Advanced Materials Research
ISSN: 1662-8985, Vol. 1112, pp 414-417
doi:10.4028/www.scientific.net/AMR.1112.414

Submitted: 2014-08-14
Revised: 2015-02-24
Accepted: 2015-02-24
Online: 2015-07-10

Characterization of Chitosan-Acrylamide Hydrogels as Soil Conditioner

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Keywords: hydrogels, chitosan, soil conditioner, gamma irradiation, biodegradation

Abstract. Hydrogels can be used as soil conditioner which acts as water reservoirs and release water depending upon the need of plant roots. Soil conditioner based hydrogels were synthesized by graft copolymerization of chitosan-acrylamide using gamma irradiation. In this research, the influence of hydrogels amounts on physical, and chemical properties of the sandy soil characterization were investigated by measuring bulk density of soil, porosity, water retention, and field capacity. Bulk density of the soil was decreased, whereas water retention and porosity were increased with increasing additions of hydrogels. The addition of 0.4% hydrogels increased the field capacity significantly. Biodegradation studies of the hydrogels were carried out by soil burial-test in a composting environment up to 6 weeks. Microscopy analysis shows structural deformation of hydrogels with time. Hydrogels show sharp weight loss until 4 weeks. Soil conditioner based chitosan-acrylamide hydrogels was found to be beneficial for maintaining the physicochemical soil properties as well as plant growth.

Introduction

The shortage of irrigation water, drought, deforestation and soil erosion are one of the major problems of agriculture around the globe. Development of non-traditional new technologies to conserve water is becoming important for attaining a sustainable economic growth, especially in agricultural countries. The use of some novel soil conditioner based hydrogels is currently becoming increasingly important to improve the crop yield and productivity, due to their water retention properties [1,2,3]. Hydrogels are cross-linked, three-dimensional hydrophilic networks that swell but not dissolve when brought into contact with water. Hydrogels polymers potentially influence infiltration rates, density, soil structure, compaction, soil texture, aggregate stability, crust hardness, and evaporation rates [2,4]. The desired features of hydrogels for agriculture purposes include high swelling rate, swelling capacity, and reswellibility. Water held in the expanded hydrogels is intended as a soil reservoir for maximizing the efficiency of plant water uptake. hydrogels can be used as soil moisture conditioners which act as water reservoirs and release water depending upon the need of plant roots.

Currently, most of hydrogels used in practice is mainly petroleum-based synthetic polymers, and thus the study and development of hydrogels based biopolymers has become subject of great interest due to their commercial and environmental advantages. In the present study, a chitosan-acrylamide graft copolymers based hydrogels was evaluated as a soil conditioner and its effect on physical, and chemical properties of the soil were studied. It is also important to study biodegradation of hydrogels.

Experimental Procedure

Preparation of Chitosan-Acrylamide Graft Copolymerization Hydrogels by Simultaneous Gamma Irradiation. Chitosan (2 g) were mixed with distilled water at 400 rpm at room temperature for 1 hour. Acrylamide monomers 3 M added into the mixture for 1 hour. The mixtures were irradiated using Gamma Chamber-40 with total dose 30 kGy.

Characterization of Soil Conditioner Properties Based Chitosan-Acrylamide Hydrogels. Bulk density (the mass of a unit volume of dry soil) and porosity of soil sample were measured using core method [2]. For the determination of water retention properties, hydrogels was mixed uniformly with sandy loam soils to concentrations of 0, 0.1, 0.2, 0.3, 0.4 and 0.5%. Then, 100 mL of tap water was slowly added to these cups and weighed (w_1). The cups were maintained at 25^{0}C and were weighed at a certain interval (w_t). The water retention ratio (%wr) of sandy soil was calculated with Eq. 1.

$$\%wr = \frac{w_t - w}{w_1 - w} \times 100\,\% \tag{1}$$

Where w is the initial weight of the soil and cups. Field capacity (FC) is the gravimetric soil water content remaining in the soil 2 d after wetting and after free drainage is negligible and calculated with Eq. 2.

$$\%FC = \frac{\text{weight of wet soil} - \text{weight of dried soil}}{\text{weight of dried soil}} \times 100\,\% \tag{2}$$

Biodegradation studies of the hydrogels were carried out by soil burial-test [5] and investigated by optical microscope (Meiji).

