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Abstract

Controlling soil erosion as one of the most important threats to soil quality and quantity, particularly in its initial stages, is greatly important in natural resources management. However, performance evaluation of various soil and water conservation techniques under real circumstances are being rarely conducted. Consequently, the present research intended to control soil erosion caused by splash and interrill erosion in two soils (marl at Marzan-Abad and loess at Maraveh-Tapeh sites) susceptible to erosion by using various additives and under field conditions. We established 0.5 m × 0.5 m plots in the field and used the sugarcane by-product biochar (BC), polyacrylamide (PAM) and BC+PAM additives together with control plots in three replications under a slope steepness of 25% at the two mentioned sites. We used a rainfall simulator to produce rainfall intensity of 50 mm h^{-1} in the experiments. Analysis of the results obtained from the variables of splash and interrill erosion during the rainfall-runoff process showed that the PAM additive significantly ($p \leq 0.05$) increased all study variables of splash erosion. However, in interrill erosion, it reduced the variables of soil loss and sediment concentration but not significantly ($p>0.05$) compared to the control plot and increased runoff compared to the control plots at the two mentioned sites. The plot treated with BC showed decreased runoff volume and coefficient and soil loss compared to the control plot at the Marzan-Abad site, but the differences were not significant statistically ($p>0.05$). However, the plot treated with BC in the loess soil at the Maraveh-Tapeh site considerably ($p \leq 0.05$) increased runoff and soil loss compared to the control plot. Finally, runoff volume and coefficient and soil loss increased in the loam and loess soils in the plots treated with BC+PAM compared to the control plot.

Keyword: Natural condition; Soil conservation; Soil amendment; Splash erosion

1. Introduction

Water and soil loss in different ecosystems, mainly in sloping agricultural lands, are major environmental threats that lead to instability and unsustainability of the ecosystems, particularly in terms of land degradation and reduced fertility and productivity. Soil erosion is accelerated as a result of increased runoff on soil surface that results in soil vulnerability with respect to reduced permeability, crusting, and slacking (Liu et al., 2014; Gholami et al., 2019). Approximately 60% of the total runoff and sediment loss that happen in various ecosystems of watersheds are caused by natural and anthropogenic factors such as rainfall intensity, geomorphology and soil management practices (Keesstra et al., 2016; Zhao et al., 2017; Wang et al., 2017). Therefore, soil conservation and erosion control are among the most important measures that need special attention in all countries. Various methods have been introduced to control soil erosion, but use of methods that can protect soil from the first impacts of erosion agents is a top priority in soil erosion control programs (Blanco-Sepúlveda, 2018).

One of the strategies introduced in recent decades is the use of soil amendments. These are substances used to enhance soil productivity and improve soil structure quality and its biochemical performance (Fangueiro et al., 2018; Maiti and Ahirwal, 2019). Organic and inorganic amendments have been studied for various purposes over the past several years, particularly with emphasis on reducing runoff and soil loss, increasing permeability and improving physical and chemical properties of soils with various properties. In this regard, use of different types of biomass such as Biochar (BC), which is produced from industrial and rural wastes and waste produced in agriculture and animal husbandry, forests and rangelands, fishing and aquaculture, and their optimal management and reproduction as eco-friendly amendments have received greater attention from researchers (Sadeghi et al., 2015; Sadeghi et al., 2016b; Głąb et al., 2016; Wang et al., 2017; Yue et al., 2017; Sadeghi et al., 2018; Zhang et al., 2019; Khadem and Raiesi, 2019; Gholami et al., 2019).

BC, carbon or pyrogenic carbon, is now widely used as a soil amendment due to its beneficial effects on soil quality (Wang et al., 2013). BC is the product of thermal-chemical conversion of biomass in a pyrolysis reactor (Verheijen et al., 2019). It has many benefits from the perspective of agriculture and natural resources that have been mentioned by various researchers. These benefits include improved soil water retention capacity (Laird et al., 2010), provision of plant nutrients and enhancement of plant growth (Graber et al., 2010), improvement of soil physical and chemical properties (Zhang et al., 2019) and reduced runoff and soil loss (Sadeghi et al., 2016b; Sadeghi et al., 2018; Gholami et al., 2019). However, some researchers including Cheng and Lehmann (2009), Rumpel et al. (2009), Major et al. (2010), Nguyen et al. (2010), and Sadeghi et al. (2016b) have pointed at BC loss along with sediments down slopes during the rainfall-runoff process caused by factors such as lack of adhesion between particles.

