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Effectiveness and Durability of Polyacrylamide (PAM) and Polysaccharide (Jag C 162) in Reducing Soil Erosion under Simulated Rainfalls

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Abstract: Polymers as a soil amendment is one of the effective measurements to reduce soil erosion. In this study, two polymers, polyacrylamide (PAM) and polysaccharide (Jag C 162), were applied to erosion plots filled with loess soil (tilted at 20°). For each polymer, four concentration levels—0, 10, 30, and 50 kg·ha^{-1}—were applied. The treated erosion plots were then subjected to two simulated rainfall events (dry and wet run) to investigate their effectiveness and durability in controlling soil erosion. Both simulated rainfall events were at an intensity of 120 mm·h^{-1}, and each event lasted for 30 min with 24 h free drainage in between. Results show that both polymers could reduce runoff, effectively control sheet erosion, and promote soil aggregates due to their capability to bind and stabilize soil particles. Such reducing effects were more pronounced on the Jag C 162-treated plots than on the PAM-treated plots. However, during the second (wet) run, there was more reduction of aggregate with size of >0.25 mm and greater increment of soil loss on the Jag C 162-treated plots than on the PAM-treated plots.

Keywords: polyacrylamide; polysaccharide; soil erosion; runoff; sediment concentration; soil aggregate

1. Introduction

Soil erosion has severely threatened the sustainability and productive capacity of agriculture, and thus has caused economic loss [1,2]. On the Chinese Loess Plateau, there is approximately 0.1 million hectares of arable land on slopes steeper than 25° [3]. Although the national "Grain-for-Green" rehabilitation project since the 1980s has highly recommended local farmers to convert farmland on steep slopes to forest or grassland to help achieve ecological restoration [4], there is still a great amount of farming occurring on steep slopes. In addition, short but heavy storms during summer, accounting for approximately half of annual precipitation, are one of the major threats to cause soil erosion [5,6]. For instance, a heavy storm (approximately 250 mm within one day) occurred in July 2017 in Suide County, northwest Loess Plateau, causing tremendous destruction and economic losses. Therefore, there is a need to find a measure to prevent soil erosion while maintaining agriculture sustainability. Apart from conventional practices such as cover crops or grass [7–11], rock fragment coverage [12–14], and geotextiles [15], soil amendments (e.g., polyacrylamide, PAM) have also been used in irrigated and rain-fed agriculture to help prevent soil and water loss [16–36]. In furrow

irrigation, the application rate of 0.7 kg ha^{-1} of PAM per season (approximately US\$ 3 ha^{-1} according to the price in year 2018), can reduce furrow reshaping and cultivation and improve water quality by reducing sediment, and in rain-fed agriculture, PAM can effectively control soil erosion and increase yield under certain management regimes [36]. However, due to the low dissolution and high viscosity of PAM, its application on soil surface could also be problematic [26,33–35], as it probably could not remediate poor soil structure [36–38]. In addition, PAM contains residual monomer of acrylamide (AMD), a carcinogenic compound that has the risk of leaching and groundwater contamination [39]. Hence, it calls for other alternative chemical polymers to be equally effective in soil erosion control while having limited negative environmental effects [40].

Alternatively, polysaccharide directly derived from plant materials (e.g., guar gum) is an environment-friendly polymer that has no irritating or adverse effects on aquatic species [41]. It can interact with soil by clay flocculation, hence reducing runoff and erosion [34,40–43]. Specifically, cationic polysaccharide guar derivatives with a molecular weight of 0.2 to 2 million could effectively increase infiltration and reduce erosion [16,33,44]. In addition, as a degradable natural polymer, polysaccharide can be potentially applicable in an agricultural field. However, conflicting evidence regarding the effectiveness of polysaccharide to retard runoff and soil erosion has been found. While Agassi and Ben-Hur [33] reported that polysaccharide reduced erosion in calcic haploxeralf soil, Ben-Hur [45] noted that polysaccharide increased erosion in Arlington sandy loam soil.

