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Using polyacrylamide to control soil splash erosion in rainfalls with variable intensity and duration

Uso de poliacrilamida para controlar la erosión del suelo por salpicadura durante lluvias con intensidad y duración variable
Uso de poliacrilamida para controlar a erosão do solo por salpico durante chuva com intensidade e duração variáveis

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ABSTRACT

Splash erosion is recognized as the first stage in soil erosion process and results from the bombing of the soil surface by rain drops. One of the soil erosion control methods is the use of chemical polymers. The purpose of this study was to investigate the effects of different rates of polyacrylamide - PAM (0, 2, 4 and 6 kg/ha) - on the rate of splash erosion at three rainfall intensities (60, 90 and 120 mm/h) and three rainfall durations (10, 20 and 30 minutes) in laboratory conditions using a FEL3 rainfall simulator and Morgan splash bowls on a marly soil with loam soil texture. In all three intensities, rainfall duration and PAM treatments, the reductions of erosion were significant at 99% level, while their interaction was not statistically significant. The results indicated that 2 kg/ha of PAM did not show any significant difference in splash erosion reduction for all the intensities and durations. Increasing the rate of PAM from 4 kg/ha to 6 kg/ha helped to reduce the splash erosion rate; however, there was not a significant difference between the rates of 4 and 6 kg/ha of PAM in the intensity of 90 and 120 mm/h. Most splash erosion reduction (54%) was obtained for the intensity of 60 mm/h and the duration of 10 min with 6 kg/ha of PAM.

RESUMEN

La erosión por salpicadura es la primera etapa del proceso de erosión del suelo y resulta del impacto de las gotas de lluvia sobre la superficie del suelo. Uno de los métodos para controlar este proceso de erosión es el uso de polímeros químicos. El objetivo de este estudio fue investigar en laboratorio los efectos de la adición de diferentes dosis de poliacrilamida – PAM (0, 2, 4 y 6 kg/ha)– sobre la salpicadura del suelo bajo tres intensidades de lluvia (60, 90 y 120 mm/h) y tres duraciones de lluvia (10, 20 y 30 minutos) utilizando un simulador de lluvia FEL3 y recipientes de salpicadura Morgan en un suelo margoso de textura franca. Bajo todas las intensidades de lluvia, duraciones de la lluvia y tratamientos con PAM, se observó una reducción significativa de la erosión del 99%, mientras que su interacción no fue estadísticamente significativa. Los resultados indicaron que la aplicación de 2 kg/ha de PAM no mostró ninguna diferencia significativa en la reducción de la erosión por salpicadura a ninguna de las intensidades y duraciones de lluvia probadas. El incremento de la dosis de PAM de 4 a 6 kg/ha promovió la reducción de la erosión por salpicadura; sin embargo, no se observaron diferencias significativas entre las dosis de 4 y 6 kg/ha de PAM utilizando intensidades de 90 a 120 mm/h). La mayoría de la reducción en la erosión por salpicadura (54%) se obtuvo para la intensidad de 60 mm/h y la duración de 10 minutos de lluvia aplicando 6 kg/ha de PAM.

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RESUMO

A erosão por salpico é a primeira etapa do processo de erosão do solo e resulta do impacto das gotas de chuva na superfície do solo. Um dos métodos para controlar este processo de erosão é o uso de polímeros químicos. O objetivo deste estudo foi o de investigar, em laboratório, os efeitos da adição ao solo de diferentes doses de poliacrilamida – PAM (0, 2, 4 e 6 kg/ha) – no salpico quando o solo foi sujeito a três intensidades (60, 90 e 120 mm/h) e três períodos (10, 20 e 30 minutos) de chuva utilizando um simulador de chuva FEL3 e recipientes de salpico Morgan num solo margoso de textura franca. Nas três intensidades e duração da chuva e nos tratamentos com PAM, observou-se uma redução significativa da erosão de 99%, embora a sua interação não seja estatisticamente significativa. Os resultados indicaram que a aplicação de 2 kg/ha de PAM não apresentou nenhuma diferença significativa na redução da erosão por salpico em nenhuma das intensidades e duração de chuva. O aumento da dose de PAM de 4 a 6 kg/ha levou à redução da erosão por salpico; embora, não se tenham observado diferenças significativas entre as doses de 4 e 6 kg/ha para intensidades de 90 e 120 mm/h. A maior redução da erosão (54%) foi obtida para a intensidade de 60 mm/h e a duração de 10 minutos de chuva aplicando 6 kg/ha de PAM.

KEYS WORDS
Marly soil, rainfall simulator, soil conditioner, raindrop.

PALABRAS CLAVE
Suelo margoso, simulador de lluvia, acondicionador del suelo, gota de lluvia.

PALAVRAS-CHAVE
Solo margoso, simulador de chuva, condicionador do solo, gota de chuva.

1. Introduction

Nowadays, soil erosion is understood as a major form of soil degradation which occurs as a natural process and can be accelerated by human activity (Sepaskhah and Mahdi-Hosseinabadi 2008). Splash erosion by rain drop impact is the first stage in the erosion process. Rain drops behave as little bombs when falling on bare soil, detaching soil particles and destroying the soil structure. The lighter materials detached by raindrop are more readily carried away by runoff. They mix with the water from the drops and when the water sinks into the soil, they clog up the soil pores. As a result, the surface crusts reduce the infiltration rate and the runoff is formed (Wuddivira et al. 2009). The large drops carry hundreds of times more energy than small drops. In general, the heavier rainfalls have larger drops. Therefore, erosion is generally the greatest during short-duration storms with high intensity. In arid areas, splash erosion plays a major role in changing the landscape (Boroghani et al. 2012). Some studies have been investigated using soil conditioners as one of the conservation methods to combat soil erosion. Soil conditioners are substances that improve the physical properties of soils; these include synthetic polymers and natural materials like gypsum. Polyacrylamide (PAM) is one of the synthetic polymers with the ability to prevent the rain drop contact with the soil surface and enhance soil stabilization. This polymer is able to reduce soil detachment, maintain the soil structure, and increase the infiltration rate early in the rain events. Therefore, the possible relationships between soil conditioners and splash sediment have become important for erosion studies. Some researchers have found that these materials significantly reduce runoff and soil erosion (Green and Stott 1999). Yonter (2010), for instance, investigated the effects of Polyvinylalcohol (PVA) and Polyacrylamide (PAM) as soil conditioners on erosion by runoff and splash under laboratory conditions with a rainfall simulator. According to their results, increases in PVA and PAM doses reduced runoff as well as erosion by runoff and by splash significantly. Sepaskhah and Bazrafshan-Jahromi (2006) also controlled runoff and erosion in the sloping land with Polyacrylamide under a rainfall simulator. It was found that at steep slopes, higher PAM application rates were required to enhance the final infiltration rate and to reduce the runoff and soil erosion. Further, Szögi et al. (2007) assessed soil conservation practices for improving the water quality of return flows from rill irrigation in the Yakima River Basin, Washington, by combining the patch application of polyacrylamide (PAM) with an additional erosion control practice. They found that PAM could be an excellent practice to control soil erosion. Sepaskhah and Shahabizad (2010) also measured the effects of water quality and PAM application rate on the control of soil erosion, water infiltration, and runoff for different soil textures in a rainfall simulator. Their results showed that at heavier soil textures, higher PAM application rates (≥ 6.0 kg/ha) were effective at enhancing the final infiltration rate and reducing the runoff and soil erosion. Kumar and Saha (2011), similarly, studied the effect of polyacrylamide and gypsum on the surface runoff, sediment yield, and nutrient losses from steep slopes. The results indicated that the concurrent application of PAM and gypsum was more effective than when gypsum is added alone after PAM treatment. Splash erosion and physical characteristics of splash have been examined in erosion studies, usually using a rain simulator. A rainfall simulator is an important tool for the study of runoff generation and soil loss because