Some other soil amendments such as high molecular weight polymers, which are formed by covalent bonds between monomers, stabilize soil aggregates in the long term, particularly in soils susceptible to erosion such as marl soils (Nehrani and Vaezi, 2013) and thereby play an effective role in reducing soil erosion through binding soil particles together. Among these polymers is anionic-Polyacrylamide (PAM) that binds fine soil particles together thus reducing their floating duration, increases their deposition rate. Such an additive may strengthen the bounds between particles, meaning a higher stability of soil aggregate, a positive effect on soil structure and consequently on its capability to infiltrate water (Hamidi Sojka et al., 2005; Nehrani and Vaezi, 2013; Karimi et al., 2015; Sarkar et al., 2018; Biju and Arnepalli, 2019). Therefore, considering the research background, the present study investigated use of BC alone and in combination with PAM to reduce runoff and soil loss during the rainfall-runoff process. In this regard, effects of these amendments on splash and interril erosion control and on different variables such as upward-splash, downward-splash, total-splash, runoff, time of runoff generation, runoff coefficient, and soil loss and sediment concentration of runoff water were studied in two types of erosion-susceptible soil (loess and marl) found in the northern regions of Iran under natural conditions. The whole study has been conducted under field conditions, which is obviously differentiated from many existing literatures, as a crucial criterion to properly assess the performance of soil and water conservation techniques leading to propose efficient and effective measures. The work was formulated for two erosion prone soils located on Marl and Loess formations in two distant localities in North Iran.

2. Materials and methods

2.1. Test materials

In this research, plots $0.5 \times 0.5\text{-m}^2$ were installed in the two study regions of Marzan-Abad (in west of Mazandaran Province) with marl formation and Maraveh-Tapeh (in north of Golestan Province) with loess soil whose characteristics have been presented in Table 1 (Sadeghi et al., 2013; Karimi et al., 2015; Sadeghi et al., 2017a). BC produced from sugarcane industries and anion PAM amendments with the properties listed in Table 2 were used in the experiments. Fig. 1 presents the locations where soil samples were taken in the mentioned Provinces.

Table 1

Table 2

Fig. 1

2.2. Rainfall and soil erosion simulation

In these experiments, well water with pH 7.27, electrical conductivity 5.13 mS m^{-1}, dissolved oxygen 30.7%, phosphorus phosphate 0.17 mg l^{-1} and nitrate 4.41 mg l^{-1} was used to simulate rainfall (Kiani-Harchegani et al., 2016 and 2019). In addition, the mean slope steepness and rainfall intensity were chosen in accordance with the general conditions in the native area of the soils and taking into account rainfalls with a return period of 25-30 years. Therefore, a 25% slope was selected for the experiments to conform to standard agricultural lands and the general and prevailing conditions in rain-fed agricultural lands and natural resources areas in Iran. Rainfall simulation experiments were also performed under soil moisture conditions similar to the general conditions prevailing in the two mentioned areas prior to rainfall and by measuring volumetric water content in those areas and in the laboratory using wet and dry sample weighing and maintaining relatively similar conditions in the predicted experiments. Therefore, the experiments were run at rainfall intensity of about 50 ± 5 mm h^{-1} lasting for 30 min according to the Intensity, Duration, and Frequency (IDF) graphs prepared for the two sites. All rainfall simulations were performed on small plots with both length and width of 0.5 m in three replications (Sadeghi et al., 2016b) in the two regions of Marzan-Abad (in western Mazandaran Province) and Maraveh-Tapeh (in northern Golestan Province). Some views of field experiments have been shown in Fig. 2.

Fig. 2

2.3. Experimental design for field inventory

In the present study, BC (800 gm^{-2}) and PAM (2 gm^{-2}) were used in individual and combination in treated plots with three replications. These levels were selected based on successful performance of the same rates in previous researches (Sadeghi et al. 2016 a and b; Sadeghi et al. 2017a; Sadeghi et al. 2018). BC was spread whilst PAM was just sprayed on the soil surface, individually. PAM was also sprayed on BC when they were concurrently used. Splash cups were installed in the plot to measure splash erosion (Fig. 2). The splashed sediment samples were collected from upward and downward parts of the splash cups during each run from the beginning of the rainfall (Kiani-Harchegani et al., 2016; Sadeghi et al. 2017b).

The time the first signs of runoff were observed at the outlet in the control and treated plots was recorded as the early stages of interrill erosion, runoff generation and combined impacts of rainfall and water flow on erosion using a stopwatch (Kiani-Harchegani et al., 2019). The volume of runoff was then measured at two min intervals for six minutes, at three min intervals for nine minutes and at five min intervals for 15 minutes in three replications.

2.4. Data analysis

After measuring the different variables caused by splash and interrill erosions in the control plots and the plots treated by BC, PAM and combination of BC and PAM, the data from the experiments were classified in Excel and their database was created. Before any statistical analysis, data normality was checked using the Kolmogorov-Smirnov test. Levene's test of variance homogeneity was then used to evaluate homogeneity of variance in the different treatments. The paired samples t-test used to compare pairwise BC and PAM on different variables of splash and interrill erosion. In addition, one-way ANOVA and Tukey's HSD test at a probability level $(P) < 0.05$ was used to compare the means of the different variables in two sites of Marzan-Abad and Maraveh-Tapeh that are affected by combined and individual application BC and PAM (Awad et al., 2012; Kiani-Harchegani et al., 2016; Wang et al., 2017).

3. Results and Discussion

The present research studied effects of individual and combined application of BC and PAM on the various variables of splash and interrill erosion under field conditions for the two studied soils.

