



HAL
open science

Field measurement of effects of individual and combined application of biochar and polyacrylamide on erosion variables in loess and marl soils

Seyed Hamidreza Sadeghi, Mahboobeh Kiani-Harchegani, Zeinab Hazbavi, Padidehsadat Sadeghi, Rafaël Angulo-Jaramillo, Laurent Lassabatère, Habibollah Younesi

► To cite this version:

Seyed Hamidreza Sadeghi, Mahboobeh Kiani-Harchegani, Zeinab Hazbavi, Padidehsadat Sadeghi, Rafaël Angulo-Jaramillo, et al.. Field measurement of effects of individual and combined application of biochar and polyacrylamide on erosion variables in loess and marl soils. *Science of the Total Environment*, 2020, 728, pp.138866. 10.1016/j.scitotenv.2020.138866 . hal-02611638

HAL Id: hal-02611638

<https://univ-lyon1.hal.science/hal-02611638v1>

Submitted on 7 Jan 2021

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Field Measurement of Effects of Individual and Combined Application of Biochar and Polyacrylamide on Erosion Variables in Loess and Marl Soils

Seyed Hamidreza Sadeghi^{1,*}, Mahboobeh Kiani-Harchegani², Zeinab Hazbavi³, Padidehsadat Sadeghi⁴, Rafael Angulo-Jaramillo⁵, Laurent Lassabatere⁶ and Habibollah Younesi⁷

1, *) Professor (Corresponding Author), Department of Watershed Management Engineering, Faculty of Natural Resources, Tarbiat Modares University, Noor 46417-76489, Iran. E-mail: sadeghi@modares.ac.ir

2) Postdoctoral Researcher, Department of Watershed Management Engineering, Faculty of Natural Resources, Yazd University, Iran. E-mail: mahboobeh.kiyani20@gmail.com

3) Assistant Professor, Department of Natural Resources, Faculty of Agriculture and Natural Resources, University of Mohaghegh Ardabili, Ardabil, Iran. E-mail: z.hazbavi@uma.ac.ir

4) M.Sc. Student, Department of Watershed Management Engineering, Faculty of Natural Resources, Tarbiat Modares University, Noor 46417-76489, Iran. E-mail: Pssadeghi1371@gmail.com

5) Chargé de Recherche CNRS, Université de Lyon; UMR5023 Ecologie des Hydrosystèmes Naturels et Anthropisés, CNRS, ENTPE, Université Lyon 1, Vaulx-en-Velin, France. E-mail: angulo@entpe.fr

6) Research, Université de Lyon; UMR5023 Ecologie des Hydrosystèmes Naturels et Anthropisés, CNRS, ENTPE, Université Lyon 1, Vaulx-en-Velin, France. E-mail: Laurent.LASSABATERE@entpe.fr

7) Professor, Department of Environment, Faculty of Natural Resources, Tarbiat Modares University, Noor 46417-76489, Iran. E-mail: hunesi@modares.ac.ir

1 **Abstract**

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

23

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

25

26

27 **1. Introduction**

28 Water and soil loss in different ecosystems, mainly in sloping agricultural lands, are major
29 environmental threats that lead to instability and unsustainability of the ecosystems,
30 particularly in terms of land degradation and reduced fertility and productivity. Soil erosion is
31 accelerated as a result of increased runoff on soil surface that results in soil vulnerability with
32 respect to reduced permeability, crusting, and slacking (Liu et al., 2014; Gholami et al.,
33 2019). Approximately 60% of the total runoff and sediment loss that happen in various
34 ecosystems of watersheds are caused by natural and anthropogenic factors such as rainfall
35 intensity, geomorphology and soil management practices (Keesstra et al., 2016; Zhao et al.,
36 2017; Wang et al., 2017). Therefore, soil conservation and erosion control are among the most
37 important measures that need special attention in all countries. Various methods have been
38 introduced to control soil erosion, but use of methods that can protect soil from the first
39 impacts of erosion agents is a top priority in soil erosion control programs (Blanco-Sepúlveda,
40 2018).

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

51 al., 2016b; Głab et al., 2016; Wang et al., 2017; Yue et al., 2017; Sadeghi et al., 2018; Zhang
52 et al., 2019; Khadem and Raiesi, 2019; Gholami et al., 2019).

53 BC, carbon or pyrogenic carbon, is now widely used as a soil amendment due to its beneficial
54 effects on soil quality (Wang et al., 2013). BC is the product of thermal-chemical conversion
55 of biomass in a pyrolysis reactor (Verheijen et al., 2019). It has many benefits from the
56 perspective of agriculture and natural resources that have been mentioned by various
57 researchers. These benefits include improved soil water retention capacity (Laird et al., 2010),
58 provision of plant nutrients and enhancement of plant growth (Graber et al., 2010),
59 improvement of soil physical and chemical properties (Zhang et al., 2019) and reduced runoff
60 and soil loss (Sadeghi et al., 2016b; Sadeghi et al., 2018; Gholami et al., 2019). However,
61 some researchers including Cheng and Lehmann (2009), Rumpel et al. (2009), Major et al.
62 (2010), Nguyen et al. (2010), and Sadeghi et al. (2016b) have pointed at BC loss along with
63 sediments down slopes during the rainfall-runoff process caused by factors such as lack of
64 adhesion between particles.

65 Some other soil amendments such as high molecular weight polymers, which are formed by
66 covalent bonds between monomers, stabilize soil aggregates in the long term, particularly in
67 soils susceptible to erosion such as marl soils (Nehrani and Vaezi, 2013) and thereby play an
68 effective role in reducing soil erosion through binding soil particles together. Among these
69 polymers is anionic-Polyacrylamide (PAM) that binds fine soil particles together thus
70 reducing their floating duration, increases their deposition rate. Such an additive may
71 strengthen the bounds between particles, meaning a higher stability of soil aggregate, a
72 positive effect on soil structure and consequently on its capability to infiltrate water (Hamidi
73 Sojka et al., 2005; Nehrani and Vaezi, 2013; Karimi et al., 2015; Sarkar et al., 2018; Biju and
74 Arnepalli, 2019). Therefore, considering the research background, the present study
75 investigated use of BC alone and in combination with PAM to reduce runoff and soil loss

76 during the rainfall-runoff process. In this regard, effects of these amendments on splash and
77 interrill erosion control and on different variables such as upward-splash, downward-splash,
78 total-splash, runoff, time of runoff generation, runoff coefficient, and soil loss and sediment
79 concentration of runoff water were studied in two types of erosion-susceptible soil (loess and
80 marl) found in the northern regions of Iran under natural conditions. The whole study has
81 been conducted under field conditions, which is obviously differentiated from many existing
82 literatures, as a crucial criterion to properly assess the performance of soil and water
83 conservation techniques leading to propose efficient and effective measures. The work was
84 formulated for two erosion prone soils located on Marl and Loess formations in two distant
85 localities in North Iran.

86

87 **2. Materials and methods**

88 **2.1. Test materials**

89 In this research, plots $0.5 \times 0.5\text{-m}^2$ were installed in the two study regions of Marzan-Abad (in
90 west of Mazandaran Province) with marl formation and Maraveh-Tapeh (in north of Golestan
91 Province) with loess soil whose characteristics have been presented in [Table 1](#) ([Sadeghi et al.,](#)
92 [2013](#); [Karimi et al., 2015](#); [Sadeghi et al., 2017a](#)). BC produced from sugarcane industries and
93 anion PAM amendments with the properties listed in [Table 2](#) were used in the experiments.
94 [Fig. 1](#) presents the locations where soil samples were taken in the mentioned Provinces.

