Hindawi
Advances in Polymer Technology
Volume 2019, Article ID 6869454, 7 pages
https://doi.org/10.1155/2019/6869454

Research Article

Comparison of the Effects of Polyacrylamide and Sodium Carboxymethylcellulose Application on Soil Water Infiltration in Sandy Loam Soils

Songrui Ning, Halidaimu Jumai, Quanjiu Wang, Beibei Zhou, Lijun Su, Yuyang Shan, and Jihong Zhang

State Key Laboratory of Eco-Hydraulics in Northwest Arid Region of China, Xi'an University of Technology, 710048 Xi'an, China

Correspondence should be addressed to Quanjiu Wang; wquanjiu@163.com and Beibei Zhou; happyangle222@gmail.com

Received 13 June 2019; Accepted 21 August 2019; Published 17 December 2019

Guest Editor: Chongyang Shen

Superabsorbent polymers have been used widely in agricultural production in arid and semi-arid regions to manage the soil water holding capacity. As the common water-retention polymers, the molecular weights, and structures of polyacrylamide (PAM) and sodium carboxymethylcellulose (CMC) are obviously different. Modified soil water management with polymers (i.e., PAM and CMC) has shown great promise for water conservation. Few researchers have reported the comparison of the effects of PAM and CMC on soil infiltration characteristics, especially in coarse-textured soils (i.e., sandy loam). In this research, two high-molecular polymers (PAM and CMC) were used to investigate the effects of polymers on soil water infiltration characteristics by laboratory experiment. The infiltration reduction effects of CMC treatments were more obvious than those of PAM treatments. With the applied rates of PAM (0.2–0.8 g/kg) and CMC (1–4 g/kg) increased, the processes of soil water infiltration were inhibited. The average infiltration time of CMC with different application rates is 1.85 times than that of PAM with different treatments. The mean wetting front distances of different application rates treatments of PAM and CMC were 22.20 and 19.23 cm. At the same application rate, applied CMC is more effective in reducing soil sorptivity than applied PAM in sandy loam soils. Moreover, the cost of application of CMC is lower than the cost of application of PAM. The mean economic inputs of PAM and CMC were 153.90 and 35.24 RMB/hm^2. Therefore, CMC was selected and recommended as the suitable water retention agent in sandy loam soils.

1. Introduction

Soil water infiltration is an essential path in the hydrologic cycle; and it mainly controls water intake by the soil profile and leakage [1]. Rapid water infiltration and leaking past the root-zone are normally associated with coarse-textured soils (i.e. sand, sandy loam, etc.). Arid and semiarid regions are characterized by low erratic rainfall, long dry seasons, and high evaporation rate [2]. The rapid infiltration of soil and scarcity of water in these regions required soil water management schemes to improve the water holding capacity of the soil.

Superabsorbent polymers have long been used in agriculture and recognized as viable soil conditioners for water-retention agents [3]. These polymers used in agriculture is commonly considered environmentally safe. Such as polyacrylamide (PAM) [$(H_2$-CH-CO-$NH_2)_n$] is a long-chain synthetic macromolecule polymer, and sodium carboxymethylcellulose (CMC) is an anionic water-soluble polymer [4, 5]. These polymers' application rates are low and can be considered as successful water retention agents for soils, with low cost, increased stability of the soil structure, etc. Effectiveness of polymers depends on many factors including soil texture and mineralogy, soil management, application rate, and method, water quality, etc. [6–8]. Several kinds of PAM have been used for over 60 years; and CMC is widely used in the biomedical field, food industry, and municipal water treatment [6, 9]. PAM applied in irrigation for reduced water infiltration was reported by Ajwa and Trout [6]. PAM applied to soil surface can be effective at reducing the steep sloping land erosion [8]. As for the application methods of PAM, spreading on soil surface was more effective than mixing with topsoil in increasing infiltration [10, 11]. Similarly, the influence of CMC on soil aggregate structure and soil water infiltration were investigated by Wu et al. [12]. A solidified layer formed after mixing CMC with undisturbed soil acts as a layer of reinforcement, antiseepage, and antierosion [13].