3.1. Differences in splash erosion variables between treatments for Loess and Marl soils

The variables of upward-splash and downward-splash erosion in the control plots and plots treated with BC, PAM, and BC+PAM at the Marzan-Abad and Maraveh-Tapeh sites were measured using splash cups at the start of rainfall (Sadeghi et al., 2017b). In this relation, the total-splash variable was the sum of the downward-splash and upward-splash variables.

The paired sample t-test compared the splash erosion variables at the Marzan-Abad and Maraveh-Tapeh sites. Fig. 3 presents the mean and standard deviation values of the splash erosion variables and the results of the test. These results show that the values of the variables at the Marzan-Abad site in the plots treated with BC and BC+PAM decreased significantly compared to the control plot ($p \leq 0.05$). However, they increased significantly in the plot treated with PAM ($p \leq 0.05$) compared to the control plot and the plots treated with BC and BC+PAM ($p \leq 0.05$). Fig. 3 shows that the upward-splash, downward-splash and total splash erosion in the plot treated with PAM had the largest difference with those in the control plot and the plots treated with BC and BC +PAM at the Maraveh-Tapeh site. These results do not conform to those reported by Kavian et al. (2014) concerning reduced splash erosion in soils with various textures under the influence of PAM probably because of the more complicated natural conditions in the processes of rainfall-runoff compared to the laboratory conditions. It is remarkable that for the two soils, similar trends are obtained with a negative effect of PAM alone, resulting in an increase in splash.

Fig. 3

3.2. Differences in splash erosion between Loess and Marl soils

To compare the variables resulting from splash erosion including upward-splash, downward-splash and total splash erosion in the control plots and the treated plots at Marzan-Abad and Maraveh-Tapeh sites, one-way ANOVA was used the results of which are presented in Table 3. These results demonstrate that upward-splash and total-splash rates in the control plot and in the plot treated with BC+PAM were significantly different ($p \leq 0.05$). The average values of upward-splash and total-splash erosion at the Marzan-Abad site were higher than the control plot and the plot treated with BC+PAM at the Maraveh-Tapeh site. However, their average rates in the plots treated with BC and PAM were not significantly different ($p > 0.05$) at the Marzan-Abad and Maraveh-Tapeh sites. In the same relation, the rates of downward-splash erosion in the control plot and the treated plots at the Marzan-Abad and Maraveh-Tapeh sites were not significantly different ($p > 0.05$).

Table 3

3.3. Differences in interrill erosion variables between treatments for Loess and Marl soils

After observing the first runoff drops in the runoff collection system of the plot, we measured interrill erosion. A chronometer recorded the time to runoff generation in the control and treated plots. Fig. 4 presents the mean and standard deviation values of the time to runoff generation in the control and treated plots at the Marzan-Abad and Maraveh-Tapeh sites. Figs. 5 and 6 shows the box plots of the various interrill erosion variables in each rainfall-runoff process for the control plots and the various treated plots at the Maraveh-Tapeh and Marzan-Abad sites. The results did not indicate any significant difference between the different treatments at these two sites ($p > 0.05$). However, at the Marzan-Abad site, the time to runoff generation was longer in the control plot than in the treated plots. This reduction in the time to runoff generation was probably due to the physical adhesion of the soil surface, the salts and the nature of the material that protected the soil mass (Hillet, 2010). These factors caused the soil surface pores to fill up sooner, the treated plot reached saturation earlier and the time to runoff generation arrived sooner compared to the control plot (Sharifi Moghaddam et al., 2014). However, at the Maraveh-Tapeh site, the time to runoff generation was longer in the treated plots than in the control plot. This showed the protective materials were more effective in loess soils in which the presence of a greater quantity of clay particles having larger specific surface and greater ability to attach to the particles of the protective materials increased their permeability and decreased their erosivity compared to the marl soils (Jafari Honar et al., 2015). These results show the contrasting sensitivity of soils to such treatment for the improvement of infiltration capability.

Table 4 lists the results related to the statistical analysis concerning pairwise comparison between treatments of interrill erosion variables including the time to runoff generation, runoff volume, pH, soil loss, and sediment concentration in runoff water using the paired sample t-test at the Marzan-Abad and Maraveh-Tapeh sites. In this relation, the results in Table 4 also demonstrate that there were no significant differences in the pairwise comparison of the time to runoff generation between the control and treated plots at the two sites ($p > 0.05$).

The results in Table 4 also suggest that there were no significant differences between the control and the treated plots in runoff volume and coefficient at the Marzan-Abad site. However, the pairwise comparison of the pH and EC (Electrical Conductivity) values showed that the control and the treated plots differed significantly in pH and EC values (Table 4 and Figs. 5a and b). Moreover, at the Marzan-Abad site, the variables of soil loss and sediment concentration were significantly different only in the pairwise comparison of the plots treated with PAM and with BC+PAM ($p \leq 0.02$). The pairwise comparison of the control plot and the other treated plots did not show any significant differences with respect to the values of the mentioned variables ($p \geq 0.05$).