95

Table 1

96

Table 2

97

Fig. 1

98

99 **2.2. Rainfall and soil erosion simulation**

100 In these experiments, well water with pH 7.27, electrical conductivity 5.13 mS m⁻¹, dissolved
101 oxygen 30.7%, phosphorus phosphate 0.17 mg l⁻¹ and nitrate 4.41 mg l⁻¹ was used to simulate
102 rainfall (Kiani-Harchegani et al., 2016 and 2019). In addition, the mean slope steepness and
103 rainfall intensity were chosen in accordance with the general conditions in the native area of
104 the soils and taking into account rainfalls with a return period of 25-30 years. Therefore, a
105 25% slope was selected for the experiments to conform to standard agricultural lands and the
106 general and prevailing conditions in rain-fed agricultural lands and natural resources areas in
107 Iran. Rainfall simulation experiments were also performed under soil moisture conditions
108 similar to the general conditions prevailing in the two mentioned areas prior to rainfall and by
109 measuring volumetric water content in those areas and in the laboratory using wet and dry
110 sample weighing and maintaining relatively similar conditions in the predicted experiments.
111 Therefore, the experiments were run at rainfall intensity of about 50 ± 5 mm h⁻¹ lasting for 30
112 min according to the Intensity, Duration, and Frequency (IDF) graphs prepared for the two
113 sites. All rainfall simulations were performed on small plots with both length and width of 0.5
114 m in three replications (Sadeghi et al., 2016b) in the two regions of Marzan-Abad (in western
115 Mazandaran Province) and Maraveh-Tapeh (in northern Golestan Province). Some views of
116 field experiments have been shown in Fig. 2.

117 **Fig. 2**

118

119 **2.3. Experimental design for field inventory**

120 In the present study, BC (800 gm⁻²) and PAM (2 gm⁻²) were used in individual and
121 combination in treated plots with three replications. These levels were selected based on
122 successful performance of the same rates in previous researches (Sadeghi et al. 2016 a and b;
123 Sadeghi et al. 2017a; Sadeghi et al. 2018). BC was spread whilst PAM was just sprayed on
124 the soil surface, individually. PAM was also sprayed on BC when they were concurrently

125 used. Splash cups were installed in the plot to measure splash erosion (Fig. 2). The splashed
126 sediment samples were collected from upward and downward parts of the splash cups during
127 each run from the beginning of the rainfall (Kiani-Harchegani et al., 2016; Sadeghi et al.
128 2017b).

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

134

135 **2.4. Data analysis**

136 After measuring the different variables caused by splash and interrill erosions in the control
137 plots and the plots treated by BC, PAM and combination of BC and PAM, the data from the
138 experiments were classified in Excel and their database was created. Before any statistical
139 analysis, data normality was checked using the Kolmogorov-Smirnov test. Levene's test of
140 variance homogeneity was then used to evaluate homogeneity of variance in the different
141 treatments. The paired samples t-test used to compare pairwise BC and PAM on different
142 variables of splash and interrill erosion. In addition, one-way ANOVA and Tukey's HSD test
143 at a probability level ($P < 0.05$) was used to compare the means of the different variables in
144 two sites of Marzan-Abad and Maraveh-Tapeh that are affected by combined and individual
145 application BC and PAM (Awad et al., 2012; Kiani-Harchegani et al., 2016; Wang et al.,
146 2017).

147

148 **3. Results and Discussion**

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

152

153 **3.1. Differences in splash erosion variables between treatments for Loess and Marl soils**

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

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

172

Fig. 3

173

174 **3.2. Differences in splash erosion between Loess and Marl soils**

175 To compare the variables resulting from splash erosion including upward-splash, downward-
176 splash and total splash erosion in the control plots and the treated plots at Marzan-Abad and
177 Maraveh-Tapeh sites, one-way ANOVA was used the results of which are presented in **Table**
178 **3**. These results demonstrate that upward-splash and total-splash rates in the control plot and
179 in the plot treated with BC+PAM were significantly different ($p \leq 0.05$). The average values
180 of upward-splash and total-splash erosion at the Marzan-Abad site were higher than the
181 control plot and the plot treated with BC+PAM at the Maraveh-Tapeh site. However, their
182 average rates in the plots treated with BC and PAM were not significantly different ($p > 0.05$)
183 at the Marzan-Abad and Maraveh-Tapeh sites. In the same relation, the rates of downward-
184 splash erosion in the control plot and the treated plots at the Marzan-Abad and Maraveh-
185 Tapeh sites were not significantly different ($p > 0.05$).