The durability of polymeric soil amendment and the residual effects of consecutive irrigation or rain events also raised much attention. Deng et al. [46] reported that polymer adsorption on soil was irreversible, and Van de Ven [47] noted that polymer desorption could occur at a low reduced rate for several hours or days. Other reports argued that the hydraulic shear stress of runoff with polymer was higher than the initial yield stresses of floc suspension, and the bridge chains of the polymer molecule were fractured. This thereby led to a decrease in the molecular weight of the polymer [48–51], as well as desorption and soil aggregate destruction [52,53]. Ben-Hur et al. [16] and Levy et al. [30] found that lower effectiveness of polymers occurs in subsequent water applications than the first application, and polysaccharide has no significant effects on infiltration rates and soil losses compared with PAM.

This study compared the effectiveness and durability of PAM and a new polysaccharide (Jag C 162) in terms of runoff and sheet erosion control during two consecutive simulated rainfall events, with the aim to discuss the possible application of an environment-friendly chemical practice to prevent soil loss while maintaining agricultural production.

2. Materials and Methods

2.1. Study Area and Soil Sampling

The study area located in Suide County (110°04′–110°41′ E, 37°16′–37°45′ N), Shaanxi Province in China, is a typical loess region in the hinterland of the Loess Plateau with heavy erosion. The region has a typical semiarid continental climate, with an average annual precipitation of approximately 500 mm, 60% or more of which are from intense rainstorms falling between July and September [54,55].

The loess soil is widely distributed on the Loess Plateau, covering 32.5% of the total area [56]. With homogeneous texture and low soil organic carbon (SOC) content (approximately 3 mg·g^{-1}), the loess soil is highly erodible and therefore very susceptible to rainfall events. Soils in this region contain calcium carbonate of 10–12%, which is the basic cementing material for loess soil due to low organic material [57,58].

The tested soil was collected from the cultivated layer (0–25 cm) of an abandoned wheat cropland in Suide County in May 2015. It is a sandy loam based on International Classification System of Soil Texture, and belongs to Regosols according to World Reference Base for Soil Resources. The D$_{50}$ of the tested soil was 0.037 mm, comprising 9.9% clay (diameter of <2 μm), 61.5% silt (diameter of 2–50 μm), and 28.6% sand (diameter of 50–250 μm). The particle size distribution was measured using Malvern Mastersizer 2000 (Malvern Instruments Ltd., Malvern, UK).

2.2. Experiment Preparation

After the soil samples were air-dried and sieved into 10 mm groups, the soil water content was re-adjusted to 14% to represent local soil moisture during the flood season on the Loess Plateau [41]. There were three treatments: control (no polymer), PAM-treated, and Jag C 162-treated plots. To collect soil sample and compare soil aggregate size distribution without bias possibly introduced by disturbed soil surface, three plots (all set at slope gradient of 20°) were prepared for each soil treatment to in sequence collect surface soil samples prior to dry run, after dry run, and after wet run. Each experimental plot (1.2 m × 0.4 m × 0.25 m) was made of a metal frame with perforated floor for free drainage. In each plot, a sand base (5 cm deep) was placed beneath soil, with a piece of gauze in between to simulate the permeable conditions of natural soil. The soil was then placed on the sand base layer by layer (four layers, each 5 cm deep). For each layer, the amount of soil was predetermined, and gently compacted by a flat plate to a certain depth to ensure uniform bulk density of 1.2 g·cm^{-3} (to represent the bulk density measured with cutting rings in the field). By such preparation, the experimental plots were used to stand for ploughed soil surface before seeding [54,57].

The polymers (PAM and Jag C 162), each with concentrations of 10, 30, and 50 kg ha^{-1}, were diluted in 2 L of water to produce final spraying solutions of 0.24, 0.72, and 1.2 kg·m^{-3}. All the polymer solutions were uniformly sprayed on the prepared soil surface, and stood for 15 h covered with a plastic sheet before being subjected to rainfall events to ensure sufficient time for the polymers to interact with soil particles and also to minimize evaporation. A controlled plot without polymer amendments was also prepared following the same protocol.

