Controlled Release of Agrichemicals Using a Root Targeted Delivery Vehicle

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INTRODUCTION

The recent increases in food prices caused by the corresponding increases in fertilizer costs have highlighted the need for reducing the overuse of fertilizers in industrial agriculture. The fertilizers, pesticides and other crop protectants that are lost due to water runoff, chemical degradation, microbial attack and other mechanisms are needless costs that persist despite the availability of commercial slow release fertilizers. There is a clear need for a new novel material that is able to address the problem of fertilizer use inefficiency. To address these issues, a new carboxymethyl cellulose hydrogel has been developed with the potential to vastly increase the efficiency of fertilizers placed in soil, resulting in a significant reduction of costs and environmental damage. In addition, this material is able to simultaneously increase the water retention of soil, increasing the survivability of plants during drought and reducing the need for irrigation.

Polymer coating of large fertilizer granules is the most common controlled release mechanism and relies on the biodegradation of the polymer coating to release fertilizers over a sustained period. Coating the fertilizers with a polymer serves to help immobilize the fertilizer pellets and hence make them resistant to runoff and leaching (Zhang, 2001). However, these types of CRF are vulnerable to changes in the soil type, moisture content and other factors which can affect the release rate (Diez, 2010), which may create situations where the plants are starved of nutrients or unable to use the fertilizer released. These reasons may be why use of current controlled release fertilizers takes up a relatively low market share of total fertilizer use compared to regular chemical fertilizers (Malhi, 2010).

In order to address these issues with currently available controlled release fertilizers, the carboxymethyl cellulose controlled release fertilizer (CRF) is being developed to address the issues with the current generation of CRF products. The results discussed detail the effectiveness of the material in delivery of both fertilizer and improving water retention of soil. Future development of this material has the potential to allow the simultaneous release of fertilizer, water, pesticides and micronutrients simultaneously. The carboxymethyl cellulose material used is also low cost, having found use commonly as filler in food products. The production process for the hydrogel material is easily scalable to large operations and can be done as a continuous or batch process depending on demand. Furthermore, each individual hydrogel functions continuously and is capable of sustained release without the need for mixing numerous different formulations or coating thicknesses as is typical of polymer coating based CRFs. The CMC CRF is derived from a similar curdlan based drug delivery material developed for controlled release of drugs to treat tumour and other diseases (24). The CMC hydrogel project discussed attempts to utilize the principles of pharmacokinetic drug release to maximize the absorption and utilization of the released fertilizer by the plant. This strategy involves optimizing the rate of release of the hydrogels while simultaneously targeting the delivery to plant roots in order to minimize fertilizer losses to runoff and chemical degradation.

MATERIALS AND METHODS

Hydrogel Synthesis

The hydrogels are manufactured through dissolution of 7 g carboxymethyl cellulose powder in 100 ml deionized (DI) water. The gel is then loaded with the desired release formulation, in this case 20-20-20 fertilizer, by dissolving the desired amount of fertilizer in 10 ml deionized water then mixing the dissolved fertilizer into the hydrogel. After loading, the gel is placed into a 30ml syringe and injected into sections of dialysis membrane. The membrane is then clamped at both ends and left in an ionic crosslinking solution composed of 40 g calcium chloride, 4 g iron (II) chloride and 4 g iron (III) chloride dissolved in 400 ml DI water for 48 hours in order to obtain the resulting ionically crosslinked hydrogel. Afterward, the crosslinked hydrogels are taken out of solution and the membrane is removed.

Growth Testing

Growth testing using plant models was done in a temperature and humidity controlled greenhouse. The testing involved placing the CMC hydrogels prepared using the above method into a small planter filled with Turface. The gel is covered with Turface and a wheat seed is placed into the pot and again covered with Turface. The pots are then watered to hydrate the soil. The growth experiments involving wheat continue for 50 days with 50 ml deionized water applied daily. The heights of the plants are recorded throughout the experiment in order to gauge the hydrogel's performance in increasing plant growth. At the end of the experiment the plants are removed from the soil and are dried completely in ambient conditions in order to obtain dry mass measurements. Each growth experiment is performed alongside a negative and positive control to help minimize the effect of variation from the experiments occurring at different times. Positive controls received 50 ml deionized water for the first 7 days and 1g/L 20-20-20 fertilizer dissolved in 50mL deionized water per day for the remaining 43 days instead of using a hydrogel device for fertilizer delivery. Negative controls received only 50 ml deionized water and did not use a hydrogel device either. All experiments are done in replicates of three to account for variation between plants. Plants that do not germinate within the first 20 days are considered to be outliers and are discarded.

RESULTS AND DISCUSSION

The growth experiments performed comparing the performance of the carboxymethyl cellulose hydrogels showed that the hydrogels were effective at increasing the efficiency of fertilizer use by crops. Hydrogels which were loaded with the same amount of fertilizer as was received by the positive control were able to increase wheat height and seed yield relative to similar plants grown with daily applications of conventional fertilizer.

The results shown in table 1 illustrate the effectiveness of the controlled release vehicle for increasing the growth of plants. When the hydrogels were loaded with the same amount of fertilizer as was given to the positive control, the seed yield of the plants was improved by up to 170% compared to the positive control.

Table 1: Dry Mass Measurements of Wheat Plants Grown with Carboxymethyl Cellulose Hydrogels

Sample	Fertilizer Loading (g)	Drying (H)	Dry Mass (% of Positive Control)	Dry Seed Mass (% of Positive Control)
positive control	N/A	N/A	100	100
negative control	N/A	N/A	9.859155	11.5747
CMC	0.47	24	20.65728	81.01006
CMC	0.47	48	16.90141	66.50003
CMC	2.15	0	78.87324	197.321
CMC	2.15	24	76.05634	198.9233
CMC	2.15	48	69.48357	271.6144

Furthermore, the amount of fertilizer loaded in the hydrogels was able to be reduced by up to approximately 78% before the yield of the wheat plants was reduced as compared to the positive control. With 30% of total fertilizer use, plants grown with the hydrogel experienced only an approximate 20% drop in yield, compared to an 80% drop for the negative control plants.

CONCLUSIONS

Overall, carboxymethyl cellulose hydrogels are a promising material for use in increasing the fertilizer use efficiency of agricultural crops. These hydrogels were shown to be able to maintain seed yield of crops despite reductions of fertilizer use of up to 78%. There is potential for improving the performance of the hydrogels further in order to maximize the efficient use of fertilizer to allow for the largest possible reductions in fertilizer use in order to help reduce costs and environmental issues caused by fertilizer losses. Alternative uses for the hydrogels in terms of drought mitigation were also identified as possible avenues of investigation. However, further investigation will be required in order to fully explore the ability of carboxymethyl cellulose hydrogels in increasing fertilizer use efficiency in a wider variety of crop plants in field conditions.

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ACKNOWLEDGMENTS

Thank you to Lynn Hoyles for helping with the growth trials and to our co-op students Ben Dippelsman and Allison Chiang.