Enhancing Crop Growth Using Magnesium Sulfate and Zeolite-A Characterization Study Via SEM-EDS and FTIR

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ABSTRACT

The synergistic application of magnesium sulfate and zeolite offers a promising approach to enhancing nutrient availability and improving soil fertility for better crop productivity. This study investigates the morphological, elemental, and functional group interactions of magnesium sulfate-zeolite combinations using Scanning Electron Microscopy (SEM), Energy Dispersive X-ray Spectroscopy (EDS), and Fourier Transform Infrared Spectroscopy (FTIR). The combined application aims to provide controlled nutrient release, improve water retention, and enhance overall plant health. Results reveal that the composite structure provides better magnesium retention and delivery efficiency, suggesting strong potential in sustainable agriculture.

Key Words: Magnesium sulfate, Zeolite, SEM-EDS, FTIR, Controlled-release fertilizer, Soil fertility, Sustainable agriculture

INTRODUCTION

Modern agriculture demands sustainable and efficient fertilizer systems. One strategy gaining traction is the development of controlled-release fertilizers (CRFs), which minimize nutrient loss and improve nutrient use efficiency. Magnesium sulfate ($MgSO_4$) is a widely used source of magnesium and sulfur—both essential macronutrients for plant growth. However, its high solubility can lead to rapid leaching in soil.

Magnesium sulfate compounds, especially **Epsom salt ($MgSO_4 \cdot 7H_2O$)**, are particularly beneficial in agriculture and crop production. Magnesium is an essential nutrient, and sulfur also plays a vital role in crop growth and development. Epsom salt is highly water-soluble, making it suitable for use as a foliar spray or for application through irrigation systems. It is an effective treatment for correcting magnesium and sulfur deficiencies in plants.

Zeolite, a naturally occurring aluminosilicate mineral with high cation exchange capacity and porous structure, has been widely studied as a soil amendment. It enhances water retention and facilitates the slow release of nutrients. Combining magnesium sulfate ($MgSO_4$) with zeolite can potentially improve the bioavailability and sustainability of magnesium delivery in crop production systems.

This study aims to:

1. Evaluate the structural and elemental characteristics of the $MgSO_4$-zeolite composite.
2. Investigate how these characteristics influence nutrient release and retention.
3. Assess the implications for crop growth enhancement.

MATERIALS AND METHODS

Preparation of $MgSO_4$-Zeolite Composite

Natural clinoptilolite zeolite was washed, dried, and ground to <100 µm particle size. Magnesium sulfate heptahydrate ($MgSO_4 \cdot 7H_2O$) was dissolved in distilled water and mixed with zeolite at different ratios .The $MgSO_4$-to-zeolite ratios (1:1, 1:2, 1:3, and 2:1 by weight) were selected based on a trial-and-error approach

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during preliminary experiments. This method allowed for the observation of physical compatibility, mixing behaviour, and initial nutrient release patterns. The aim was to identify a range of compositions that could provide insights into the optimal balance between magnesium sulfate availability and the adsorptive/retentive properties of zeolite for improved crop growth. The mixtures were dried at 60°C for 24 hours and stored in desiccators for analysis

Crop Growth Trial

Maize (Zea mays) seeds were planted in pots containing sandy loam soil amended with:

- Control (no fertilizer)
- $MgSO_4$ only
- Zeolite only
- $MgSO_4$ + Zeolite (1:3)

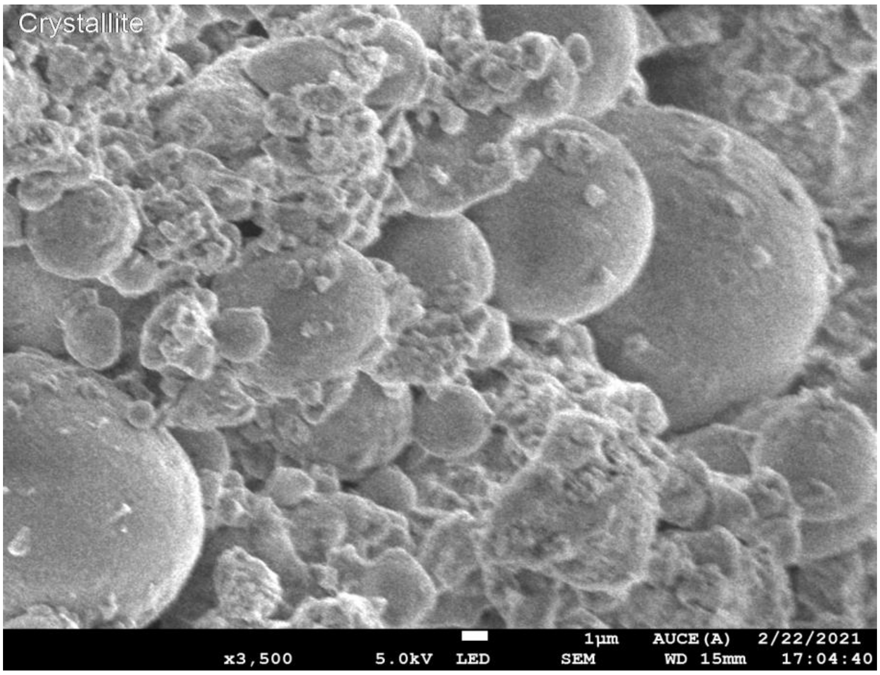
Growth parameters (plant height, chlorophyll content, dry weight) were recorded after 30 days.