it can be used either under laboratory conditions, or in disturbed or natural soil. Frauenfeld and Truman (2004), for example, applied the simulated rainfall (57 mm/h) for 70 minutes and measured runoff, soil loss, splash water and splash sediment values at the intervals of 5 minutes. Boroghani et al. (2012) also investigated the effects of various amounts of PAM on the splash erosion control in a marly soil and with the rain intensities of 65, 95 and 120 mm/h using a rainfall simulator for about 10 minutes. Al-Uzairy (2015), on the other hand, investigated the interaction and the effectiveness of two soil amendments, gypsum and polyacrylamide (PAM), in minimizing soil erosion under saline conditions. The results obtained showed that PAM could be successfully used for controlling or minimizing the adverse impacts of salinity such as increased erosion, surface sealing and poor runoff water quality. Özdemir et al. (2015) examined the effect of incorporating various organic and inorganic matter sources such as lime, zeolite, polyacrylamide and biosolid on the instability index. Sadeghi et al. (2016a) evaluated the quantitative effect of polyacrylamide (PAM) and acrylamide (AMD) monomer on runoff and soil loss in experimental plots under laboratory conditions. The results proved a significant PAM polymer emission in runoff and sediment, a significant AMD monomer emission in output runoff and no significant AMD residue in the output sediment. Also, Sadeghi et al. (2016b) investigated effects of polyacrylamide in controlling of splash erosion from a soil induced freeze-thaw cycle. The collected data on upward segments of cups treated with freeze phenomena showed that PAM played an effective and significant role in splash and had no significant effect on freezing-thawing processes. Shengqiang and Dongli (2018) investigated the synergistic effect of rock fragment cover and PAM amendment rates on infiltration, runoff, and erosion processes with saline-sodic soils under laboratory conditions. The results showed that the PAM amendment significantly increased the infiltration rate for rainfall erosion processes, but it was reduced with the PAM application rates increasing significantly. According to studies it seems that PAM is a cost-effective and safe technology alone or in conjunction with other erosion control practices. On the other hand, stabilization of splash erosion as the first process of soil erosion causes other kinds of erosions as rill and inter rill erosion to be controlled and decreases the costs of the soil conservation. Also, marly lands with high development in Zagros, Alborz and central regions of Iran covered a large area of the country in the study area. Marly units in catchments had the highest rate of soil erosion and runoff yield. This soil series is known as the most erodible soil series in the study region (Boroghani et al. 2012). To our knowledge, there has been no study investigating the effect of various doses of PAM on the splash erosion control with variable intensity and duration of rainfall simultaneously. Therefore, in the present research, the effects of different concentrations of polyacrylamide (0, 2, 4 and 6 kg/ha) on controlling splash erosion with different rainfall intensities (60, 90 and 120 mm/h) and durations (10, 20 and 30 minute) were investigated concurrently using an FEL3 rainfall simulator with a marly soil.

2. Materials and Methods

The experiment was carried out in the Soil Conservation and Watershed Management Research Institute (SCWMRI), Tehran, Iran. Tested soil samples were collected in the Taleqan Catchment with an area of approximately 1135 km^2; this area was situated between 36°5´-36°23N and 50°21´-51°1E, 40 km away from the Tehran-Qom highway. Soil texture, as determined by the hydrometer method, was 18% clay, 49% silt, and 33% sand; it was determined as loam with a bulk density of 1.21 g/cm^3. Some physical and chemical properties of the soil samples used in the experiment are given in **Table 1**.

