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Use of Multi-Diffusion Model to Study the Release of Urea from Urea Fertilizer Coated with Polyurethane-Like Coating (PULC)

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Abstract

Controlled release fertilizer (CRF) play an important role in nutrient loss prevention and plant's uptake efficiency. This study uses a multi-diffusion model to simulate urea release from urea fertilizers coated with polyurethane-like coating (PULC). In this model, finite element method (FEM) and 2D geometry are applied for three sizes of urea granule using COMSOL Multiphysics software. Modeling results are in agreement with the experimental data for the "constant release" stage. Standard error of estimate (SEE) ranges from 0.00417 to 0.02084 in these simulations. Besides, relationship of coating thickness with release time and percent of urea released at the end of "constant release" stage has also been established.

Keywords: *Urea Release, Urea Diffusion, Finite Element Method, Multi-diffusion modeling, Transient state*

1. Introduction

Controlled release fertilizer (CRF) is meant to control the release of nutrients over the time instead of quickly dissolving in the moist soil after fertilizer application. Nutrient concentration is kept at appropriate level so that it helps to prevent nutrient loss and enhance nutrient utilization efficiency by plants [1]. The amount of fertilizers received by plant when applied in conventional forms is only 30-50%. However, CRFs

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resulted in minimum losses of the fertilizer which may be caused by volatilization or leaching, thus preventing the seedling damage. CRFs also provide good protection to ecosystem if the carrier/coating material is biodegradable [2]. Urea was selected as the material to be coated because of its high nitrogen content, low cost, and commercial availability [3].

First study on the application of controlled release technology to fertilizers was conducted in 1962 by Ortil et al. [4]. Nutrient released from CRFs are usually controlled by the diffusion through the coating layer. One of the major factors controlling the release of CRFs is the rupture of the coating membrane found in sulphur coated urea (SCU). Glaser et al. studied the release of polymer-coated granule and applied one-dimensional coordinate diffusion system in 1987 [4]. Gambash et al. used semi-empirical model in their study, and the effect of geometry and size was ignored. Besides these assumptions, the lag period, during which no release is observed, was not included [5]. Lu and Lee applied the Fick's law in spherical coordinate for the release of latex coated urea (LCU) [6]. Al-Zahrani modeled unsteady state release from polymeric membrane particle and assumed a well-mixed condition inside sphere particle [2]. Most of these modeling efforts were based on the assumption that the release of nutrients from coated fertilizer is controlled by simple solute diffusion. Based on Raban's experiments, it is proved that the release from a single granule of a polymer coated CRF consists of three stages: an initial stage during which no release is observed (lag period), a stage of constant release, and finally a stage of gradual decay of the release rate [4]. In 2007, Lu proposed a mathematical model for the release of a scoop of polymer coated urea which also took into account the effect of population of granules. This model was based on mass balance equation of pseudo-steady state of Fick's law. However, the first stage of release process was neglected [7].

Most of the studies in this area only concentrate on the simple diffusion of urea through coating layer without considering the diffusion through multilayer (coating and environment). To have a deeper insight into the "constant release" process of urea, this study investigates the release of urea from urea fertilizer coated with polyurethane-like coating (PULC).

Nomenclature

C is concentration of urea, mol/m^3
D_e is effective diffusivity of urea in porous medium (coating), m^2/s
D_{urea} is diffusivity of urea in liquid, m^2/s
ε is porosity of the coating, %
J_{Urea} is the diffusive flux at outer shell of urea granule in mol/(m^2.s)
l is coating thickness, mm
m_{core} is mass of urea in core, g
m_{sat} is mass of urea in core when solid core is totally dissolved, g
R_0 is urea core radius, mm

2. Model Development

Fig. 1a illustrates the dissolution model of a spherical urea granule. In this model, coated urea granule is surrounded by water environment (fluid zone). Urea granule consists of two parts: urea core and coating layer outside the urea core. Model assumes that coating layer is saturated with water at the time when the release begins. Water at the surface of urea core will start dissolving solid urea. This urea solution is kept at saturated level; as long as solid urea exists in the core. Urea starts releasing through the coating layer by means of diffusion. Based on mass transport equation in porous medium, a transient stage for urea diffusion through the coating layer can be written as in Eq. 1 [7]

$$D_e\left[\frac{\partial^2 C}{\partial r^2}+\frac{2}{r}\frac{\partial C}{\partial r}\right]=\varepsilon\frac{\partial C}{\partial t} \tag{1}$$

Since the urea pellet is motionless, it is assumed that urea flux from the coating interface to the liquid is controlled by the diffusion of urea in liquid. Hence, it is calculated on the basis of mass transport equation of urea in water as follows Eq. 2 and Eq. 3: