

Article

Development, Numerical Simulation and Laboratory Validation of a Load-Cell-Based Mass Flow Rate Measuring Sensor for Dry Fertilizers in Seed Drills

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Abstract

An impact-based sensing system was developed and validated for real-time measurement of granular fertilizer mass flow rate in seed drills. Discrete Element Method (DEM) simulation was used to optimize the geometric configuration of the sensing unit, focusing on the fertilizer distance between the fertilizer tube outlet and the impact plate of the sensing unit (offset distance), using urea and NPK fertilizers. The simulation results identified an offset distance of 2.5 cm as the optimum configuration for both urea and NPK fertilizers, providing the most stable and repeatable flow response with minimum variability and flow interruption. The sensor was experimentally evaluated under controlled laboratory conditions using different positions of the fertilizer rate adjusting lever and machine forward speeds. The ANOVA results showed that both factors and their interaction significantly affected fertilizer flow rate ($p < 0.0001$). The measured flow rates exhibited strong agreement with gravimetric reference data, yielding a near-linear relationship ($R^2 = 0.9999$), with an overall accuracy of approximately 97% and mean relative errors between 5.1% and 7.4%. These results demonstrate that the developed load-cell-based impact sensor enables accurate and repeatable granular fertilizer flow rate measurement. In general, the impact-based sensor developed in this study combines competitive accuracy with simplicity, affordability and broad applicability and potential for integration with variable-rate application systems.

Keywords: precision agriculture; variable-rate technology; granular fertilizer; mass flow sensor; load cell



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1. Introduction

Granular fertilizers play a critical role in improving crop productivity and maintaining soil fertility by supplying essential nutrients required for plant growth [1]. However, inaccurate fertilizer application can reduce nutrient use efficiency, increase production costs, and contribute to environmental problems such as soil degradation and water contamination. To address these challenges, variable-rate technology (VRT), as a core component of precision agriculture (PA), has been widely adopted to enable site-specific fertilizer application based on spatial variability in soil and crop requirements [2,3]. VRT systems operate using map- or sensor-based strategies that dynamically adjust fertilizer application