Table 1. Physical and chemical properties of soil samples

Particle size distribution (%)			pH	EC (dS/m)	Na (meq/L)	HCO_3^- (meq/L)	K (meq/L)	$CaCO_3$ (%)	Organic Carbon (%)
clay	sand	slit							
18	33	49	8.56	1.54	3.25	3.48	0.37	20.07	0.154

A FEL3 simulator model was used for simulating rainfall in this study. The FEL3 could be used in the laboratory or at the field for soil erosion simulation and stabilization studies. It can be ideal to investigate the relationship between rainfall and soil erosion and identify methods by which erosion may be prevented. The rain produced by the rainfall simulator must be actually similar to the natural rainfall to study soil erosion correctly. This similarity must be applied to rainfall intensity, uniformity of rainfall intensity, raindrop size, and velocity of rain drop incidence (Boroghani et al. 2012). In the present study, for the calibration of FEL3 rainfall, the simulator model assessed the rainfall intensity and the uniformity of rain intensity by increasing disk degrees (disk degrees can be changed by about 5-40 degrees), as well as measuring the droplet diameter and its distribution in order to assess the disk crater size in rainfall distribution. Average simulated rain diameters equal to 1.21, 1.5 and 1.62 mm with the height of the rainfall 2.65 m, and kinetic energy of simulated rain for intended rain intensities equal to 27.9, 29.51 and 30.62 J/m^2 × mm was calculated using the Wishmayer Smith equation. The rainfall intensities of 60, 90 and 120 mm/h were considered as suitable ones for tests. In the first step, around 50-80 kg of soil samples (0-10 cm) was taken from the selected locations on the study region map; then they were dried at normal atmospheric conditions. Later on, these air dried soil samples were sieved through a 2 mm sieve. After filling the perforated Morgan splash bowl (2.5 cm height and 10 cm diameter, 78.5 cm^2 area, Morgan 1978) with soil samples, polyacrylamide was weighted in doses of 2, 4 and 6 kg/ha and sprayed on the uncompressed soil surface (**Figure 1**); the simulated rainfall (60, 90 and 120 mm/h) was applied to the soil samples for 10, 20 and 30 min. It is necessary to mention that the bottom of the splash bowl was pierced to drain water from the bottom of the bowl, and water could not accumulate on the surface of the soil. Control treatments (without PAM) were used for comparison in all experiments. At the end of each experiment, soil samples were put in an oven again for 24 hours at a temperature of 105 ºC to calculate their second weights. According to Cheng et al. (2008), the splash erosion measure is defined as erosion rate and can be calculated on the basis of **Equation (1)**:

$$S = \frac{D_2 - D_1}{(t_2 - t_1)A}$$

where
S: Splash rate (g/(min × m^2))
D_1, D_2: Sediment yield between t_1 and t_2 (g)
t_1, t_2: Rain duration (min)
A: Splash bowl surface (m^2)

Splash erosion rate for each treatment was obtained by calculating the average from 3 examined repetitions for that treatment in each sample. To investigate the effects of treatments in each rainfall intensity individually, one-way analysis of variance was carried out and the effects of different treatments of PAM were investigated for each rain intensity separately. A completely randomized experimental design with three replications was used for the statistical analysis of the data. Data were analyzed using an SPSS statistical package program in this experiment at a 95% certainty level. To measure specific differences between pairs of means and to find out if survey or experiment results are significant were used Duncan and ANOVA test respectively.

Figure 1. View of a splash bowl.

3. Results and Discussion

3.1. The splash erosion rate without PAM

The results of the statistical analysis of different levels of splash rate in soil with rainfall intensities of 60, 90 and 120 mm/h and 10, 20 and 30 minutes duration indicated that there was a significant difference between different rainfall intensities and the desired times in terms of increasing the amount of splash at the level of 0.05, while the interaction of the two factors of intensity and duration did not show significant differences in the rate of splash erosion (**Table 2**). As shown in **Table 3**, as the rainfall was increased from 60 to 120 mm/h, the amount of splash rate was enhanced, as expected. For example, during a 10-minute period, the amount of splash loss was increased from 46.2 g at an intensity of 60 mm/h to 68.3 g at 120 mm/h; however, no significant difference was observed. Because of increasing rain intensity, kinetic energy and the number of droplets colliding with the surface of the soil, the amount of splash erosion was increased (Soltani-Gerdefaramarzi et al. 2014). It should be noted that the results of this part of the experiment in the study were published by Soltani-Gerdefaramarzi et al. (2014) and are referenced here only for relevance to the research topic.

