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Metal Complexes: Future Prospective for Agricultural Efficacy

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INTRODUCTION

Agriculture will need to adapt in order to meet the increasing demand for food for the continuously growing world population (Shahid, 2023; Shahid *et al*., 2024). To feed the projected 9 billion global population by 2050, the world will require to increase the food production (Shahid *et al*., 2023). Agriculture remains a key economic sector in many countries, with an increase in mineral fertilizer use to boost the agricultural productivity. This has led to the development of new and cost reducing fertilizer technologies. Over 250 manufacturers are active in the national fertilizer market, and environmental impact is a key consideration in choosing fertilizer technologies. Irresponsible practices such as over-fertilization and excessive irrigation have degraded the natural environment, and irregular rainfall and drought have reduced crop yields. To address this, researchers are exploring ways to maintain optimal soil conditions, especially improving porosity. This article highlights the use of Agro-Hydrogel as a novel fertilizer prototype, incorporating micronutrients like Zn(II), Mn(II), Cu(II), and Fe(III) in complexation with novel chelating agents viz., EDDS, IDHA, and GLDA. These agents, compared to traditional chelators such as EDTA, are non-toxic, biodegradable, and eco-friendly (Lipowcza, *et al*., 2021; Rani, 2022). Their use is growing due to changes in legislation, and major chemical companies now offer them in their groups for special efficacy.

As per European regulations, only a limited number of compounds are authorized for use in fertilizers. Schiff bases play a significant role in biological systems as models for assessing protein activity (Piwowar, 2022). Their appeal lies in their easy preparation, structural diversity, and variability, making them attractive for various applications. Research on Schiff bases shows that the surrounding environment of metals and the conformational flexibility of ligands are crucial, as they enable metalloproteinases to perform specific biological functions.

These chelating agents help prevent negative reactions between fertilizers and the soil's water system, ensuring that plants can access nutrients effectively. Additionally, slow-release fertilizer hydrogels help reduce irrigation frequency and prevent moisture loss, addressing the global issue of fertilizer waste (Stephens *et al*., 2018). This aims to evaluate the feasibility of using Agro® Hydrogel to incorporate Zn(II), Mn(II), Cu(II), and Fe(III) ions with chelating agents such as EDDS, IDHA, and GLDA. Previous studies showed successful incorporation of these micronutrients via a sorption method, examining the influence of various factors like adsorbent dose, pH, and temperature. Kinetic models were applied to understand the adsorption mechanism, and the results indicated optimal sorption characteristics (Ogino *et al*., 2020).

The effect of Agro-Hydrogel mass on adsorption was studied by varying its weight, revealing that increasing the adsorbent dose reduced adsorption capacity, likely due to particle agglomeration (Khan *et al*., 2022). Adsorption efficiency also varied with pH, with the optimal pH for most complexes being between 4 and 10. Kinetic studies indicated that equilibrium was reached in about 60 minutes, with the pseudo-second-order model best fitting the adsorption data (Randive *et al*., 2021). Maximum adsorption capacities were determined for various metal-chelate combinations. Temperature was also found to impact adsorption efficiency, which was investigated within the range of 295-315 K. Overall, this highlights the influence of chemical conditions on the adsorption of metal ions by Agro-Hydrogel in the presence of new-generation chelating agents, providing insights into potential applications in fertilizer technology.

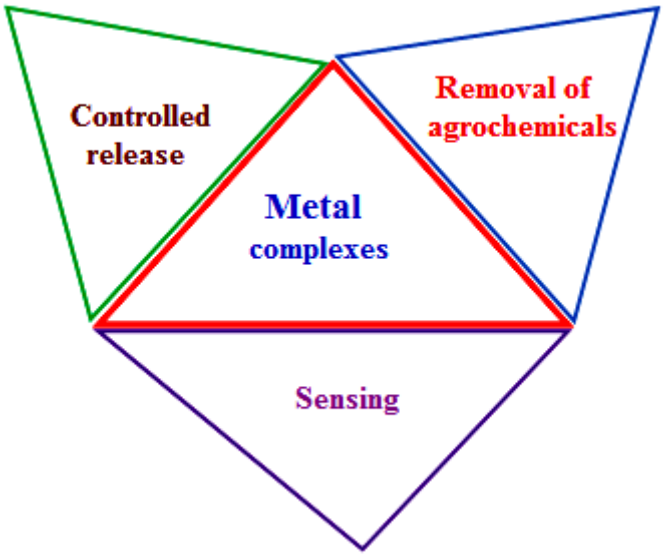

Fig.1. **Proposed application of Metal Complexes**

Effect of adsorption mass

The effect of varying Agro® Hydrogel masses (ranging from 0.06 to 1.6 g) on adsorption capacity, with other parameters held constant, reveals the optimization of the minimum dosage needed for effective adsorption of Cu(II), Zn(II), Mn(II), and Fe(III) complexes with EDDS, IDHA, or GLDA. According to previous reports as increasing the adsorbent mass led to a significant decrease in adsorption capacity for IDHA complexes. This reduction in adsorption efficiency as the Agro-Hydrogel dosage increased can be attributed to particle agglomeration, which reduces the availability of active sites for sorption, despite maintaining a constant adsorbate concentration.

Effect of initial pH

The point of zero charge (pHZPC) for the hydrogel is 6.9. At pH values higher than pHZPC, the surface charge is negative, while below this pH, the charge becomes positive. The adsorption process seems to be more effective at pH levels below the pHZPC, indicating that the surface charge on the sorbent beads is positive under these conditions. It shows the percentage removal of Cu(II), Zn(II), Mn(II), and Fe(III) complexes with IDHA at different pH values using Agro-Hydrogel. For Cu(II) and Zn(II) complexes, the adsorption percentage (S%) shows a slight increase between pH 4 and 10. In contrast, the adsorption efficiency for Mn(II) and Fe(III) complexes, particularly for Fe(III), decreases significantly, suggesting that different adsorption mechanisms or complex forms, such as [M(IDHA)]2- for Mn(II) or [M(IDHA)]- for Fe(III), are involved. Moreover, the adsorption efficiency of Zn(II)-IDHA complexes improves as the pH increased from 10 to 12. Overall, the adsorption process is most favorable at pH values between 4 and 10, but it declines sharply at pH 2, especially for Fe(III) complexes. In the case of hydrogels, various mechanisms such as electrostatic interactions, hydrogen bonding, π-π interactions, ion exchange, surface complexation, and coordination/chelation contribute to the adsorption process. The specific mechanisms can vary depending on the composition of the hydrogel and the experimental conditions, including pH, temperature, and concentration.

CONCLUSION

This article provides an updated overview of how chemical conditions influence the kinetic and adsorption behavior of superabsorbents toward metal ions in the presence of new-generation chelating agents, specifically IDHA, EDDS, and GLDA. In summary, the sorption efficiency of Cu(II), Zn(II), Mn(II), and Fe(III) complexes with these agents on Agro-Hydrogel is influenced by factors such as pH, contact time, temperature, concentration, and the type of complexing agent used. The adsorption efficiency improves with longer contact times, with equilibrium reached after approximately 60 minutes. The order of sorption capacity for Agro® Hydrogel shows that the metal complexes are more efficient as compare to ligand. Additionally, the process is pH-dependent. These outcomes could serve as a foundation for developing innovative fertilizer strategies that enhance plant productivity.

Conflict of interest

All the authors declare no conflict of interest.

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