However, a number of PAM studies have been performed on silt loam or clay loam soils [6]. As common water-retention agents, the molecular weights, and structures of PAM and CMC are obviously different [14]. Many scholars have studied the effects of application of PAM and CMC on soil infiltration. However, there are few studies on the comparison of the effects of PAM and CMC on soil infiltration characteristics. It is essential to provide information for selecting water retention agents with high cost-performance in agricultural production, especially in coarse-textured soils with strong permeability (i.e., sandy loam). Therefore, in this study, sandy loam soils were chosen to compare the effects of PAM and CMC on soil infiltration characteristics (i.e., cumulative infiltration, wetting front, and soil sorptivity); moreover, the economic inputs was calculated for each polymer. The results of the experiment are also compared and discussed in detail.

2. Materials and Methods

2.1. Materials. The experimental soil was taken from a field site (34°4′N 108°2′E) located at Yangling, an agricultural high-tech demonstration zone in northwest China. The soil was obtained from the top 20 cm, and the bulk density at the site of 1.35 g/cm^3. After removal of impurities by hand, the soil was air-dried (water content of 0.03 cm^3/cm^3), ground and sieved (<2 mm) before use. The particle size distribution was measured using Malvern Mastersizer 2000 (Malvern Instruments Ltd., Malvern, UK), and the soil sample contained 7.6% clay (diameter of <0.002 mm), 30.25% silt (diameter of 0.002–0.02 mm), and 62.15% fine sand (diameter of 0.02–2 mm). The soil texture is classified as sandy loam based on the International Classification System of Soil Texture.

Two superabsorbent polymers including polyacrylamide (PAM, mean M.W. = 20 million, anionic) and sodium carboxymethyl cellulose (CMC, mean M.W. = 90,000) were analytical grade reagents purchased from Shanghai Chemical Agents Co., Ltd.

2.2. Experimental Design. The experiment was carried out in July 2018 using transparent polyvinyl chloride (PVC) columns at the State Key Laboratory of Eco-Hydraulics in northwest Arid Region of China, Xi'an University of Technology. Laboratory experiment was designed to investigate soil water infiltration characteristics influenced by using two different water retention agents (PAM and CMC). The average daily air temperature and relative humidity were about 27°C and 65% in the laboratory, respectively.

The experiment was conducted by one-dimensional vertical infiltration of water. PVC columns had 20 cm of inner diameter, 35 cm of height, and the bottom of each PVC column was padded with a filter paper and a permeable gauze. For each column, the filled height of the soil column was 28 cm with a bulk density of 1.35 g/cm^3 based on actual field conditions; and filled layer by layer and weighed at every 5 cm interval and the height of the last filled layer (soil surface layer) was 3 cm. The soil was disturbed between layers to hinder the stratification during infiltration. The soil surface was covered with a filter paper to avoid erosion.

As water retention agents are often applied on the soil surface layer [10, 11, 15, 16], PAM and CMC were also applied and mixed to the soil surface layer according to the mass ratio (w/w), and then filled as the top layer of the soil column. Treatments were applied as follows: PAM and CMC were mixed with the soil at the surface layer, and the rates applied were 0 (control, CK), 1, 2, 3, and 4 g/kg for PAM, and 0.2, 0.4, 0.6, and 0.8 g/kg for CMC, respectively [8, 10–12, 16]. Each treatment had double replicates, and a total of 18 soil columns.

A Mariotte bottle with 16 cm in the inner diameter and 50 cm in height was used to supply water and sustain a constant head for each soil column during the experiment [17]. The Mariotte bottle had an outlet at the bottom and was connected to the external air through an air intake tube. Before the experiment began, the height of the Mariotte bottle was adjusted to set the lower end of the intake tube at about 15–20 mm above the soil surface, to maintain a constant water head with 15–20 mm. Changes in the wetting front and the infiltration amount were recorded every 1 min for the first 5 min, every 3 min for 5–20 min, and every 5 min for 20–45 min, every 15 min for 45–120 min, every 30 min for 120–300 min, and each 60 min for 300–660 min and then the observation interval increased gradually until the end of the experiment. When the cumulative infiltration amount reached a fixed value, the water level in the Mariotte bottle droped to 15.80 cm (equal to 3175.17 cm^3), then the water supply was closed immediately and the infiltration process completed.

2.3. Data Analysis. A power function can be utilized to fit the dynamic process of the time and distance of the wetting front migration as follows:

$$F = at^b, \tag{1}$$

where F is the wetting front migration distance, cm; t represents the infiltration time, min; and a and b are the fitting parameters. The a value indicates the wetting front migration distance within the first unit of time, and the b value designates the attenuation of the wetting front advance process.