3.2. The effect of PAM on splash erosion

In this section, the varied treatments of PAM in various rainfall intensities and durations and under a rainfall simulator are presented. Splash erosion rate was reduced when PAM was applied on the soil surface of samples, but its effective rate of application was different. The data in **Table 4** indicate that there was a significant difference between control treatment (without PAM) and treatments involving 4 and 6 kg/ha of PAM, especially for 6 kg/ha. Without considering the rainfall intensity and duration treatment, the

Table 2. ANOVA results for two factors intensity and duration of rainfall

	df	Mean square	F	sig
Rainfall intensity	2	1011.520	60.26	0.00**
Rainfall duration	2	174.36	10.38	0.01**
Rainfall intensity× Rainfall duration	4	6.13	0.366	0.830 [ns]
Error	18	302.10	-	-

df, F and sig are degrees of freedom, F-statistic and significance respectively.

Table 3. Result of mean comparison for all time durations and intensity according to Duncan's test

	(Mean ± SD)		
Treatment	Time 10	Time 20	Time 30
Intensity of 60 mm/h	46.2 ± 3.9[a]	51.0 ± 3.9[a]	53.8 ± 3.9[c]
Intensity of 90 mm/h	54.3 ± 3.1[a]	57.3 ± 3.1[ab]	65.0 ± 3.1[b]
Intensity of 120 mm/h	68.3 ± 2.8[a]	69.9 ± 2.8[ab]	76.0 ± 2.8[b]

SD: Standard Division; Values with common letter shows no significant difference at the probability level of 95%.

rate of 6 kg/ha of PAM had the highest effect on the splash erosion control (approximately a reduction of 29%). The amount of splash erosion reduction varied from 8% for the application of 2 kg/ha to 18% and 29% for 4 and 6 kg/ha of PAM respectively; it was slightly less than the values of 14%, 23% and 27%, as reported by Boroghani et al. (2012). The differences could be due to a distinct rainfall intensity and the consideration of the varied rainfall duration treatments. They measured the splash erosion in the rainfall intensities of 65, 95 and 120 mm/h for about 10 minutes in their study.

Time could be considered as a factor in these ANOVAs but the interactions were not significant; the significant difference was revealed only for the prime factors, which meant the multiple comparison tests had to be performed to the mean of each level. For the PAM dose, the mean of control samples, PAM 2 kg/ha, PAM 4 kg/ha, and t PAM 6 kg/ha were compared through the three durations (**Table 5**). The lowest splash erosion rate was observed in the treatment 6 kg/ha (27.5 g) at the intensity of 60 mm/h, while the highest was in the control treatment at the intensity of 120 mm/h (71.4 g). There were

Table 4. Results of a comparison of all treatment averages according to Duncan's test. Differences between means that share a letter are not statistically significant at the probability level of 95%

Treatment	PAM (kg/ha)			
	Control	2	4	6
Splash (g/min × m^2)	60.25[a]	55.43[ab]	49.31[bc]	42.94[c]

significant differences between PAM and control treatments in all three intensities. At the same time, the mean of Time 10, Time 20, and Time 30, through three levels of PAM, were compared (**Table 6**). As the results showed, in this case, in all three intensities and durations of rainfall, splash erosion rate was increased through three levels of PAM. The highest splash rates were obtained at the intensity of 120 mm/h and the duration of 30 min (67.9 g), as expected, and the lowest ones took place at the intensity of 60 mm/h and in the time duration of 10 min through three levels of PAM.