Result and Discussion

Effect of Hydrogels on Bulk Density and Porosity of Soil. The bulk density and porosity of soil are important measurements for the physical arrangement of solids and voids relative to each other [4-7]. The results of soil bulk density presented in Table 1 revealed that, a decrease in the bulk density and increase in total porosity was noticed with the increase of the hydrogels concentration.

Table 1. Effect of hydrogels concentration on bulk density and porosity

Hydrogels Concentration [%]	Bulk Density [g/cm^3]	Porosity [%]
0	1.47	32.5
0.1	1.42	35.4
0.2	1.40	37.6
0.3	1.36	42.6
0.4	1.30	44.2
0.5	1.28	45.9

Hydrogels within the soil matrix absorb water and become larger in size. The soil particles are displaced and rearranged around the swollen hydrogels. The soil volume increases and hence the ratio of the dry mass of the soil to its volume decreases. Studies on the soil conditioning based polymers show decreasing effect of this material on bulk density [2]. The decreasing effect of polymer's grains between soil particles and it expands and contracts with absorption and desorption of moisture and makes soil particles close to each other and with establishment of aggregate, causes stability of soil structure and increase of soil porosity that will decrease bulk density [7]. Swelling hydrogels makes soil substantially loosened and aerated, and bonds between micro aggregates within wetted soil aggregates weaken at the same time thus increasing soil porosity.

Effect of Hydrogels on Water Retention. The effect of hydrogels on water retention is presented in Fig. 1. Soil water retention increased with increasing hydrogels concentrations. The time needed for losing 50 % of the initial water in the hydrogels amended soils with 0.4 and 0.5 % was much longer than that recorded for control or low hydrogels concentration. It means that sandy soil mixed with hydrogels exhibits a slower water-evaporation rate compared with that without hydrogels.

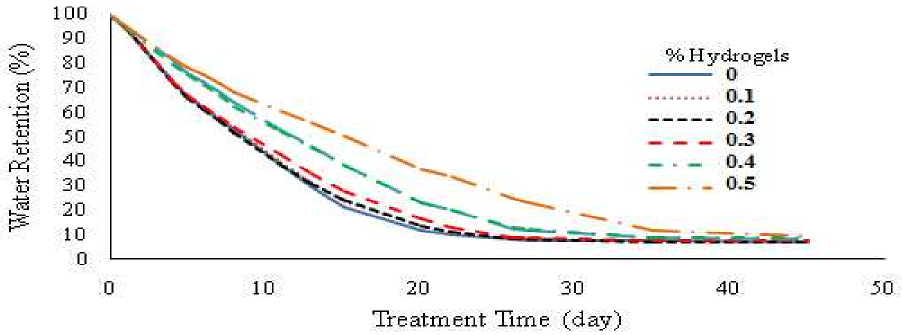


Fig.1 Effect of hydrogels concentration on water retention.

Chitosan-acrylamide hydrogels are capable of quickly absorbing water after contact with it and holding it up to many times of its volume and allow the water absorbed in it to be slowly released with the decrease of the soil moisture so as the result increase water retention in soil. The previous studies reported that evaporation from a macromolecular hydrogels is significantly slower than the evaporation of free water from a soil exposed to atmosphere, due to the macromolecular network hindrance and the interaction between water and polymer molecules [1,2,4,6].

Effect of Hydrogels on Field Capacity. The addition of hydrogels increased field capacity as shown in Fig. 2. Adding hydrogels to sandy soil increases the amount plant-available water. It means that hydrogels accumulates the gravitation water in the soil, which under natural conditions rapidly permeates the soil profile and becomes unavailable for plants. Increase available water of plant could be affected by swelling process of hydrogels. Swelling of the hydrogels is may be attributed from hydroxyl (OH) groups and amino ($-NH_2$) groups of chitosan and acrylamide which is interaction with water molecules by hydrogen bonding, and from the presence porous network in the hydrogels.