2.3. Rainfall Simulation

Two simulated rainfall events were in sequence applied to the prepared erosion plots. The first rainfall event was applied on dry soil 15 h after the application of PAM and Jag C 162, and the second rainfall event was on wet soil 24 h after the first rainfall event. Each rainfall event lasted for 30 min. The simulated rainfall events were conducted using a side jet rainfall simulator in the Simulation Rainfall Hall of the State Key Laboratory of Soil Erosion and Dryland Farming on the Loess Plateau at the Institute of Soil and Water Conservation, Chinese Academy of Science and Ministry of Water Resources in China. The simulated rainfall events were generated by a rainfall simulator system with nozzles on two sides. The rainfall intensity and coverage area were changed by controlling the water pressure and nozzle size. The fall height of raindrops was approximately 16 m above the soil surface in all the experiments. The rainfall intensity used in this study was 120 mm·h^{-1} generated by nozzles (FULLJET, SPAYING SYSTEMS CO., Wheaton, IL, USA) with opening diameters of 5 mm and 7 mm under pressure of 48 MPa. The raindrop diameters of the simulated rainfall were from 0.125 mm to 4.5 mm with D$_{50}$ of 2 mm (Laser Precipitation Monitor, Thies Clima, Göttingen, Germany). The raindrop kinetic energy was on average 7.07 J·m^{-2}·mm^{-1} with terminal velocity of 6.5 m·s^{-1}, comparable with the kinetic energy distribution of natural raindrops under low intensity on the Loess Plateau [59]. Nine years of precipitation data (from 1961 to 1969) collected from a field experimental observation station near Suide County show that the peak rainfall intensities of individual rainfall events ranged from 2.87 mm h^{-1} to 148.12 mm h^{-1}. Although rainfall events lasting for 30 min with intensity of 120 mm h^{-1} is not possible in Suide County, increased intensity is often considered necessary to compensate for the deficiency of kinetic energy associated with simulated rainfall in order to recreate conditions that were as comparable as possible with natural rainfall [5]. Therefore, a simulated rainfall event lasting for 30 min with an intensity of 120 mm h^{-1} and total kinetic energy of 424.41 J·m^{-2}, accounting for 28–42% of total kinetic energy of annual erosivity precipitation according to the data from weather station on the Loess Plateau, was considered valid to represent the most frequent rainfall events in the Suide County. All treatments had two replications for each rainfall.

2.4. Runoff and Sediment Collection

For all the treatments, the runoff samples were collected every 3 min at the lower edge of the erosion plots, and immediately weighed to obtain the amount of runoff discharge. Afterwards, the suspending runoff samples were left to settle, and the supernatant was then decanted off. The remaining sediment was dried in an oven at 105 °C and weighed to calculate soil erosion rate.

Soil surface samples, taken prior to dry run, after dry run, and after wet run, were wet sieved using a TTF-100 soil aggregate analyzer (Shangyu, China) into six classes: >5 mm, 2~5 mm, 1~2 mm, 0.5~1 mm, 0.25~0.5 mm, and <0.25 mm. During wet sieving, the sieve tower was oscillated up and down 4 cm in water for 30 strokes over one minute of time. To minimize undesired disaggregation during sieving, each soil sample was prewetted by spray and left to stabilize for 5 min before conducting wet sieving tests. Six replicates were conducted for each soil surface sample. The aggregate fractions collected from each size class were dried and weighed. Previous studies have reported that micro-aggregates or fine particles are crucial to form cohesive structural crusts on eroding surface, directly affecting soil roughness and thus runoff erosivity and transport capacity [60]. However, sediment discharge is largely determined by the abundance of transportable loose particles on eroding surface, which was mostly resulted from fractions breaking off macro-aggregates [60–63]. Therefore, the polymer-introduced additional aggregation and the sequent erosion-induced aggregate destruction become the essential indicator to evaluate the effectiveness of polymers in amending soil erodibility. All the data were analyzed using SPSS 16.0 and Excel 2007.