186 **Table 3**

187 **3.3. Differences in interrill erosion variables between treatments for Loess and Marl soils**

188 After observing the first runoff drops in the runoff collection system of the plot, we measured
189 interrill erosion. A chronometer recorded the time to runoff generation in the control and
190 treated plots. **Fig. 4** presents the mean and standard deviation values of the time to runoff
191 generation in the control and treated plots at the Marzan-Abad and Maraveh-Tapeh sites. **Figs.**
192 **5** and **6** shows the box plots of the various interrill erosion variables in each rainfall-runoff
193 process for the control plots and the various treated plots at the Maraveh-Tapeh and Marzan-
194 Abad sites. The results did not indicate any significant difference between the different
195 treatments at these two sites ($p > 0.05$). However, at the Marzan-Abad site, the time to runoff
196 generation was longer in the control plot than in the treated plots. This reduction in the time to
197 runoff generation was probably due to the physical adhesion of the soil surface, the salts and
198 the nature of the material that protected the soil mass (Hillet, 2010). These factors caused the

199 soil surface pores to fill up sooner, the treated plot reached saturation earlier and the time to
200 runoff generation arrived sooner compared to the control plot (Sharifi Moghaddam et al.,
201 2014). However, at the Maraveh-Tapeh site, the time to runoff generation was longer in the
202 treated plots than in the control plot. This showed the protective materials were more effective
203 in loess soils in which the presence of a greater quantity of clay particles having larger
204 specific surface and greater ability to attach to the particles of the protective materials
205 increased their permeability and decreased their erosivity compared to the marl soils (Jafari
206 Honar et al., 2015). These results show the contrasting sensitivity of soils to such treatment
207 for the improvement of infiltration capability.

208 Table 4 lists the results related to the statistical analysis concerning pairwise comparison
209 between treatments of interrill erosion variables including the time to runoff generation,
210 runoff volume, pH, soil loss, and sediment concentration in runoff water using the paired
211 sample t-test at the Marzan-Abad and Maraveh-Tapeh sites. In this relation, the results in
212 Table 4 also demonstrate that there were no significant differences in the pairwise comparison
213 of the time to runoff generation between the control and treated plots at the two sites ($p >$
214 0.05).

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

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

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

241 **Fig. 4**

242 **Table 4**

243

244 **3.4. Differences in interrill erosion between Loess and Marl soils**

245 Variables of interrill erosion including time to runoff generation, runoff volume, runoff
246 coefficient, pH, soil loss and sediment concentration between the control and treated plots at
247 the Marzan-Abad site with those at the Maraveh-Tapeh site compared by one-way ANOVA.
248 Table 5 lists the results, which shows there were no significant differences between the

249 control plot and the treated plots at the two sites in the time to run off generation and soil loss
250 ($p \geq 0.05$). However, in general, the variables of runoff volume, runoff coefficient, pH, and
251 sediment concentration differed significantly at the 95% level. Of course, there were no
252 significant differences between the control plot and the plots treated with BC, BC+PAM in
253 EC values and the measured runoff volume at the 2 sites.

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

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

263 Moreover, Fig. 5(b) suggests increases in runoff EC values in the treated plots compared to
264 the control plots at the Marzan-Abad and Maraveh-Tapeh sites. However, these increases
265 were significantly larger in the plots treated with BC and BC+PAM. Results shown in Figs.
266 5(c) and 5(d) indicate that the runoff volume and coefficient were different in the treated plots
267 compared to the control plots at the two sites. The mean runoff volumes in the various treated
268 plots were lower than the control plot at the Marzan-Abad site but higher than the control plot
269 at the Maraveh-Tapeh site. In general, runoff volume and coefficient had higher values with
270 wider change ranges at the Maraveh-Tapeh site compared to the Marzan-Abad site.

271 Figs. 6(a) and 6(b) present intergroup and intragroup behavioral changes in the variables of
272 soil loss and sediment concentration during the rainfall-runoff process happening in the
273 control and the various treated plots at the Marzan-Abad and Maraveh-Tapeh sites. The

274 results indicate that the change ranges in the values of the mentioned variables in the control
275 and treated plots was wider at the Marzan-Abad site than at the Maraveh-Tapeh site. The
276 behaviors of the values of sediment quantity and runoff volume at the two sides were opposite
277 each other. This could result from the different nature and intrinsic structure and texture of
278 loess and marl soils caused by their interplay with hydrological processes (Glaser et al.,
279 2002).