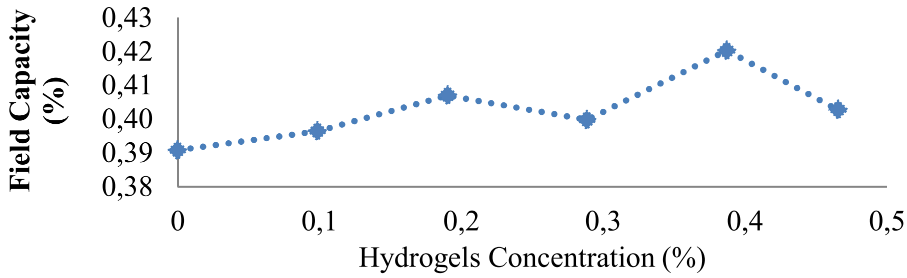


Fig. 2 Effect of hydrogels concentration on field capacity.

Biodegradability Studies. It is clear from Fig. 3 that the weight of chitosan-acrylamide hydrogels was reducing sharply with time until 28 days.

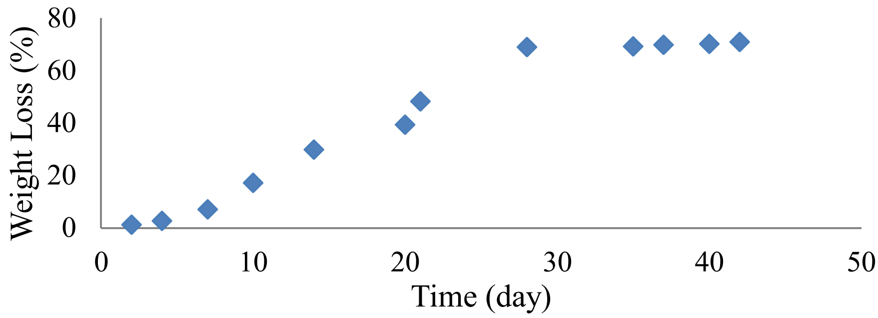
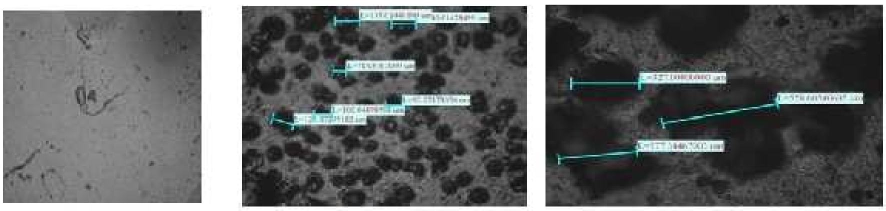


Fig. 3 Weight loss profile of chitosan-acrylamide hydrogels.

The intermolecular and intramolecular linkage of -OH between chitosan and acrylamide molecules and the hydrophilic groups were reduced lead to decrease of weight loss of hydrogels. The main mechanism of chain scission during the biodegradation is a chemical and enzymatic hydrolysis [5]. Hydrogels ability to absorb water influences biodegradation of a material facilitating the action of the enzymes that convert the polymer into smaller fragments by the soil microorganisms. Optical microscope images provide very good evidence in favour of biodegradation of hydrogels.



a. 0 day b. 14 days c. 28 days

Fig. 4 Microscope image of hydrogels biodegradation.

It can be seen from the Fig. 4, before degradation the hydrogels surface was almost smooth. After two weeks, irregularities and voids can be observed on the hydrogels, which means that the internal structure of chitosan-acrylamide hydrogels has started to degrade. After four weeks, hydrogel film surface becomes more irregular, roughness, number and size of voids increased. These defects are understood as surface irregularity that disrupts the hydrogels surface affected by biodegradation processes.

Conclusion

Chitosan-acrylamide hydrogels was concluded to be highly suitable as soil conditioner. Increasing additions of hydrogels caused decrease of bulk density and increase of porosity, water retention, and field capacity. It can be concluded from weight loss and the morphological studies that chitosan-acrylamide hydrogels was degraded in soil burial test.

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Advanced Materials Research and Production
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