3. Results

3.1. Temporal Variations of Soil Erosional Responses

The temporal patterns of runoff rates from the two polymer-amended plots over the two simulated rainfall events are illustrated in Figure 1. In general, the two polymer-treated plots generated lower runoff rates for both rainfall events when compared with the untreated plots (control). There were slightly higher runoff rates during the second rainfall event (wet run) than during the first one (dry run) for all the treatments. The reduction of the sum of runoff depths from the PAM-treated plots was less than 11% during both runs, whereas runoff depth reduction from the Jag C 162-treated plots was lower during the wet run (10% less) than during the dry run (15–25%) (Table 1).

The amount of soil loss was found to decrease by 40–85% from the PAM treatment and 65–93% from the Jag C 162 treatment compared with the control. The soil loss decreased as the concentrations of PAM and Jag C 162 increased (Table 2). The effects of soil erosion reduction were also different between the two rainfall events. For the PAM plots, the amount of soil loss during the wet run was approximately 1–1.5 times greater than that during the dry run, whereas the amount of soil loss from the Jag C 162 plots during the wet run was 2–3 times larger than that during the dry run (Table 2). In addition, the Jag C 162-treated plots with a concentration of 30 kg·ha^{-1} was more efficient in runoff and erosion reduction than the PAM-treated plot with a concentration of 50 kg·ha^{-1} (Tables 1 and 2).

Table 1. Sum of runoff depths on soil surface treated with different concentrations of PAM and Jag C 162.

Soil Treatment	Concentration (kg·ha^{-1})	Sum of Runoff Depths (mm)			Reduction Compared with Control (%)		
		Dry Run	Wet Run	Total	Dry Run	Wet Run	Total
Control	0	29	31	60			
PAM	10	32	30	62	−12	2	−5
	30	26	31	57	9	0	4
	50	25	28	53	11	11	11
Jag C 162	10	24	30	54	17	2	9
	30	21	28	49	25	10	17
	50	23	28	51	20	10	15

Table 2. Soil losses from soil surface treated with different concentrations of PAM and Jag C 162.

Soil Treatment	Concentration (kg·ha^{-1})	Soil Loss (kg)			Reduction Compared with Control (%)		
		Dry Run	Wet Run	Total	Dry Run	Wet Run	Total
Control	0	0.287	0.397	0.685			
PAM	10	0.162	0.186	0.348	44	53	49
	30	0.072	0.116	0.188	75	71	73
	50	0.043	0.058	0.101	85	85	85
Jag C 162	10	0.057	0.134	0.192	80	66	72
	30	0.026	0.078	0.104	91	80	85
	50	0.019	0.058	0.077	93	85	89
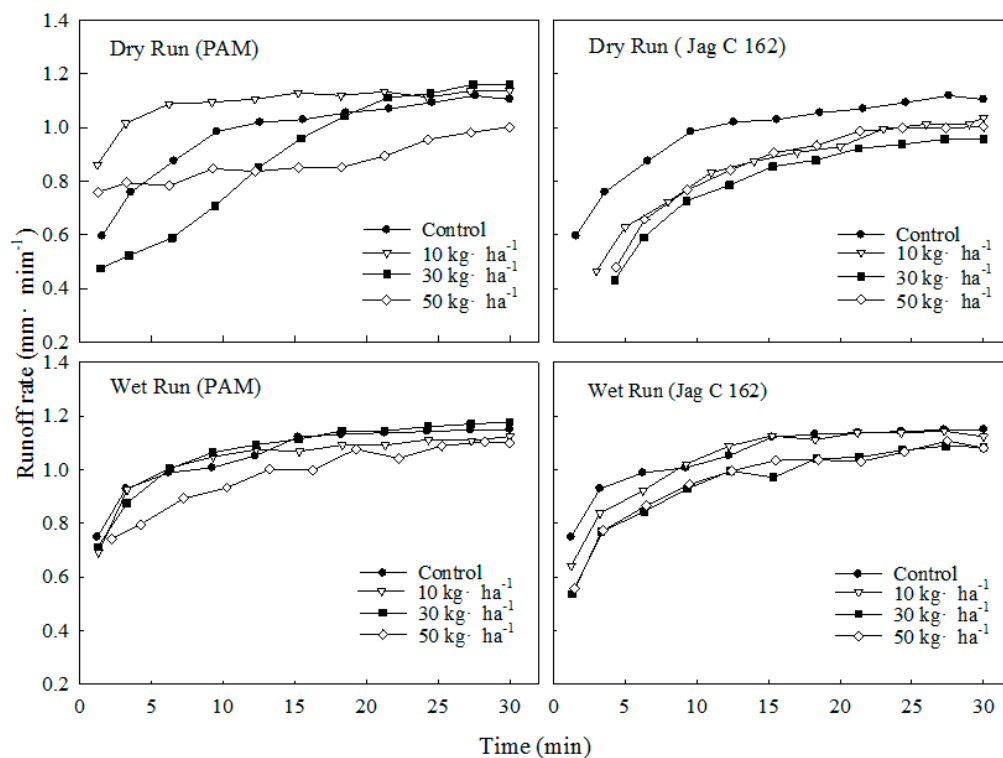
Figure 1. Temporal changes of runoff rates during dry and wet run after polyacrylamide (PAM) and polysaccharide (Jag C 162) treatment.

