

Understanding Fertilizer Migration in Soil by Integrating Gravity, Sorption, and Transport: Modeling and Experiments

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The increasing global population and urbanization necessitate higher agricultural output, leading to intensified fertilizer application. While crucial for enhancing crop yields, excessive fertilizer use threatens environmental sustainability. Understanding the mechanisms governing fertilizer transport in soil is key to improving application strategies and minimizing environmental impacts.

This study presents a model that simulates fertilizer migration in soil by integrating key transport mechanisms, including advection and dispersion by the Advection-Dispersion Equation (ADE), buoyancy-induced flow using Darcy's law, and desorption by the dynamic Langmuir isotherm. The model is implemented numerically, with optimized time and spatial discretization ensuring accuracy and stability.

Fertilizer release is represented using a sponge-like material, such as activated carbon, with fertilizer adsorbed onto its surface. Upon contact with water, the fertilizer is gradually desorbed and transported through a structured porous medium that mimics soil. The model accounts for buoyancy effects due to density differences between fertilizer solution and soil water, influencing both vertical and lateral transport. By incorporating these coupled processes, the model improves predictions of fertilizer retention and movement under varying soil conditions.

The model will be validated through laboratory experiments, focusing on dye desorption from a sponge-like medium representing a solid fertilizer source into a porous structure mimicking soil. Simulated dye concentrations will be compared with experimental observations in space and time, capturing how desorbed dye disperses via flow or propagates downward due to buoyancy, influencing desorption dynamics.

Figure 1 summarizes the physical aspects of the experiment, including a photograph and an image-processed version. This visualization highlights key structural and physical features of the experimental setup. Figure 2 shows the dye's mass center displacement over time, revealing movement along both the horizontal (x) and vertical (y) axes. The observed vertical shift highlights the role of density-driven movement, emphasizing the need to account for buoyancy in fertilizer transport models.

By refining our understanding of fertilizer behavior in soil, this research supports improved fertilization practices, helping to balance agricultural productivity with environmental protection. The insights gained may support the development of strategies to optimize nutrient application, reduce leaching, and promote sustainable soil and water management.

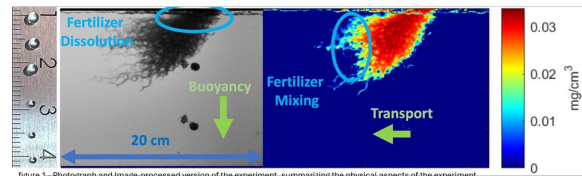


Figure 1 - Photograph and image-processed version of the experiment, summarizing the physical aspects of the experiment

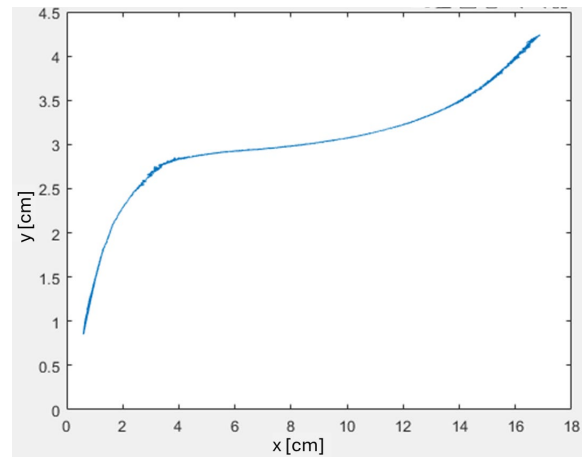


Figure 2- Initial analysis of the dye's mass center displacement over time. The trajectory shows movement along both the horizontal (x) and vertical (y) axes