At the Maraveh-Tapeh site, the interrill erosion variables including runoff volume, runoff coefficient, pH, soil loss and sediment concentrations exhibited behaviors that were more complicated during the rainfall-runoff process. Fig. 4 demonstrates that there were significant differences between the control plot and the plots treated with BC, PAM and BC + PAM in runoff volume and coefficient ($p \leq 0.02$). However, the various treated plots did not differ significantly with each other ($p \geq 0.1$). The results shown in Figs. 5(c) and 5(d) also confirm these results. Soil aggregates adsorbed the additives sprayed on the soil surface in this research and thus they became more stable and more adhesive. This increase was much more evident in the loess soils of Maraveh-Tapeh than in the marl soils of Marzan-Abad because of the higher clay content and the larger specific surface of the particles in the loess soils (Jafari Honar et al., 2015). Therefore, the additives were more effective in creating the hydrophobic layer during the rainfall-runoff and hence the runoff volume and coefficient were higher than the control plot at the Maraveh-Tapeh site.

Results in Table 4 also indicate that there were significant differences between the control plot and the treated plots at the Marzan-Abad site in the variables of pH, soil loss and sediment concentration. However, the control plot and the plot treated with PAM at this site did not differ significantly in EC values, soil loss and sediment concentration ($p \geq 0.16$).

Fig. 4

Table 4

3.4. Differences in interrill erosion between Loess and Marl soils

Variables of interrill erosion including time to runoff generation, runoff volume, runoff coefficient, pH, soil loss and sediment concentration between the control and treated plots at the Marzan-Abad site with those at the Maraveh-Tapeh site compared by one-way ANOVA. Table 5 lists the results, which shows there were no significant differences between the control plot and the treated plots at the two sites in the time to run off generation and soil loss ($p \geq 0.05$). However, in general, the variables of runoff volume, runoff coefficient, pH, and sediment concentration differed significantly at the 95% level. Of course, there were no significant differences between the control plot and the plots treated with BC, BC+PAM in EC values and the measured runoff volume at the 2 sites.

As shown by the box plots in Figures 5 and 6, we can see the intergroup and intragroup behavioral changes at the two sites for the various interrill erosion variables. Fig. 5(a) demonstrates the maximum intergroup and intragroup changes in runoff pH values at the Marzan-Abad and Maraveh-Tapeh sites. The runoff pH values in the various treated plots at these two sites indicate increases compared to the control plots. The increase in runoff pH was due to the application of BC (which has a high pH value).

BC with its high pH value is very probably able to cause the development of the mineral phases of hydroxides, phosphates and carbonates that lead to aggregate coalescence, particularly in the long term (Czimczik and Masiello, 2007; Omondi et al., 2016).

Moreover, Fig. 5(b) suggests increases in runoff EC values in the treated plots compared to the control plots at the Marzan-Abad and Maraveh-Tapeh sites. However, these increases were significantly larger in the plots treated with BC and BC+PAM. Results shown in Figs. 5(c) and 5(d) indicate that the runoff volume and coefficient were different in the treated plots compared to the control plots at the two sites. The mean runoff volumes in the various treated plots were lower than the control plot at the Marzan-Abad site but higher than the control plot at the Maraveh-Tapeh site. In general, runoff volume and coefficient had higher values with wider change ranges at the Maraveh-Tapeh site compared to the Marzan-Abad site.

Figs. 6(a) and 6(b) present intergroup and intragroup behavioral changes in the variables of soil loss and sediment concentration during the rainfall-runoff process happening in the control and the various treated plots at the Marzan-Abad and Maraveh-Tapeh sites. The results indicate that the change ranges in the values of the mentioned variables in the control and treated plots was wider at the Marzan-Abad site than at the Maraveh-Tapeh site. The behaviors of the values of sediment quantity and runoff volume at the two sides were opposite each other. This could result from the different nature and intrinsic structure and texture of loess and marl soils caused by their interplay with hydrological processes (Glaser et al., 2002).

Therefore, we must consider this behavioral difference in introducing protection and management strategies. Finally, Figs. 6(a) and 6(b) revealed that the plots treated with PAM at the Marzan-Abad and Maraveh-Tapeh sites decreased soil loss and sediment concentration but increased runoff volume compared to the control plots (Fig. 5c). These results conform to those reported by many researchers including Yu et al. (2003), Lentz and Sojka, (2009), Nehrani and Vaezi (2013), Sadeghi et al. (2013) and Karimi et al (2015). In this relation, the additive BC at the Marzan-Abad site decreased runoff volume and coefficient and reduced soil loss in the treated plot compared to the control plot. These results agree with the laboratory results that Sadeghi et al. (2017a) found in protecting marl soil using BC produced from dairy factory waste. They also are in agreement with results reported by Gholami et al. (2019) that showed runoff volume and soil loss decreased in soils treated with BC. In general, BC decreases soil bulk density, increases soil aggregate stability and porosity and is more effective in coarse-textured soils that in soft-textured ones (Omondi et al., 2016). These effects increase soil permeability and reduce runoff. However, in loess soils treated with BC at Maraveh-Tapeh site soil loss increased compared to the control plot. These results conform to those in the study by Zhang et al. (2016) who reported that soil loss increased during interrill erosion in loess soils. Finally, results in Figs. 5(c) and 5(d) also indicate that runoff volume and coefficient increased in plots treated with BC+PAM compared to the control plots in loam and loess soils at Marzan-Abad and Maraveh-Tapeh sites, respectively. Moreover, Figs. 6(a) and 6(b) also demonstrated that soil loss and sediment concentration increased in plots treated with BC+PAM compared to the control plots at both sites. Therefore, we should not recommend these two additives in combination for reducing runoff and sediment during the interrill erosion process in erodible soils such as marl and loess.