The sediment concentration from the two polymer-treated plots was lower than that of the controlled plots, in which accumulated sediment concentration was over 20 kg·m^{-3}. The sediment concentration showed increasing tendency from 5 kg·m^{-3} to 10 kg·m^{-3} on the Jag C-162-treated plots during both rain events, but stabilized below 15 kg·m^{-3} on PAM-treated plots. The reduction of sediment concentration from the dry run to the wet run was more pronounced on the Jag C 162 plots (from 85% to 75%) than on the PAM plots (from 71% to 68%) (Figure 2).
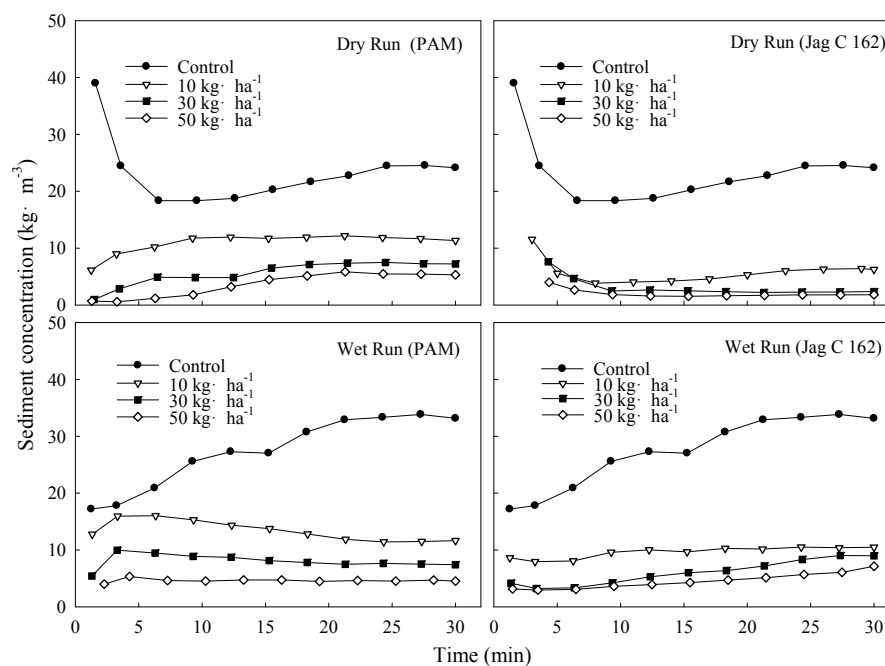
Figure 2. Temporal changes of sediment concentration during dry and wet run after PAM and Jag C 162 treatment.

