soil zone. Spectroscopic analysis showed rapid transformation into Zn-Al layered double hydroxide and ZnO-associated species, which reduced Zn mobility. In contrast, $ZnSO_4$ and Zn-EDTA showed greater diffusion, higher soil solution Zn concentrations, and significantly greater plant Zn uptake.

These findings show that fertilizer source controls Zn speciation, mobility, and plant availability in neutral soils. Zinc sulfate performed similarly to chelated Zn while remaining more cost-effective, providing an efficient and practical fertilizer option for

improving Zn nutrition in crop production systems.

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Chahal, S. K., Hettiarachchi, G. M., Nelson, N. O., & Guttieri, M. J. (2026). Chemical speciation of zinc in fertilized neutral soils governs zinc mobility and phytoavailability. *Soil Science Society of America Journal*, *90*, e70176. https://doi.org/10.1002/saj2.70176

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