Table 5

4. Conclusion Remarks

The present research intended to protect two types of soil (marl and loess soils) susceptible to splash and interrill erosion at the Marzan-Abad and Maraveh-Tapeh sites during the simulated rainfall-runoff process in small plots by using the BC, PAM and BC+PAM additives. In general, the results suggested that the loess and marl soils behaved similarly during splash erosion. The largest amount of soil loss that happened due to upward-splash, downward-splash and total-splash variables was recorded in the plot treated with PAM compared to the control plot, and the quantities of soil loss caused by splash erosion in plots treated with BC and BC+PAM were lower than those in the control plots at the two sites. At the Marzan-Abad site, this reduction in soil loss was not significant compared to the control.

In interrill erosion, there were no significant differences between the treated and control plots in the time to runoff generation at the two sites. However, the time to runoff generation was shorter in the treated plots compared to the control plot at the Marzan-Abad site but longer at the Maraveh-Tappeh site. In the interrill erosion process, soil loss and sediment concentrations decreased in the plots treated with PAM compared to the control plots at the Marzan-Abad and Maraveh-Tapeh sites but runoff volume increased. However, runoff volume and coefficient and also soil loss decreased in the plot treated with BC compared to the control plot at the Marzan-Abad site, whereas soil loss increased in the plot treated with BC compared to the control plot in the loess soil at the Maraveh-Tapeh site. Finally, runoff volume and coefficient increased in the plots treated with BC+PAM compared with the control plots in the loam and loess soils at the Marzan-Abad and Maraveh-Tapeh sites, respectively. The addition PAM appears to be the best solution for the two soil regarding the limitation of soil erosion. However, the effect on the soil capability to infiltrate water and reduce runoff is mostly ensured by BC, mostly for loess soils. Differences in the hydrological behavior in the loam and loess soils treated with these protective materials indicated that, in order to use any of the additives, we must consider the purpose of soil conservation during each stage of the soil erosion process and then suggest management actions and apply them. In conclusion, we believe that study of experiments conducted on various temporal and spatial scales and under natural rainfall (by taking into account the environmental and economic goals) enables us to attain a more comprehensive summation in this relation and introduce strategies that are more practical. Additional perspective insists on coupling of physicochemical processes (hydrophobicity) and geochemical processes (mineral precipitation, dissolution, etc.).

Fig. 5

Fig. 6

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Figures Captions

Fig. 1. Location of Marzan-Abad (Marl Soil) and Maraveh-Tapeh (Loess Soil) sites in Iran

Fig. 2. Experimental setting for rainfall simulation in the Marzan-Abad and Maraveh-Tapeh sites, Iran

Fig. 3. Comparing pairwise of splash erosion variables by paired-samples t-test

Fig. 4. Average and standard deviation of time to runoff generation from treated plots

Fig. 5. Box plots of interrill erosion results. a: pH; b: EC; c: runoff; d: runoff coefficient, minimum, second quartile, median, third quartile and the maximum values

Fig. 6. Box plots of interrill erosion results. a: soil loss; b: sediment concentration, minimum, second quartile, median, third quartile and the maximum values

Table 1. Physical and chemical properties of the soils tested

Study soils	E. Longitude	N. Latitude	OM (%)	EC (ds/m)	pH	BD (gr/cm^3)	Particle Size Distribution (%)		
							Clay	Silt	Sand
Marl	51º 23′	36º 28′	1.63	0.21	7.68	1.12	42	43	15
Loess	55º 26′	37º 35′	0.155	137.3	8.2		57	36	7

Table 2. Some properties of the BC (%) and PAM prepared and used for the study

Amendments	Form	Ash	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	Cl	K_2O	CaO	TiO_2	Cr	MnO	Fe_2O_3	Ni
BC	Powder	29.78	1.87	2.787	3.377	15.502	0.604	8.592	4.883	11.007	18.578	0.306	0.013	0.04	2.469	0.01
PAM	Liquid	A granular anionic PAM having a mean molecular mass of 10–15million $gmol^{-1}$ was dissolved in deionized water and aged (25 °C, dark) for one week to obtain a uniform solution. The standard solutions (100mg l^{-1}) was then used for the study (Sadeghi et al., 2016a).														