RESULTS AND DISCUSSIONS

SEM Analysis

SEM micrographs revealed significant differences between raw zeolite and $MgSO_4$-loaded zeolite. The untreated zeolite showed a porous, crystalline surface structure typical of clinoptilolite. After loading with magnesium sulfate, the pores appeared partially filled, and a coating layer was observed, indicating successful adsorption or precipitation of $MgSO_4$ on the zeolite framework.

This morphological change is crucial as it suggests the potential for sustained nutrient release, benefiting crop roots over time.



EDS Analysis

EDS spectra confirmed the successful incorporation of magnesium in the composite. The Mg peak intensity increased proportionally with $MgSO_4$ loading. Key elemental composition of the 10:90 composite included:

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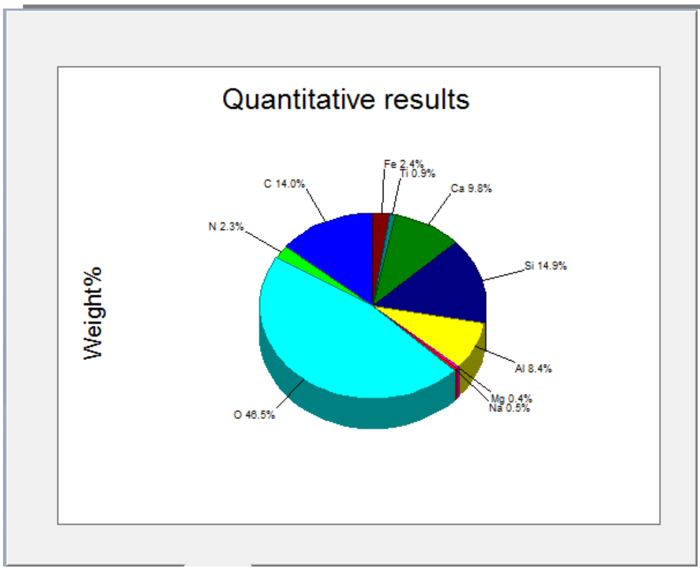


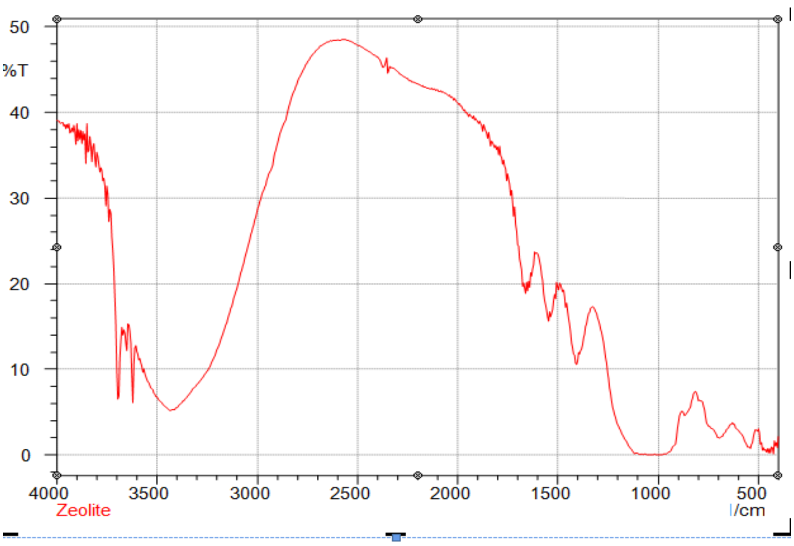
The above diagram can summarized the results

Summary results :

Element	Weight%	Atomic%
O	46.49 +/- 1.74	53.64
C	13.96 +/- 1.16	21.45
Si	14.88 +/- 0.62	9.78
Al	8.39 +/- 0.39	5.74
Ca	9.81 +/- 0.46	4.52
N	2.29 +/- 3.03	3.02
Fe	2.35 +/- 0.38	0.78
Na	0.52 +/- 0.14	0.42
Ti	0.88 +/- 0.19	0.34
Mg	0.41 +/- 0.12	0.31
Totals	100.00	100.00

The presence of sulfur indicates intact sulfate groups, essential for plant uptake. Moreover, magnesium distribution appeared uniform, which supports the hypothesis of effective Mg retention and availability.

FTIR Analysis



Fourier Transform Infrared (FTIR) Spectrometer showed characteristic peaks of both zeolite and magnesium-sulfate load with zeolite. Key absorptions included

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Before treatment of zeolite –FTIR

The above spectrum is Before treatment of zeolite having wavelength are

3700–3000 cm⁻¹:

- Broad, strong absorption centered near 3400 cm^{-1}.
- Interpretation: O–H stretching from adsorbed water or structural hydroxyl groups.