3.3. Intensity of 60 mm/h

ANOVA results for the two factors, rainfall durations and amounts of PAM, in the intensity of 60 mm/h (**Table 7**) indicated that different rates of PAM (0, 2, 4 and 6 kg/ha) for controlling erosion at the rain intensity of 60 mm/h provided significant differences. In contrast, the interaction between rainfall duration and PAM treatments was not significantly different. The comparison of the means was tested at the intensity of 60 mm/h for all time durations treatments and PAM rates, according to Duncan's test. The results showed

Table 5. Means of erosion in PAM treatments through the three durations

Treatment	(Mean ± SD) Control (kg/ha)	PAM 2 (kg/ha)	PAM 4 (kg/ha)	PAM 6 (kg/ha)
Intensity of 60 mm/h	50.3 ± 3.6[a]	45.0 ± 3.6[a]	36.6 ± 3.6[b]	27.5 ± 3.6[c]
Intensity of 90 mm/h	58.9 ± 2.3[a]	54.3 ± 2.3[b]	49.1 ± 2.3[c]	44.6 ± 2.3[d]
Intensity of 120 mm/h	71.4 ± 3.4[a]	66.8 ± 3.4[ab]	62.2 ± 3.4[b]	56.7 ± 3.4[c]

SD: Standard Division; Values with common letter shows no significant difference at the probability level of 95%.

Table 6. Means of erosion (Kg/ha) for different time and through three levels of intensity of rain

Treatment	(Mean ± SD) Time 10	Time 20	Time 30
Intensity of 60 mm/h	34.2 ± 2.5[c]	39.7 ± 2.5[b]	45.6 ± 2.5[a]
Intensity of 90 mm/h	47.6 ± 3.3[b]	49.8 ± 3.3[b]	57.7 ± 3.3[a]
Intensity of 120 mm/h	61.9 ± 2.6[b]	63.0 ± 2.6[b]	67.9 ± 2.6[a]

SD: Standard Division; Values with common letter shows no significant difference at the probability level of 95%.

that in the time duration of 10, 20 and 30 minutes of rainfall, the rate of 2 kg/ha PAM did not have any statistically significant difference, in comparison with the control treatment, in reducing the splash erosion (**Table 8**). However, the doses of 4 and 6 kg/ha PAM decreased the splash erosion by up to 35% and 54% respectively in the duration of 10 min; these reductions were of 29% and 50% in the duration of 20 min, and of 20% and 34% in the duration of 30 min, respectively; these values were statistically significant. It should be noted that most of the splash control amount in the intensity of 60 mm/h (54%) was produced in the duration of 10 min for 6 kg/ha of PAM. It seems that with the enhancement of the rain duration, the effect of PAM value diminishes. Also, these results revealed that the control treatments had the highest splash erosion and by increasing PAM rates, the amount of splash erosion was reduced in all durations of rainfall. The mean comparison of control treatments and the varied rate of PAM for all time durations showed that splash erosion was increased (from 46.2 to 53.8 g, for the control samples, to 21.2 to 35.3 g for the 6 kg/ha of PAM treatment) with the enhancement of rain duration, as expected;

however, this increment was not a statistically significant difference at the probability level of 95%. It could be explained that the protective layer formed by PAM was degraded rapidly and did not have any effect on reducing splash erosion at various rain durations.

3.4. Intensity of 90 mm/h

The results of statistical analysis for the rainfall intensity of 90 mm/h showed that different doses of PAM and rainfall durations had a significant difference at the probability level of 95%.

Table 7. ANOVA results for rainfall durations and amounts of PAM at intensity of 60 mm/h

	df	Mean square	F	sig
Rainfall duration	2	386.52	23.461	0.00**
PAM treatments	3	902.85	54.802	0.00**
PAM treatments × Rainfall duration	6	8.59	0.522	0.786 ^{ns}
Error	24	16.47	-	-

df, F and sig are degrees of freedom, F-statistic and significance, respectively.

