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ABSTRACT

Numerical Studies and Analysis of Shockwave-Induced Soil Loosening for Agricultural Applications

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Soil compaction significantly affects crop productivity by restricting root growth, reducing water infiltration, and limiting gas exchange. Traditional tillage methods, while effective, contribute to soil erosion and carbon emissions. To address these challenges, this study investigates the feasibility of shockwave-based soil loosening using numerical simulations. A computational fluid dynamics (CFD) model was developed to analyze the behavior of supersonic shockwaves generated within the soil medium. The numerical model employs the Navier-Stokes equations with AUSM+ flux splitting and preconditioning methods to capture compressible flow dynamics. The soil is treated as a porous medium, with simulations evaluating shockwave propagation, pressure distribution, and energy dissipation. The study explores the effects of multi-nozzle configurations, varying injection pressures, and the presence of reflection waves within the system.
Simulation results reveal that shockwaves initially exhibit a spherical expansion pattern, followed by rapid attenuation due to energy dissipation. The multi-nozzle interaction enhances localized soil loosening, with overlapping shockwaves increasing the affected area. Standing wave effects were observed in regions with strong wave reflections, amplifying pressure fluctuations and improving aeration efficiency. Additionally, results indicate that shockwave propagation speed decreases with increasing distance, emphasizing the need for optimized nozzle placement to ensure uniform coverage. To validate the numerical findings, a controlled experimental setup was developed using an acrylic water tank to visualize shockwave interactions. Pressure sensor measurements further confirmed the simulation trends, reinforcing the reliability of the numerical model. The proposed technique presents a sustainable alternative to conventional tillage, capable of improving soil aeration without excessive surface disturbance.
This study establishes a quantitative framework for evaluating shockwave-induced soil loosening, paving the way for future advancements in precision agriculture. Further research will focus on optimizing injection parameters, refining soil-structure interaction models, and exploring the long-term effects of shockwave treatments on different soil types.

Keywords: Shockwave Soil Loosening, Computational Fluid Dynamics (CFD), Porous Medium Modeling, Precision Agriculture