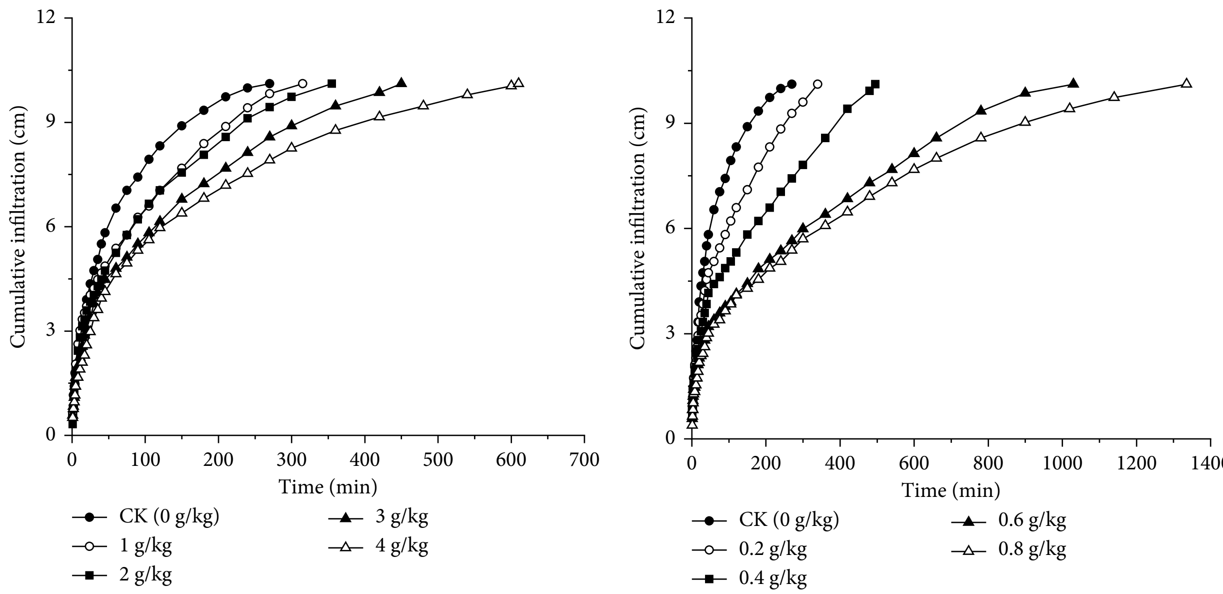
Infiltration data were fitted using the Philip model [18] as follows:

$$I(t) = St^{0.5}, \tag{2}$$

where $I(t)$ represents the cumulative infiltration, cm; S represents the sorptivity, cm min$^{-0.5}$; and t is the infiltration time, min. Sorptivity represents the ability of soil to release fluid by relying on capillary force, which is a vital indicator of soil water infiltration capacity at early phases; the higher the S value, the greater the soil water infiltration capacity.

3. Results

3.1. Effects of PAM and CMC Application Rates on Cumulative Infiltration. Based on the experimental observations, the



(a) Applied PAM

(b) Applied CMC

Figure 1: Effects of different application rates for (a) PAM and (b) CMC on cumulative infiltration in sandy loam soils.