Table 3. Statically significant differences among splash erosion results in Marzan-Abad and Maraveh-Tapeh sites by one-way ANOVA

Variable/ Criteria	Upward-splash		Downward-splash		Total-splash	
	F-value	Significance level	F-value	Significance level	F-value	Significance level
Control	38.60	0.00	4.85	0.09	12.98	0.02
BC	1.12	0.35	0.70	0.44	1.10	0.35
PAM	0.98	0.38	0.61	0.48	0.76	0.43
BC+PAM	7.15	0.05	5.75	0.07	20.21	0.01

Table 4. Statically significant differences between treatments among interrill erosion variables: pairwise comparison using student t-test

Soil origin	Treatment		Time to runoff	Runoff	Runoff coefficient	pH	Electrical conductivity	Soil loss	Sediment concentration
Marzan-Abad	Control	BC	0.30	0.17	0.09	0.00	0.00	0.36	0.23
		PAM	0.22	0.92	0.43	0.00	0.00	0.12	0.94
		BC+PAM	0.15	0.75	0.73	0.00	0.02	0.24	0.11
	BC	PAM	0.26	0.09	0.13	0.00	0.00	0.27	0.26
		BC+PAM	0.43	0.17	0.06	0.03	0.30	0.06	0.29
	PAM	BC+PAM	0.10	0.69	0.29	0.00	0.02	0.02	0.00
Maraveh-Tapeh	Control	BC	0.75	0.02	0.02	0.00	0.01	0.00	0.01
		PAM	0.51	0.00	0.00	0.00	0.73	0.45	0.16
		BC+PAM	0.41	0.00	0.00	0.00	0.01	0.00	0.00
	BC	PAM	0.53	0.61	0.74	0.00	0.01	0.00	0.00
		BC+PAM	0.67	0.55	0.35	0.01	0.00	0.00	0.01
	PAM	BC+PAM	0.85	0.20	0.17	0.00	0.01	0.00	0.00

Table 5. Statically significant differences among interrill erosion results between the Marzan-Abad and Maraveh-Tapeh sites (one-way ANOVA).

Variable	Time to runoff		Runoff		Runoff coefficient		pH		Electrical conductivity		Soil loss		Sediment concentration	
	F-value	Significance level	F-value	Significance level	F-value	Significance level	F-value	Significance level	F-value	Significance level	F-value	Significance level	F-value	Significance level
Control	1.93	0.23	3.67	0.07	7.89	0.01	138.59	0.00	884.21	0.00	3.03	0.10	20.41	0.00
BC	0.34	0.59	12.28	0.00	76.49	0.00	282.73	0.00	0.33	0.57	4.15	0.06	6.01	0.02
PAM	1.03	0.36	7.45	0.01	39.55	0.00	356.33	0.00	373.21	0.00	0.08	0.78	4.88	0.04
BC+PAM	1.30	0.31	10.66	0.00	67.62	0.00	107.09	0.00	0.54	0.47	0.65	0.42	3.55	0.05

Fig. 1. Location of Marzan-Abad (Marl Soil) and Maraveh-Tapeh (Loess Soil) sites in Iran

Fig. 2. Experimental setting for rainfall simulation in the Marzan-Abad and Maraveh-Tapeh sites, Iran