3.2. Aggregate Size Distribution of the Eroded Surface Soil

In terms of changes in aggregate size distribution (Figure 3), soil aggregates of size >0.25 mm on the eroded plots were effectively increased with concentrations of PAM and Jag C 162. Such increase was more pronounced on the Jag C 162-treated plots (30–50%) than that on the PAM-treated plots (18–23%). After the wet run, soil aggregates of size >0.25 mm on the Jag C 162-treated plots were 0.6–0.9 times as many as that after the dry run, whereas the soil aggregate size distribution on the PAM-treated plots remained rather stable during both runs. Coarse aggregates of >2 mm on the Jag C 162-treated plots were more than that on the PAM-treated plots prior to and after the dry run. However, the proportions of aggregates with size of <1 mm after wet run were greater on the Jag C 162-treated plots than that on the PAM-treated plots (Table 3).
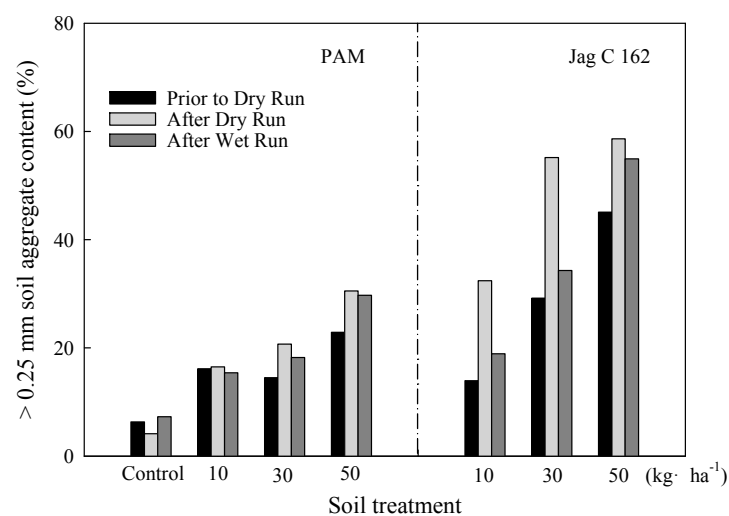

Figure 3. Effects of PAM and Jag C 162 on >0.25 mm soil aggregates.

Table 3. Size distribution of soil aggregates from soil surface treated with different concentrations of PAM and Jag C 162. Subscripts indicate the standard deviation of the six samplings.