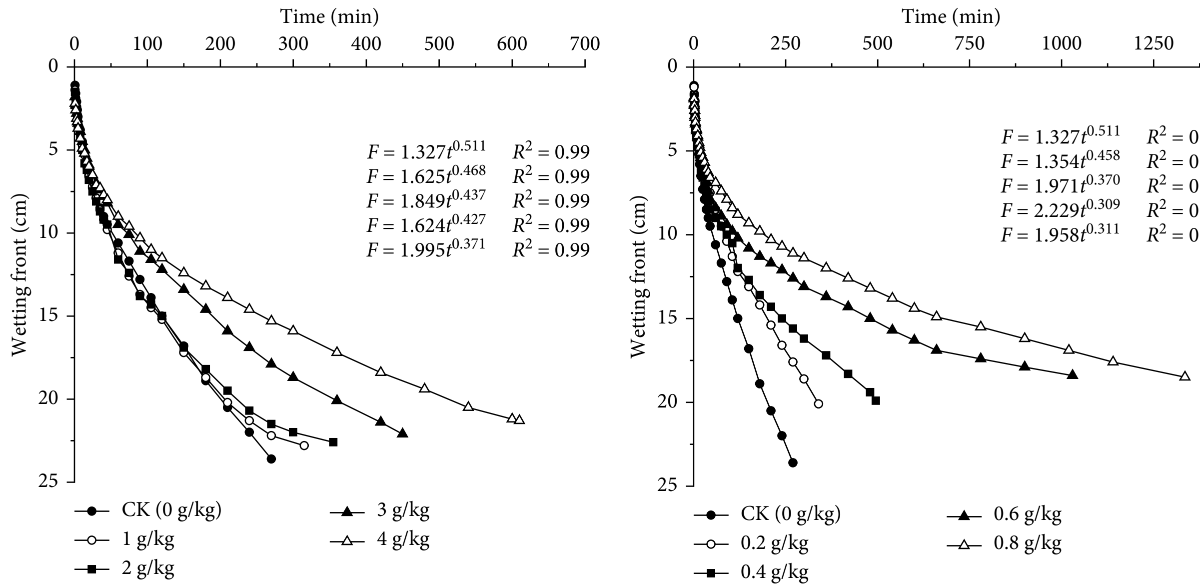
effects of increasing application rates of PAM and CMC on the progresses of cumulative infiltration are shown in Figure 1. At the initial phase of water infiltration, the soil mass was drier with a lower soil matric potential [19], and the infiltration rate was equal to the applied water rate, and the cumulative infiltration was nearly equal to the applied water amount. In this situation, soil water infiltration was less affected by PAM and CMC application rates. The curves of the cumulative infiltration were steep, illustrating a high curve coincidence degree. After the soil surface was ponded, the effects of different water retention agents on the soil water cumulative infiltration were gradually revealed as the infiltration times increased.

The cumulative infiltration of each water retention agent at different dosages varies with time. The infiltration time of CK treatment is the shortest (270 min). Compared with the infiltration time of CK, the infiltration times of PAM application rates ranging from 1 to 4 g/kg were relatively increased 16.67%, 31.48%, 66.67%, and 125.93% when the infiltration experiment completed. The results showed that the application of PAM had the reducing infiltration effect in sandy loam soils. The effects of reducing infiltration enhanced as the PAM application rates increased. This may be the result of PAM being a long chain synthetic polymer that acts as a strengthening agent, holding soils in place, and binding soil particles together as flocculated soil; moreover, PAM is a high-molecular water-soluble polymer with decreased permeability, due to an apparent increase in effective viscosity of the soil solution [6]. This result is similar to the one-dimensional vertical infiltration characteristics under the condition of PAM mixed with soil application fully [16]. Correspondingly, the infiltration time relatively increased to 25.93%, 83.33%, 281.48%, and 394.44% as the CMC application rates increased from 0.2 to 0.8 g/kg when compared to CK treatment, and the longest infiltration time was 1335 min for the treatment with CMC at an application rate of 0.8 g/kg. The larger the application rates of CMC, the more obvious the effect of hindrance of the infiltration. This may be attributed to the fusion of CMC with water molecules in soil to form hydrogel which increases the viscosity of water and the water stable aggregate content so as to hinder the infiltration of water [12]. This conclusion is similar to that reported by [12] when CMC and soil samples are mixed together fully.

The mean infiltration times of different application rates treatments of PAM and CMC were 433 min and 800 min, respectively. The average infiltration time of CMC with different application rates is 1.85 times than that of PAM with different treatments. This result shows that the infiltration reduction effect of CMC treatments with different dosage is better than that of PAM treatments in sandy loam soils in this study.

3.2. Effects of PAM and CMC Application Rates on Wetting Front. Figure 2 shows the dynamic progresses of wetting fronts with PAM and CMC at different application rates. Overall, the wetting fronts increased gradually as the infiltration time expanded, and the distances of wetting fronts are different at diverse application rate treatments when the same cumulative infiltration (3175.17 cm^3) is reached. As the application rates of PAM and CMC increase, the distance of all the wetting fronts becomes shorter. Similar phenomena were also reported by other researchers [8].

Compared with the wetting front distance of CK (23.60 cm) at the completion of the infiltration experiment , the wetting front distances were reduced to 3.39%, 4.24%, 6.36%, and 9.75% as PAM application rates increased, respectively (Figure 2(a)). Similarly,the wetting front distances reduced to 14.83%, 15.68%, 22.03%, and 21.61% as the application rates of CMC increased, respectively (Figure 2(b)). Moreover, the mean wetting front distances of different application rates



(a) Applied PAM (b) Applied CMC

Figure 2: Effects of different application rates for (a) PAM and (b) CMC on dynamic changes of wetting front in sandy loam soils.

Table 1: Influence of PAM and CMC application rates on infiltration characteristics.