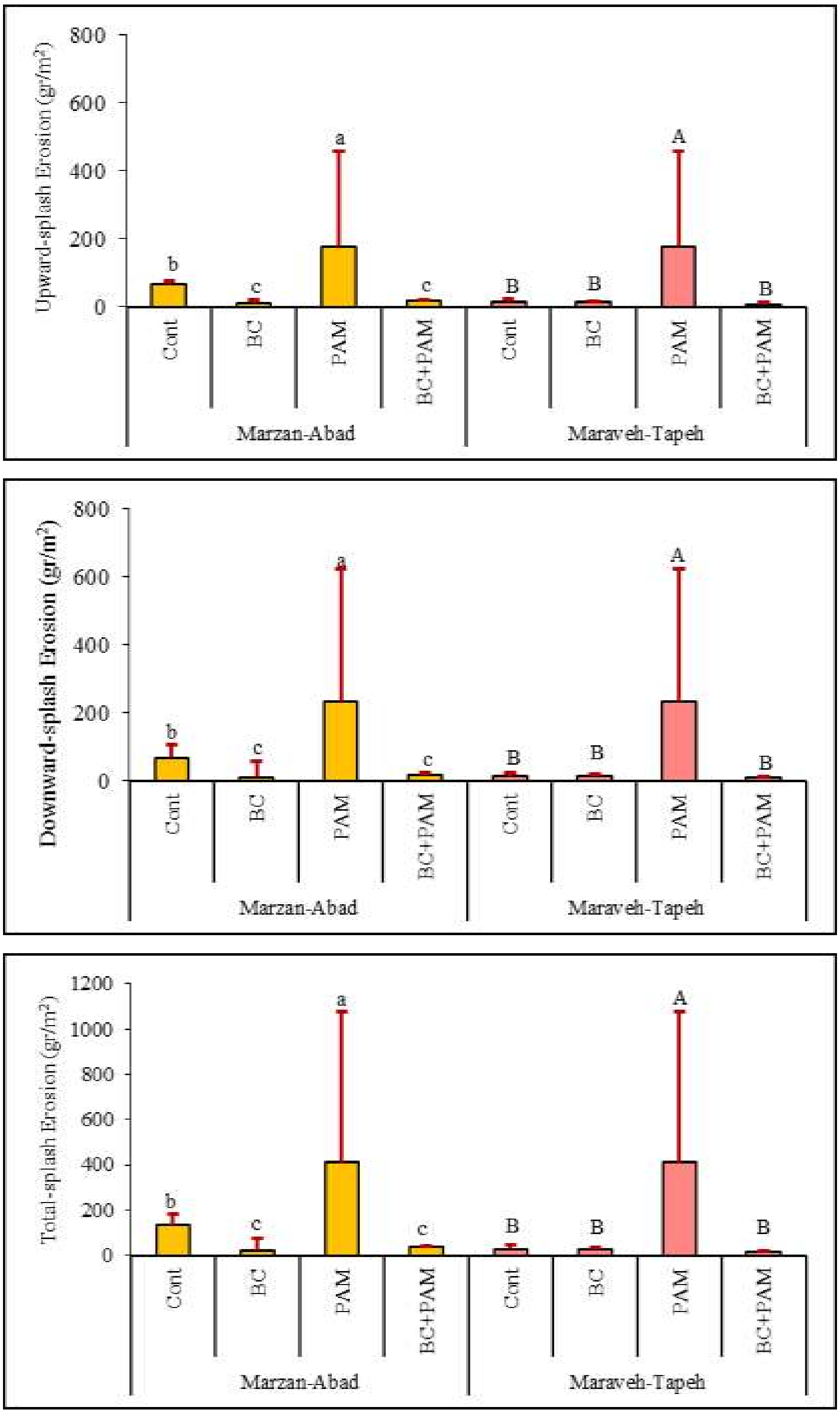


Fig. 3. Comparing pairwise of splash erosion variables by paired-samples t-test

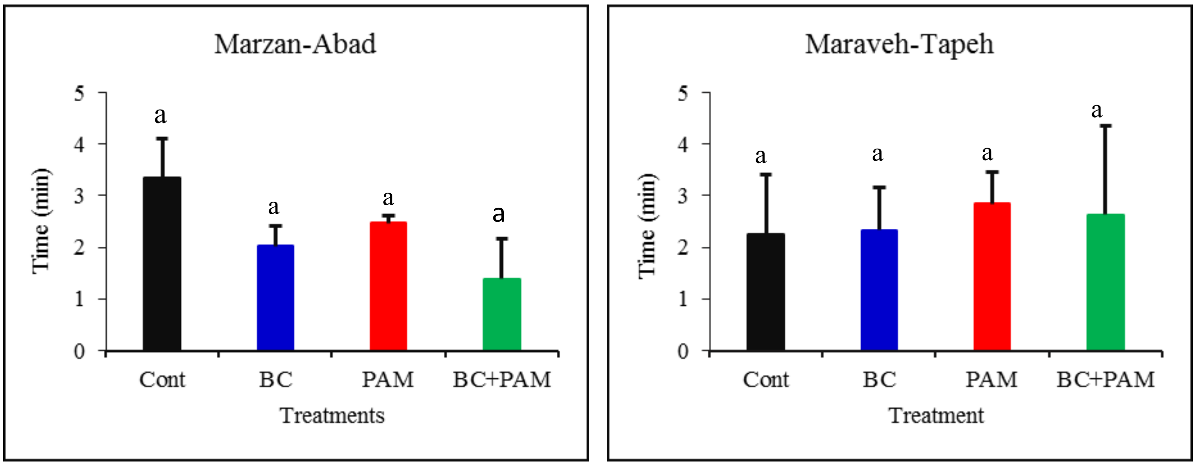
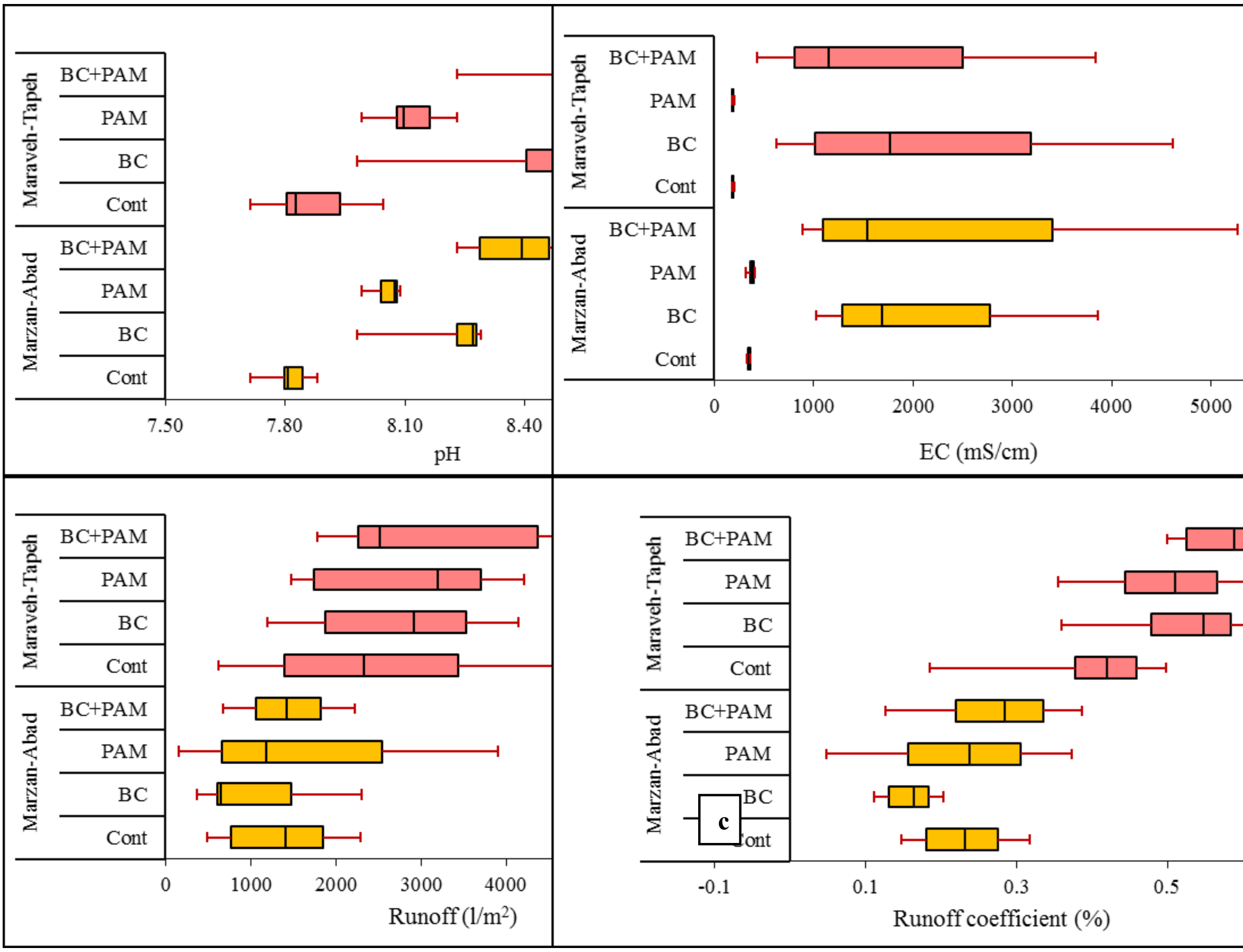