Run Event	Size Distribution (mm)	Mass Fraction of Size Classes (%)						
		Control	PAM			Jag C 162		
			10 kg·ha^{-1}	30 kg·ha^{-1}	50 kg·ha^{-1}	10 kg·ha^{-1}	30 kg·ha^{-1}	50 kg·ha^{-1}
Prior to dry run	>5	0.22 ± 0.18	1.87 ± 1.87	7.74 ± 1.54	15.70 ± 1.68	0.27 ± 0.12	11.32 ± 3.12	38.5 ± 2.49
	2–5	0.45 ± 0.35	2.68 ± 0.48	1.05 ± 0.41	1.14 ± 0.17	1.84 ± 0.45	8.55 ± 1.93	3.07 ± 0.97
	1–2	0.46 ± 0.13	2.36 ± 0.41	0.63 ± 0.12	0.71 ± 0.19	3.28 ± 0.48	3.25 ± 0.72	1.05 ± 0.26
	0.5–1	1.84 ± 0.41	4.70 ± 1.2	2.04 ± 1.15	2.00 ± 1.05	4.54 ± 0.74	3.61 ± 1.12	1.23 ± 0.38
	0.25–0.5	3.36 ± 1.76	4.54 ± 1.03	3.04 ± 1.32	3.33 ± 1.88	4.02 ± 1.01	2.46 ± 0.5	1.25 ± 0.47
	<0.25	93.68 ± 1.56	83.85 ± 2.53	85.51 ± 1.76	77.13 ± 3.74	86.06 ± 1.49	70.81 ± 2.06	54.89 ± 3.4
After dry run	>5	0.24 ± 0.15	0.38 ± 0.39	13.03 ± 1.35	20.83 ± 1.22	1.78 ± 0.51	36.61 ± 13.63	49.12 ± 3.82
	2–5	0.34 ± 0.22	1.55 ± 0.62	1.79 ± 0.36	1.37 ± 0.35	9.54 ± 1.34	7.68 ± 3.63	3.01 ± 1.18
	1–2	0.40 ± 0.14	2.82 ± 0.52	1.11 ± 0.28	0.92 ± 0.22	5.89 ± 0.92	3.10 ± 0.83	1.91 ± 0.82
	0.5–1	1.13 ± 0.75	6.08 ± 1.24	2.10 ± 0.51	2.61 ± 0.76	8.22 ± 1.97	4.03 ± 1.21	2.48 ± 0.61
	0.25–0.5	2.04 ± 1.29	5.66 ± 0.51	2.66 ± 0.83	4.79 ± 1.46	6.98 ± 3.15	3.75 ± 1.48	2.12 ± 0.17
	<0.25	95.85 ± 1.71	83.50 ± 1.64	79.31 ± 2.1	69.49 ± 1.8	67.60 ± 5.63	44.83 ± 9.64	41.36 ± 1.66
After wet run	>5	0.16 ± 0.06	0.63 ± 0.47	10.98 ± 4.19	17.87 ± 4.36	0.24 ± 0.11	0.77 ± 0.87	13.73 ± 12.2
	2–5	0.41 ± 0.28	2.01 ± 0.64	1.58 ± 1.09	2.61 ± 1.12	0.68 ± 0.28	2.85 ± 2.03	7.76 ± 2.92
	1–2	0.47 ± 0.15	2.64 ± 1.33	0.87 ± 0.41	1.66 ± 0.5	1.25 ± 0.59	5.30 ± 2.14	10.31 ± 5.18
	0.5–1	1.95 ± 0.77	5.47 ± 1.63	1.95 ± 0.7	3.28 ± 1.29	6.57 ± 1.24	13.02 ± 4.05	14.12 ± 8.99
	0.25–0.5	4.29 ± 1.23	4.65 ± 1.14	2.86 ± 1.58	4.33 ± 2.23	10.16 ± 2.57	12.39 ± 3.96	9.02 ± 6.77
	<0.25	92.73 ± 1.19	84.60 ± 3.46	81.76 ± 6.21	70.26 ± 6.01	81.09 ± 3.15	65.68 ± 7.57	45.06 ± 12.15

4. Discussion

4.1. Effectiveness of PAM and Jag C 162

In general, the reduced sum of runoff depths on the PAM- (11% less compared to that of the control) and Jag C 162-treated plots (10–25% less compared to that of the control) (Table 1) demonstrate that PAM and Jag C 162 could change soil erosional responses. Such effects were more pronounced in reducing soil loss, as the amount of soil loss decreased by 40–85% on PAM-treated plot and 65–93% on Jag C 162-treated plot (Table 2). The effects of polymer treatments in reducing soil erosional responses were mostly because polymers could facilitate clay flocculation [21,28,34,36,53,64], thereby enhancing soil structure by promoting aggregation process and increasing aggregate sizes (Table 3). This further led to less detachment on the polymer-treated plots, which generated less depositional particles to be transported away by runoff [65–67]. In addition, the reduced runoff could further result in less erosivity, weaker runoff transportability, and less sediment discharge after polymer treatments [68,69].

Furthermore, the effects of polymer treatment in reducing soil erosional response were more effective on the Jag C 162-treated plot than on the PAM-treated plot both during the dry and wet run (Figure 2, Table 2). This phenomenon can be mostly attributed to the different adsorption mechanisms of the two polymers. The polysaccharide (Jag C 162) with low molecular weight could easily penetrate into aggregates and be absorbed at the planar clay surface, whereas PAM absorption occurred mainly at the edges of clay minerals without deeply penetration. Therefore, the guar polymers (Jag C 162) resulted in higher floc volumes than that of PAM [70]. Similar effects were observed in previous studies. For example, Ben-Hur [16,34] studied the effects of polysaccharide guar derivatives and PAM on infiltration rates, and found that the polysaccharide guar derivatives were more effective in maintaining infiltration than PAM. However, Levy et al. [30] compared the effects of anionic PAM and polysaccharide guar derivatives on two soils and reported that the polysaccharide treatment (20 g·m^{-3}) was less efficient to facilitate infiltration and reduce erosion in comparison with the PAM treatment (10 g·m^{-3}). These discrepancies are mostly because of different soil and polymer properties in various experiments [24,27,71,72]. Additional studies should be further conducted to investigate the effectiveness of different polymers on various soil types so as to meet different demands from farmers.