Treatment	Application rate	a	b	R^2
CK	0 g/kg	1.327	0.511	0.99
PAM	1 g/kg	1.625	0.468	0.99
	2 g/kg	1.849	0.437	0.99
	3 g/kg	1.624	0.427	0.99
	4 g/kg	1.955	0.371	0.99
	—	1.763*	0.426*	—
CMC	0.2 g/kg	1.354	0.458	0.99
	0.4 g/kg	1.971	0.370	0.99
	0.6 g/kg	2.229	0.309	0.99
	0.8 g/kg	1.958	0.311	0.99
	—	1.878*	0.362*	—

Note. ∗ is the mean value of the 4 fitted coefficients of a and b.

Table 2: Influence of PAM and CMC application rates on soil sorptivity.

Treatment	Application rate	S (cm/min$^{0.5}$)	R^2	Treatment	Application rate	S (cm/min$^{0.5}$)	R^2
CK	0 g/kg	0.72	0.97	—	—	—	—
PAM	1 g/kg	0.64	0.98	CMC	0.2 g/kg	0.59	0.99
	2 g/kg	0.61	0.98		0.4 g/kg	0.47	0.99
	3 g/kg	0.53	0.98		0.6 g/kg	0.34	0.99
	4 g/kg	0.46	0.97		0.8 g/kg	0.31	0.99

treatments of PAM and CMC were 22.20 cm and 19.23 cm. From the points of view of application rates and reduced wetting front distances, the infiltration reduction effect of CMC treatments was more obvious than that of PAM treatments at the application rates in this study.

With an increase in PAM rates from 1 to 4 g/kg, the a value initially increased from 1.625 to 1.849, and then decreased to 1.624 and increased to 1.955 again; and the b value decreased from 0.468 to 0.371 gradually (Table 1). For CMC application rates from 0.02 to 0.08 g/kg, the a value initially increased from 1.354 to 2.229, and then decreased to 1.958; and the b value increased from 0.458 to 0.309, and then decreased to 0.311 (Table 1). The mean values of a for PAM treatments (1.763) were lower than the CMC treatments (1.878). The average values of b for PAM treatments (0.426) were higher than the CMC treatments (0.362).

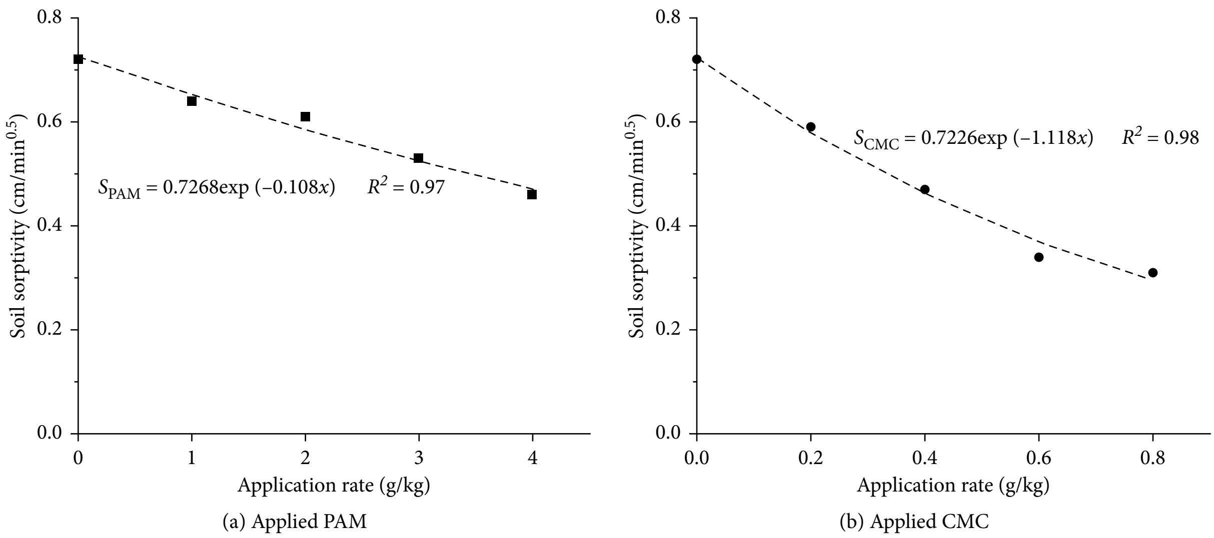


Figure 3: Effects of different application rates for (a) PAM and (b) CMC on soil sorptivity in sandy loam soils.

