Evaluation of alginate-cellulose used in controlled release fertilizer for slow nutrient release and water retention

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Abstract. Alginate-cellulose is a green material with water retention properties. This research proposed the simulation model of controlled-release fertilizer by using the material with similar properties to Alginate-cellulose. We use the simulation model to investigate polymer-blended fertilizer performance compared to polymer-coated fertilizer and study the controlling factor of controlled releases, such as the shape of fertilizer and roughness of polymer coating. Our simulation result concludes that the fertilizer shape with a higher perimeter to the area for the unit area and roughness on imperfection coating causes the faster nutrient release. Moreover, we discover that polymer-blended fertilizer is acceptable for the alternative method of controlled-release fertilizer and can perform better with increased polymer proportion, especially when the polymer proportion is more than 30%.

1. Introduction

The use of controlled release fertilizer (CRF) has multiple advantages such as the reduction of the excessive loss of nutrients, optimizing the nutrient concentration, and environment-friendly [1, 2, 3, 4, 5]. Polymers such as organic polymers, biopolymers, natural biomolecule materials and nanocomposites can be used for coating. Usually, the coating layer controls the release of coated fertilizer through the diffusion process.

Most of the previous studies assume that the CRF granule has a perfect coating and spherical shape. These studies mainly focus on the time of fertilizer released out of the coating granule in the various surrounding. These surroundings include the granule that fully immerses in the water or the granule surrounded by different soil mediums [2]. The results show that the fertilizer quickly dissolved when immersed in water, and the release depends on the soil characteristics (i.e., porosity, particle size, and surface area). However, there is still a limited understanding in the effect of the shape and the roughness on the nutrient release.

Furthermore, the direct mixing of biopolymer with urea nutrient or “polymer blended fertilizer” can be another candidate for the production of CRF due to the simplicity of the production process. The simulation relates to polymer blended fertilizer is crucial for
understanding the effectiveness of this type of CRF. Making use of water retention, water can diffuse into the fertilizer, and the size of fertilizer can be roughly unchanged during the releasing process.

In this study, we use the diffusion equation to simulate the time-dependent nutrient concentration of control release fertilizer. The effects of shape, roughness, and blended polymer are studied using the spatial dependence of diffusion coefficient. The simulation methods are described in Section 2. The nutrient release results are shown in Section 3, and the conclusion is given in Section 4.

2. Simulation methods

We use the diffusion process to mimic the release of nutrients. The governing equation is

\[ \frac{\partial}{\partial t} c(r, t) = -\nabla \cdot E(r, t) \]

where \( c(r, t) \) is the nutrient concentration and \( E(r, t) = \nabla c(r, t) \) is the flux of the concentration. We solve this equation numerically by using the finite difference method. We solve for the average concentration inside a cell and evaluate fluxes at the cell boundaries. By defining the fluxes at the boundaries, the total amount of fertilizer is conserved. Figure 1a shows the fluxes at the boundaries of a cell at an arbitrary point \((i,j)\). The fluxes are evaluated by the following equations,

\[ F_{x1} = -D \frac{(c_{i,j} - c_{i-1,j})}{\Delta x}, \quad F_{y1} = -D \frac{(c_{i+1,j} - c_{i,j-1})}{\Delta y}, \]

\[ F_{x2} = -D \frac{(c_{i+1,j} - c_{i,j})}{\Delta x}, \quad F_{y2} = -D \frac{(c_{i,j+1} - c_{i,j})}{\Delta y}, \]

where \( \Delta x, \Delta y \) are the grid spacing in \( x \) and \( y \) direction and we assume that \( \Delta x = \Delta y \). The diffusion coefficient at point \((i,j)\) is \( D_{ij} \). In this model, we categorize the media into three regions which are 1) the polymer media, 2) the nutrient media, and 3) the water media. We assume the effective diffusion coefficient of the polymer media is \( D_0 \). We assume the polymer media has the effective diffusion coefficient equal to \( D_0 \) and the diffusion coefficient of the nutrient media is equal to \( 10D_0 \). Due to the fact that the diffusion coefficient of the nutrient media is not the primary control factor of the release time, changing this value had no effect on the physical properties of the fertilizer, so the diffusion coefficient is equal to \( 10D_0 \) to reduce the computational resources. Since the water media has a much higher diffusion coefficient than the other two regions, we assume that the nutrient concentration inside the water media \( c_{ij} = 0 \). We also define the core radius of the fertilizer as \( r_0 = 30\Delta x \). The time step size is \( \Delta t = (\Delta x)^2/10D_0 \). The number of grid in \( x \) and \( y \) direction is \( Nx \times Ny = 50 \times 100 \). All simulations have a reflecting boundary on the left side of the box. Our fertilizer can have a shape of a 2D circular disk, and square disk. The polymer can be coated on and blended in the fertilizer. The level of polymer roughness can also be modified. Figure 1b shows samples of the fertilizer in a 2D circular disk. The fertilizer in the left panel has polymer blended with the nutrient. The middle panel shows the perfect polymer-coated fertilizer. In the right panel, we add roughness to the polymer layer.

3. Results

The results of nutrient release in time were calculated using the sum of the amount of mass that diffuses to the water media. The results were shown in Figure 2. We also provide the time for 90% of nutrient release to water in the table alongside with the figure. In Figure 2a, the comparison results between a circle and square shape of the fertilizer without polymer with the same area of nutrient media are shown. We found that the circle shape releases slower than the square shape due to lower perimeter per area. Figure 2b compares the different types of
fertilizer which are the fertilizer without polymer, 50% polymer blended, and coated fertilizer. The time for 90% of nutrient release slightly increase when the polymer is blended and largely increase when the polymer is coated.

Figure 1: (a) Geometry model of fertilizers. (b) Concentration flux on each boundary of the element.

The relationship between the percentage of blended polymer and the nutrient release time is investigated and shown in Figure 3a. The time for 90% of nutrient release is proportional to the percentage of blended polymer. However, when the percentage of blended polymer exceed 30%, the time for 90% nutrient release will increase notably and show the sudden improvement for the slow release performance. In Figure 3b, the comparison of nutrient release between perfect and imperfect coating circle fertilizer. We found that the imperfect coating has a slower time for 90% of nutrient release. To confirm this result, the flux of nutrient release is shown in Figure 4. Because water media has a much higher diffusion coefficient, the flux tends to be larger in areas with low water media contact surface, such as near the coating layer’s sharp edge and at lower coating thicknesses, as shown in figure 4.

4. Discussion and Conclusion

In this work, we study how the shape of the fertilizer and the way we use polymer in fertilizer affect the nutrient release. The shape with the higher perimeter to area ratio for the unit area has the shorter nutrient release time. Then we found that the polymer-blended fertilizer can be an alternative method for control release fertilizer when the percentage of blended polymer
Figure 3: (a) Comparison of the nutrient release profiles for circle polymer-blended fertilizer with different polymer proportion. (b) Comparison between the release profiles of nutrient in perfection and imperfection of polymer-coated fertilizer.

Figure 4: Vector plot of flux toward coating boundary

becomes larger than 30%. The further improvement of polymer blended fertilizer can be obtained by increasing the percentage of polymer. The imperfect coating can reduce the nutrient releasetime. The major factor is the thin part and sharp edge of the coating region tends to increase the nutrient outflow to the water media.

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