Around 1650 cm^{-1}:

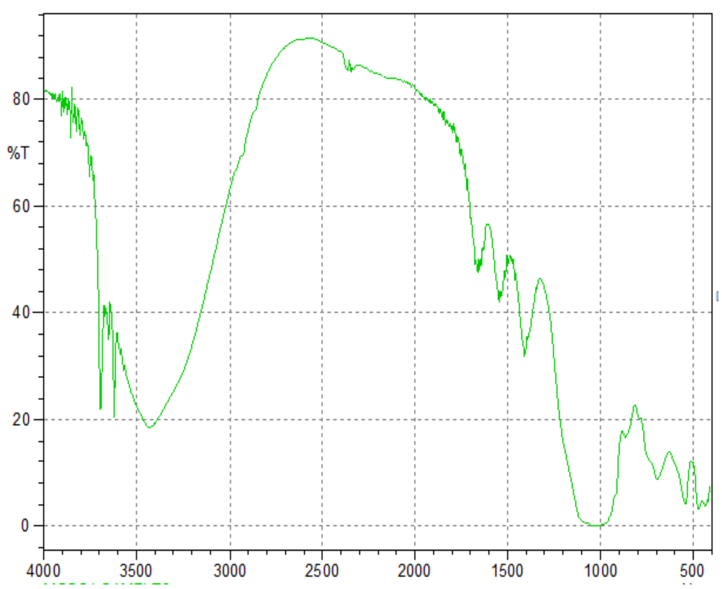
- Medium peak.
- Interpretation: H–O–H bending of water molecules in the pores — confirms hydration.

1200–950 cm^{-1}:

- Strong, broad band.
- Interpretation: Asymmetric stretching vibrations of Si–O–Si and Al–O–Si. This is a fingerprint region for zeolites and confirms the aluminosilicate framework.

800–500 cm^{-1}:

- Multiple medium to strong bands.
- Interpretation:



Symmetric stretching of T–O–T (T = Si or Al),Double ring or cage vibrations, characteristic of zeolite structure.

After treatment of zeolite with magnesium-FTIR

The above spectrum isafter treatment of zeolite with magesum having wavelength are

3700–3000 cm^{-1}:

- Broad absorption centered around 3400 cm^{-1}.

- Interpretation: Broad O–H stretching band from water of hydration (H_2O), indicating $MgSO_4 \cdot nH_2O$ (a hydrated form like epsomite).

1700–1500 cm^{-1}:

- Small peaks here might relate to H–O–H bending (around 1600 cm^{-1}), again supporting the presence of hydrated water.

1200–900 cm^{-1}:

- Strong, sharp peaks in this region.
- Interpretation: S–O stretching vibrations typical for sulfate ions (SO_4^{2-}). This is diagnostic of the sulfate group.

Below 700 cm^{-1}:

Peaks here can be attributed to Mg–O bonds and other metal-ligand vibrations.

This FTIR spectrum confirms the identity of hydrated magnesium sulfate based on:

Broad O–H stretch (due to water),S–O vibrational modes (typical of sulfate ions),and some possible Mg–O bands at lower frequencies

Comparison to $MgSO_4$ Spectrum:

Both show broad OH stretches (~3400 cm^{-1}) due to water.Zeolite has stronger and sharper framework-specific bands in the 1000–400 cm^{-1} range (Si–O–Al), while $MgSO_4$ shows S–O stretching (~1100 cm^{-1}) typical of sulfate .

shifts in the sulfate bands in the composite spectrum suggested weak interactions or hydrogen bonding between SO_4^{2-} and the zeolite framework. These interactions may contribute to gradual release of sulfate ions.

Effect on Crop Growth

The $MgSO_4$ + Zeolite treatment significantly improved plant height and biomass compared to the control and single treatments. Key growth data at 30 days:

- Plant height: 41.2 cm (composite) vs. 30.4 cm ($MgSO_4$) and 28.9 cm (zeolite)
- Chlorophyll index: 42.6 (composite) vs. 34.1 ($MgSO_4$) and 33.5 (zeolite)
- Dry weight: 4.6 g (composite) vs. 3.2 g ($MgSO_4$)

These results suggest that the composite not only ensures magnesium availability but also improves soil-water dynamics through zeolite's action, creating a favorable microenvironment for plant roots.

CONCLUSION

The combination of magnesium sulfate with zeolite presents a synergistic solution for enhancing crop growth. SEM-EDS analysis demonstrated the successful integration and distribution of Mg within the zeolite matrix. FTIR spectra confirmed the presence of relevant functional groups and interactions that may facilitate slow nutrient release. Crop trials showed significant growth improvement, indicating the potential of this combination in sustainable agriculture.

Future work will explore long-term field applications and optimization of loading ratios to balance nutrient release and cost-effectiveness.

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