Table 3: Influence of PAM and CMC application rates on economic inputs.

Treatment	Application rate	Input (RMB/hm^2)	Treatment	Application rate	Input (RMB/hm^2)
CK	0 g/kg	0	—	—	—
PAM	1 g/kg	61.56	CMC	0.2 g/kg	14.09
	2 g/kg	123.12		0.4 g/kg	28.19
	3 g/kg	184.68		0.6 g/kg	42.28
	4 g/kg	246.24		0.8 g/kg	56.38
	Mean	153.90		Mean	35.24

3.3. Effects of PAM and CMC Application Rates on Soil Sorptivity. For the two different polymer water retention agents (PAM and CMC), the coefficient of determination (R^2) for the fit of the Philip model to cumulative infiltration ranged from 0.97 to 0.99. This result shows that the Philip model had a high goodness-of-fit for simulation of water infiltration under the application of high-molecular polymer materials to the soil surface layer of sandy loam. Table 2 shows that the sorptivity (S) decreased from 0.64 to 0.46 cm/min$^{0.5}$ as the PAM application rate increased from 1 to 4 g/kg gradually, compared with CK (0.72 cm/min$^{0.5}$). Correspondingly, the sorptivity reduced from 0.59 to 0.31 cm/min$^{0.5}$ as the CMC application rates increased from 0.2 to 0.8 g/kg. This result demonstrated that applied PAM and CMC could significantly reduce soil sorptivity and soil water infiltration capacity in sandy loam soils.

Overall, soil sorptivity showed a decreased trend with the increased application rates of each polymer water retention agent (Figure 3). This opens the possibility to use an exponential equation to fit the trend between sorptivities and application rates as follows:

$$S_{PAM} = 0.7268\exp(-0.108x) \quad R^2 = 0.97, \tag{3}$$

$$S_{CMC} = 0.7226\exp(-1.118x) \quad R^2 = 0.98, \tag{4}$$

where S_{PAM} and S_{CMC} represent the sorptivity of the treatments of PAM and CMC appilied to the soil surface layer, cm/min$^{0.5}$, respectively; x represents the application rates of PAM and CMC, g/kg. This result indicated that the applied CMC is more effective than applied PAM in reducing soil sorptivity at the same application rate in sandy loam soils.

3.4. Economic Inputs of PAM and CMC Application Rates. Farmers pursue higher economic benefits, water-retention agents with lower cost are usually priority selected. To providing reference for agricultural production, it is necessary to calculate the cost for each polymer material. The purchase prices of PAM and CMC are 152 RMB/kg and 174 RMB/kg in this study, respectively.

The PAM application rates were 1, 2, 3, and 4 g/kg, corresponding to 0.405, 0.810, 1.215, and 1.620 kg/hm^2, respectively. Similarly, the application rates were 0.2, 0.4, 0.6, and 0.8 g/kg for CMC, equal to 0.081, 0.162, 0.243, and 0.324 kg/hm^2 in the field. The results of economic inputs are presented in Table 3. The mean economic inputs of PAM and CMC were 153.90 and 35.24 RMB/hm^2. Compared with the cost of application of PAM, the input of application CMC is lower. This result indicated that the economic inputs of CMC treatments with different dosages is lower than that of PAM treatments in this study.

4. Discussion

Higher effectiveness and lower cost of water-retention polymers for soil water infiltration management, has resulted in rapid adoption to agricultural production in arid and semiarid regions [20]. PAM has been applied to millions of hectares worldwide as a highly effective soil water enhancing polymer, compared with CMC [21].

Lentz [22] found PAM-treated water infiltration could be inhibited through structured soils, relative to the control treatment. Soil column infiltration also demonstrated that PAM-treated water could reduce infiltration rates in sandy loam soils by more than 50% [6]. The difficulties of PAM solution application inhibited the large-area usage of PAM in dryland agriculture in practice [23]. In terms of reducing soil water infiltration, the effect of dry PAM application to the soil surface was significantly higher than PAM mixing with soil [10, 11]. The soil water infiltration rate reduced by mixing dry PAM with the upper 5 mm of the soil surface layer [11]. The infiltration reduction effects were also obvious when PAM was mixed with the upper 3 cm of the soil surface layer in sandy loam soils, according to the quality ratio of the polymer to soil surface layer (*w*/*w*). 4 g/kg was the best rate of PAM for reducing soil water infiltration in sandy loam soils in this study. This approach is convenient for applications in practice. The infiltration rates and hydraulic conductivity decreased after PAM was applied; this may be attributed to PAM being a long-chain macromolecular synthetic polymer, acting as a strengthening agent, holding soils in place ,and binding soil particles together as flocculated soil. Another possible reason is the increase in viscosity water when PAM is added. However, many researchers also reported the saturated hydraulic conductivity and infiltration rate increased with increasing PAM content [10, 24]. For example, both infiltration rate and cumulative infiltration of sloping land (silty loam) increased as the application rates of PAM increased [8, 25, 26]. This may be the result of PAM being so effective in decreasing seal formation and stabilizing surface structure, even at these small application rates.