4.2. Durability of PAM and Jag C 162 between Two Rainfall Events

The lower reduction of runoff and soil loss during the wet run on the PAM-treated plots in comparison with the dry run (Figures 1 and 2, Tables 1 and 2) suggests its greater durability in terms of stabilizing soil surface than the Jag C 612-treated plots. This was probably related to the different soil aggregate stabilities during the two runs. While the soil aggregate size distribution after the dry and wet run was comparable on the PAM-treated plots, the soil aggregates were detectably destructed on the Jag C 162-treated plots after the wet run with a sharp decrease of >5 mm macroaggregates (Table 3). This finding can probably be explained by the failure of low residual polysaccharide to stabilize soil aggregates, thus being unable to withstand runoff detachment [30]. According to a previous report by Lu and Wu [73], most of PAM retained in the top 0–2 cm of soil. While only a few millimeters of soils were lost via erosion in this study, there were abundant amount of PAM left on the eroding surface after two rounds of rainfall events.

Different durability can also be reflected by the increased soil erosional responses on the Jag C 162-treated plots during the wet run, whereas the sediment concentration in PAM-treated plots stabilized below 15 $kg \cdot m^{-3}$ during both rainfall events (Figure 2). It indicates that PAM could better resist against runoff detachment than Jag C 162 during two rainfall events due to the sediment detachment mechanism in the experimental conditions. Jomaa et al. [74] noted that the soil erosion response during subsequent rainfall event was dependent on whether steady-state erosion condition was achieved during the first rainfall event. In this study, earlier steady-state sediment concentration was reached in PAM-treated plots during dry run leading to less erosion during wet run when in comparison with Jag C 162-treated plots (Figure 2). Our findings are consistent with previous reports, where Ben-hur [16] found that PAM was more effective than polysaccharide in preserving the infiltration during succeeding water applications without polymers. Deng et al. [46] reported that when PAM-treated soil was subjected to four consecutive washes, less than 3% of the adsorbed PAM was removed from clay minerals. Although not examined in this study, the less durable Jag C 162 in stabilizing soil surface is very likely to be even less reliable in subsequent rainfall events, thus generating larger runoff and soil loss than the PAM-treated plots when applied during the rainy season.

5. Conclusions

Two polymer amendments were sprayed over a loess soil and subjected to simulated rainfall events to investigate their effectiveness and durability in terms of sheet erosion control. Our results show that both polymers could reduce runoff, control sheet erosion, and promote soil aggregates. Furthermore, Jag C 162 was found to be more efficient than PAM due to its better capability to bind and stabilize soil aggregates. However, the less reduction of runoff and soil loss during the wet run on the PAM-treated plots suggests its greater durability in terms of stabilizing soil erosional responses than the Jag C 612-treated plots. Even though PAM showed better durability in controlling soil erosion during subsequent rainfall events than Jag C 162, the potential risks of groundwater contamination due to residual monomer of acrylamide (a carcinogenic compound) should not be ignored, especially when used in agricultural fields. In contrast, polysaccharide derived from plant materials has an environmental advantage, with no irritating or adverse effects on aquatic species. Hence, further studies are needed to explore an environment-friendly polymer with equal effectiveness in soil erosion control, especially under natural rainfall conditions with uneven distribution on spatial and temporal scales.

Author Contributions: Shaojuan Lu and Zhanli Wang conceived and designed the experiments. Shaojuan Lu performed the experiments. Baoyuan Liu and Jun'e Liu analyzed the data and provided writing ideas. Shaojuan Lu and Yaxian Hu finalized the manuscript. All authors reviewed the manuscript.

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