Table 8. Comparison of mean results of splash erosion for time durations and PAM treatments according to Duncan's test

Treatment	Control (kg/ha)	PAM 2 (kg/ha)	PAM 4 (kg/ha)	PAM 6 (kg/ha)
Intensity of 60 mm/h (Mean ± SD)				
Time 10	46.2 ± 3.2^{a} (% of reduction)	39.9 ± 3.2^{a} (13.6%)	29.8 ± 3.2^{b} (35%)	21.1 ± 3.2^{c} (54%)
Time 20	51.6 ± 2.9^{a} (% of reduction)	44.9 ± 2.9^{a} (13%)	36.8 ± 2.9^{b} (28.6%)	26.0 ± 2.9^{c} (50%)
Time 30	53.8 ± 3.7^{a} (% of reduction)	50.2 ± 3.7^{ab} (6%)	43.0 ± 3.7^{bc} (20%)	35.3 ± 3.7^{c} (34%)
Intensity of 90 mm/h (Mean ± SD)				
Time 10	54.3 ± 2.7^{a} (% of reduction)	51.6 ± 2.7^{a} (5%)	44.0 ± 2.7^{b} (19%)	40.5 ± 2.7^{b} (25%)
Time 20	57.3 ± 2.7^{a} (% of reduction)	52.0 ± 2.7^{ab} (9%)	47.0 ± 2.7^{ab} (18%)	43.0 ± 2.7^{c} (25%)
Time 30	65.0 ± 2.9^{a} (% of reduction)	59.4 ± 2.9^{ab} (8%)	56.1 ± 2.9^{ab} (13.7%)	50.3 ± 2.9^{c} (22.6%)
Intensity of 120 mm/h (Mean ± SD)				
Time 10	68.3 ± 3.1^{a} (% of reduction)	65.4 ± 3.1^{ab} (4%)	59.8 ± 3.1^{bc} (12.4%)	54.1 ± 3.1^{c} (21%)
Time 20	69.9 ± 3.0^{a} (% of reduction)	64.1 ± 3.0^{ab} (8%)	62.0 ± 3.0^{bc} (11.3%)	56.0 ± 3.0^{c} (20%)
Time 30	76.0 ± 2.3^{a} (% of reduction)	71.0 ± 2.3^{a} (6.5%)	64.8 ± 2.3^{b} (15%)	59.9 ± 2.3^{b} (21%)

SD: Standard Division; Values with common letter shows no significant difference at the probability level of 95%.

However, the interaction effect between rain duration and PAM amounts for this intensity did not show a statistically significant difference. In **Table 9**, the outputs of statistical analysis are presented for the 90 mm/h rain intensity.

Table 8 includes the results of the application of different rates of PAM (0, 2, 4 and 6 kg/ha) on splash erosion reduction in the marly soil at the rain intensity of 90 mm/h. As shown, the higher amount of PAM led to the lower splash erosion in the intensity of 90 mm/h. According to **Table 8**, there was not a significant difference at the probability level of 95% between 2 kg/ha of PAM and control treatment in all time durations (5%, 9% and 8% splash erosion reduction in 10, 20 and 30 min of the rain duration, respectively); however, according to Duncan's test, it was shown in the intensity of 90 mm/h for the other treatments of PAM, especially 6 kg/ha, that splash rate was decreased up to 25%, 25% and 22.6% for rain durations 10, 20 and 30 min, respectively. However, the splash erosion decrease for the rates of 4 and 6 kg/ha of PAM was not significant statistically.

Table 9. ANOVA results for rainfall durations and amounts of PAM at intensity of 60 mm/h

	df	Mean square	F	sig
Rainfall duration	2	338.49	28.205	0.00**
PAM treatments	3	347.57	28.961	0.00**
PAM treatments × Rainfall duration	6	2.82	0.235	0.961 ns
Error	24	12.00	-	-

df, F and sig are degrees of freedom, F-statistic and significance, respectively.