The application of CMC is usually based on the ratio of the quality of the polymer to soil. When CMC and silty loam soils are mixed together fully, Wu et al. [12] reported the soil infiltration capacity and the stable infiltration rate reduced as the CMC content increased. In this study, the infiltration reduction effects were also found when PAM and CMC were mixed with the upper 3 cm of the soil surface layer in sandy loam soils. Compared with the applied method of mixed together fully, the method of mixed with the upper 3 cm of the soil surface layer reduced the CMC rates, which obviously saves the cost and facilitates large-scale promotion in practice. 0.8 g/kg was the recommendation rate of CMC in sandy loam soils. This provides a references for the widely application CMC as a suitable water retention agent.

5. Conclusions

In this research, the different high-molecular water-soluble polymers (i.e., PAM and CMC) have different effects on soil water infiltration characteristics. The infiltration reduction effects of CMC treatments were more obvious than that of PAM treatments. Applied CMC is more effective than applied PAM in reducing soil sorptivity. The economic input of the application of CMC is lower than the application of PAM. Therefore, the application of CMC was recommended to agricultural production for reducing soil water infiltration in sandy loam soils. The next step was to investigate the effects of two different water retention agents on soil water evaporation to further understand the soil hydraulic characteristics.

Data Availability

The data used to support the findings of this study have not been made available because it is part of a research program of the National Key R&D Program of China, and it will be further studied.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

This study was financially supported by the National Natural Science Foundation of China (41830754, U1706211, 41977007) and the National Key R&D Program of China (2016YFC0501401).

References

[1] V. Abrol, M. Ben-Hur, F. G. A. Verheijen, J. J. Keizer, M. A. S. Martins, and H. Tenaw, “Biochar effects on soil water infiltration and erosion under seal formation conditions: rainfall simulation experiment,” *Journal of Soils and Sediments*, vol. 16, no. 12, pp. 2709–2719, 2016.

[2] A. Maghchiche, A. Haouam, and B. Immirzi, “Use of polymers and biopolymers for water retaining and soil stabilization in arid and semiarid regions,” *Journal of Taibah University for Science*, vol. 4, no. 1, pp. 9–16, 2010.

[3] F. Esposito, M. A. Del Nobile, G. Mensitieri, and L. Nicolais, “Water sorption in cellulose-based hydrogels,” *Journal of Applied Polymer Science*, vol. 60, no. 13, pp. 2403–2407, 1996.

[4] J. H. Guo, G. W. Skinner, W. W. Harcum, and P. E. Barnum, “Pharmaceutical applications of naturally occurring water-soluble polymers,” *Pharmaceutical Science & Technology Today*, vol. 1, no. 6, pp. 254–261, 1998.

[5] M. Ben-Hur, “Using synthetic polymers as soil conditioners to control runoff and soil loss in arid and semi-arid regions—a review,” *Soil Research*, vol. 44, no. 3, pp. 191–204, 2006.

[6] H. A. Ajwa and T. J. Trout, “Polyacrylamide and water quality effects on infiltration in sandy loam soils,” *Soil Science Society of America Journal*, vol. 70, no. 2, pp. 643–650, 2006.

[7] R. A. McLaughlin and N. Bartholomew, “Effects of polyacrylamide and soil properties on flocculation,” *Soil Science Society of America Journal*, vol. 71, no. 2, pp. 537–544, 2007.

[8] Y. Li, M. Shao, and R. Horton, “Effect of polyacrylamide applications on soil hydraulic characteristics and sediment

yield of sloping land," *Procedia Environmental Sciences*, vol. 11, pp. 763–773, 2011.

[9] C. Chang, B. Duan, J. Cai, and L. Zhang, "Superabsorbent hydrogels based on cellulose for smart swelling and controllable delivery," *European Polymer Journal*, vol. 46, no. 1, pp. 92–100, 2010.