Fig. 4. Average and standard deviation of time to runoff generation from treated plots



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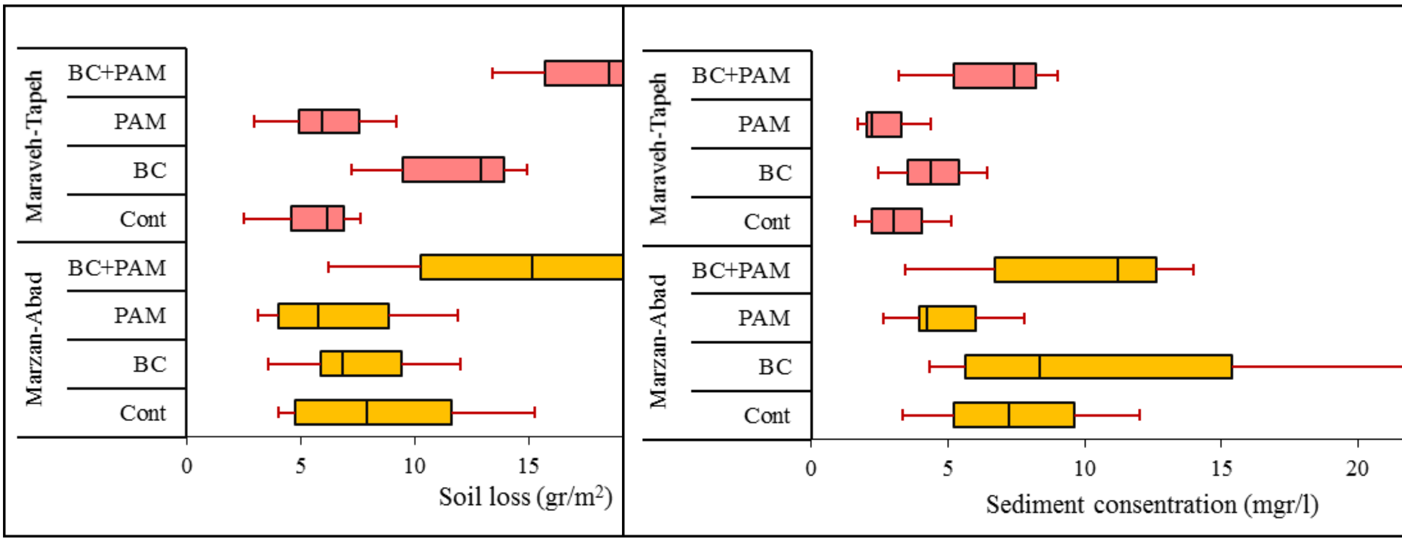

Fig. 6. Box plots of interrill erosion results. a: soil loss; b: sediment concentration, minimum, second quartile, median, third quartile and the maximum values