3.5. Intensity of 120 mm/h

Table 10 indicates the results of ANOVA for the two factors of rain durations and various rates of PAM in the intensity of 120 mm/h. As shown, there was a significant difference at the probability level of 95% for both rainfall duration and PAM treatment; however, the interaction effect of these two factors was not significant, similar to the results related to the intensity of 60 and 90 mm/h. The results of statistical analysis (**Table 8**) also revealed that the rate of 6 kg/ha had the highest effect on the splash erosion control, in comparison with the others, with the intensity of 120 mm/h, as it caused about 21% depression in splash erosion, while the rates of 2 kg/ha and 4 kg/ha resulted in about 4% and 12% decrease, respectively, in the rain duration of 10 min. In the rainfall duration of 20 min, splash erosion reduction was 8%, 11.3% and 20% for 2, 4 and 6 kg/ha, respectively, and for the 30 min rain duration, the reduction was about 6.5, 15 and 21 percent in 2, 4 and 6 kg/ha, respectively. Also, it did not show a significant difference between the dose of 2 kg/ha and control treatment at the rain intensity of 120 mm/h, similar to the two

Table 10. ANOVA results for rainfall durations and amounts of PAM in intensity of 120 mm/h

	df	Mean square	F	sig
Rainfall duration	2	123.25	10.281	0.01**
PAM treatments	3	359.98	30.028	0.00**
PAM treatments × Rainfall duration	6	3.81	0.318	0.921 ns
Error	24	11.99	-	-

df, F and sig are degrees of freedom, F-statistic and significance, respectively.

other intensities. It should be noted that there was no significant difference between the rates of 4 kg/ha PAM and 6 kg/ha in that rain intensity category. According to the results obtained by Boroghani et al. (2012), the rate of 4 kg/ha had the highest effect on the splash erosion control in comparison with the others. Based on this study, generally, PAM could be effective even at higher rainfall intensities.

4. Conclusions

Several researchers have investigated the use of PAM in a multitude of applications, but no comprehensive studies have been carried out at different application rates of PAM in different intensity and duration of rainfall. The present study was performed using simulated rainfall in a marly soil as the most erodible soil series, where rainfall intensity, duration and other experimental conditions were controlled. The results of this research accorded with many studies on PAM efficacy for soil erosion control and indicated that PAM is effective in decreasing soil loss. In this experiment, it was found that the control treatments had the highest splash, and by increasing PAM, the splash erosion rate was reduced in all rainfall durations. Also, the rates of 2 kg/ha of PAM did not result in any significant difference in reducing splash erosion at the rainfall intensities of 60, 90 and 120 mm/h among all treatments and durations. Due to high rainfall intensity and duration and as a result, destruction of the soil surface with rain drops, the protective layer formed by 2 kg/ha of PAM was degraded rapidly and had less effect on reducing splash erosion at various rainfall intensities and durations. It was also found that 2 kg/ha of PAM in all of the tests reduced the splash erosion less than 10%. The data indicated that increasing the treatments of PAM from 4 kg/ha to 6 kg/ha had more impact in further reduction of splash erosion. However, no significant difference was found between the rates of 4 kg/ha PAM and 6 kg/ha with the intensity of 90 and 120 mm/h. As a result, the optimal amount of PAM application based on PAM and soil loss was at a rate of of 4 kg/ha and no significant reduction in soil loss was observed with the increased polyacrylamide content of 6 kg/ha. Data indicated that most of the splash erosion reduction (54%) was obtained for the intensity of 60 mm/h in the duration of 10 min with 6 kg/ha of PAM; also, with the increment of the rainfall intensity and duration, the effect of PAM was diminished. It could be concluded that PAM reduces erosion and mainly decreases the initial stage of erosion, i.e. splash erosion, where splash erosion control is the most important factor in an erosion control program, especially in arid environments.

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