[10] J. Yu, T. Lei, I. Shainberg, and J. Zhang, "Effects of different application methods of polyacrylamide (PAM) on soil infiltration and erosion," *Transactions of the Chinese Society of Agricultural Engineering*, vol. 26, no. 7, pp. 38–44, 2010.

[11] J. Yu, T. W. Lei, I. Shainberg, A. I. Mamedov, and G. J. Levy, "Infiltration and erosion in soils treated with dry PAM and gypsum," *Soil Science Society of America Journal*, vol. 67, no. 2, pp. 630–636, 2003.

[12] J. Wu, W. Tao, H. Wang, and Q. Wang, "Influence of sodium carboxyl methyl cellulose on soil aggregate structure and soil water movement," *Transactions of the Chinese Society of Agricultural Engineering*, vol. 31, no. 2, pp. 1060–1074, 2015.

[13] X. Pei, Q. Yang, Q. Xu, X. Zhang, and Y. Huang, "Research on glue reinforcement mechanism and scouring resistant properties of soil slopes by modified carboxymethyl cellulose," *Chinese Journal of Rock Mechanics and Engineering*, vol. 35, no. 11, pp. 2316–2327, 2016.

[14] F. Nnadi and C. Brave, "Environmentally friendly superabsorbent polymers for water conservation in agricultural lands," *Journal of Soil Science and Environmental Management*, vol. 2, no. 7, pp. 206–211, 2011.

[15] B. N. Aluzairy, "The effectiveness of two soil amendments: gypsum and polyacrylamide on soil erosion under saline conditions in Australia," *International Journal of Environmental Science & Development*, vol. 6, no. 5, pp. 375–379, 2015.

[16] C. Wang, Q. Wang, T. Lv, and L. Zhuang, "The studies of infiltration characteristics on sandy saline alkali soil by chemical amelioration," *Journal of Soil and Water Conservation*, vol. 28, no. 1, pp. 31–35, 2014.

[17] E. J. Hewitt, *Sand and Water Culture Methods Used in the Study of Plant Nutrition*, Commen Wealth Agricultural Bureaux, Farnham Royal, England, 2nd edition, 1966.

[18] J. R. Philip, "The theory of infiltration: 4. Sorptivity and algebraic infiltration equations," *Soil Science*, vol. 84, no. 3, pp. 257–264, 1957.

[19] J. Sun, R. Yang, W. Li, Y. Pan, M. Zheng, and Z. Zhang, "Effect of biochar amendment on water infiltration in a coastal saline soil," *Journal of Soils and Sediments*, vol. 18, no. 11, pp. 3271–3279, 2018.

[20] R. E. Sojka, D. L. Bjorneberg, J. A. Entry, R. D. Lentz, and W. J. Orts, "Polyacrylamide in agriculture and environmental land management," *Advances in Agronomy*, vol. 92, pp. 75–162, 2007.

[21] J. A. Entry, R. E. Sojka, and B. J. Hicks, "Carbon and nitrogen stable isotope ratios can estimate anionic polyacrylamide degradation in soil," *Geoderma*, vol. 145, no. 1-2, pp. 8–16, 2008.

[22] R. D. Lentz, "Inhibiting water infiltration with polyacrylamide and surfactants: applications for irrigated agriculture," *Journal of Soil and Water Conservation*, vol. 58, no. 5, pp. 290–300, 2003.

[23] A. I. Mamedov, I. Shainberg, L. E. Wagner, D. N. Warrington, and G. J. Levy, "Infiltration and erosion in soils treated with dry PAM, of two molecular weights, and phosphogypsum," *Soil Research*, vol. 47, no. 8, pp. 788–795, 2010.

[24] Y. Fei, D. L. She, L. Gao, and P. Xin, "Micro-CT assessment on the soil structure and hydraulic characteristics of saline/sodic soils subjected to short-term amendment," *Soil and Tillage Research*, vol. 193, pp. 59–70, 2019.

[25] I. Shainberg, D. N. Warrington, and P. Rengasamy, "Water quality and PAM interactions in reducing surface sealing," *Soil Science*, vol. 149, no. 5, pp. 301–307, 1990.

[26] X. C. Zhang and M. P. Miller, "Polyacrylamide effect on infiltration and erosion in furrows," *Soil Science Society of America Journal*, vol. 60, no. 3, pp. 866–872, 1996.