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Synergy of Nano-sulfur and Organic Matter in Enhancing the Efficiency of Urea Fertilizers

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Abstract

One of the most severe sustainability dilemmas in modern agriculture is the low Nitrogen Use Efficiency (NUE) of conventional nitrogen fertilizers, particularly urea. Upon entering the soil, urea undergoes extremely rapid hydrolysis driven by microbial urease enzymes, leading to a sudden surge in ammonium concentration. This process often outpaces the actual nutrient uptake capacity of plants, resulting in significant ammonia volatilization, nitrate leaching, and denitrification losses. These phenomena not only raise economic concerns but also induce critical environmental burdens, such as eutrophication and the emission of greenhouse gases. To address these anomalies, research has focused on the development of an innovative hybrid coating system that combines the advancements of nanotechnology with the biochemical advantages of organic raw materials derived from the circular economy. The study centers on the coating of urea granules with a nano-sulfur (nS) layer. The application of nano-sulfur represents a technological breakthrough compared to traditional sulfur coatings; due to its exceptionally high specific surface area and excellent dispersion capabilities, it forms a more continuous, hydrophobic phase on the fertilizer surface, free of micro-cracks. This physical barrier effectively regulates osmotic water infiltration into the granule, thereby delaying the release of the active ingredient and the onset of hydrolytic processes. However, the efficiency of the system is finalized through the integration of organic additives, where lignite, biochar, and compost—along with various animal by-products such as meat meal and blood meal—contribute synergistically to the optimization of nutrient management. Porous organic components, such as lignite and biochar, not only stabilize the nano-sulfur layer but also possess a high cation exchange capacity, enabling them to bind released ammonium ions and reduce volatile losses. Concurrently, animal-derived protein sources function as slow-release organic nitrogen sources that gradually become available to the plants. The presence of these materials in the micro-environment modifies soil biological activity and improves the water-retention capacity of the rhizosphere, which is of decisive importance for the continuity of nutrient release during drought periods. Consequently, the applied complex hybrid coating system does not merely synchronize nitrogen release kinetics with plant demand but also indirectly improves nitrogen uptake by providing sulfur as a supplementary nutrient, as sulfur is essential for protein synthesis and nitrogen metabolism. Preliminary results clearly support that the combined application of nano-sulfur and a diverse organic matrix drastically reduces environmental emissions while maximizing the agronomic efficiency of fertilization. By repurposing animal by-products and fossil-derived organic matter (lignite) as value-added resources, this approach may become a pillar of circular agriculture, offering a sustainable and precision-oriented alternative for future plant nutrition strategies.

Keywords: nano sulfur, animal by-product, nitrogen use efficiency (NUE)

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