280 Therefore, we must consider this behavioral difference in introducing protection and
281 management strategies. Finally, Figs. 6(a) and 6(b) revealed that the plots treated with PAM
282 at the Marzan-Abad and Maraveh-Tapeh sites decreased soil loss and sediment concentration
283 but increased runoff volume compared to the control plots (Fig. 5c). These results conform to
284 those reported by many researchers including Yu et al. (2003), Lentz and Sojka, (2009),
285 Nehrani and Vaezi (2013), Sadeghi et al. (2013) and Karimi et al (2015). In this relation, the
286 additive BC at the Marzan-Abad site decreased runoff volume and coefficient and reduced
287 soil loss in the treated plot compared to the control plot. These results agree with the
288 laboratory results that Sadeghi et al. (2017a) found in protecting marl soil using BC produced
289 from dairy factory waste. They also are in agreement with results reported by Gholami et al.
290 (2019) that showed runoff volume and soil loss decreased in soils treated with BC. In general,
291 BC decreases soil bulk density, increases soil aggregate stability and porosity and is more
292 effective in coarse-textured soils than in soft-textured ones (Omondi et al., 2016). These
293 effects increase soil permeability and reduce runoff. However, in loess soils treated with BC
294 at Maraveh-Tapeh site soil loss increased compared to the control plot. These results conform
295 to those in the study by Zhang et al. (2016) who reported that soil loss increased during
296 interrill erosion in loess soils. Finally, results in Figs. 5(c) and 5(d) also indicate that runoff
297 volume and coefficient increased in plots treated with BC+PAM compared to the control plots
298 in loam and loess soils at Marzan-Abad and Maraveh-Tapeh sites, respectively. Moreover,

299 Figs. 6(a) and 6(b) also demonstrated that soil loss and sediment concentration increased in
300 plots treated with BC+PAM compared to the control plots at both sites. Therefore, we should
301 not recommend these two additives in combination for reducing runoff and sediment during
302 the interrill erosion process in erodible soils such as marl and loess.

303 **Table 5**

305 **4. Conclusion Remarks**

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

315 In interrill erosion, there were no significant differences between the treated and control plots
316 in the time to runoff generation at the two sites. However, the time to runoff generation was
317 shorter in the treated plots compared to the control plot at the Marzan-Abad site but longer at
318 the Maraveh-Tappeh site. In the interrill erosion process, soil loss and sediment
319 concentrations decreased in the plots treated with PAM compared to the control plots at the
320 Marzan-Abad and Maraveh-Tapeh sites but runoff volume increased. However, runoff
321 volume and coefficient and also soil loss decreased in the plot treated with BC compared to
322 the control plot at the Marzan-Abad site, whereas soil loss increased in the plot treated with
323 BC compared to the control plot in the loess soil at the Maraveh-Tapeh site. Finally, runoff

324 volume and coefficient increased in the plots treated with BC+PAM compared with the
325 control plots in the loam and loess soils at the Marzan-Abad and Maraveh-Tapeh sites,
326 respectively. The addition PAM appears to be the best solution for the two soil regarding the
327 limitation of soil erosion. However, the effect on the soil capability to infiltrate water and
328 reduce runoff is mostly ensured by BC, mostly for loess soils. Differences in the hydrological
329 behavior in the loam and loess soils treated with these protective materials indicated that, in
330 order to use any of the additives, we must consider the purpose of soil conservation during
331 each stage of the soil erosion process and then suggest management actions and apply them.
332 In conclusion, we believe that study of experiments conducted on various temporal and spatial
333 scales and under natural rainfall (by taking into account the environmental and economic
334 goals) enables us to attain a more comprehensive summation in this relation and introduce
335 strategies that are more practical. Additional perspective insists on coupling of
336 physicochemical processes (hydrophobicity) and geochemical processes (mineral
337 precipitation, dissolution, etc.).

338 **Fig. 5**

339 **Fig. 6**

340

341 **Acknowledgements**

342 The authors would like to give their thanks to Tarbiat Modares University for providing
343 facilities at the Rainfall Simulation and Soil Erosion Laboratory of the Faculty of Natural
344 Resources Noor, Iran, where all lab works have been conducted. This research has been
345 collaboratively supported by the Iranian Ministry of Science, Research and Technology,
346 Center for International Scientific Studies and Collaboration (CISSC), and the French PHC-
347 Gundishapur Project (No42534UA) whose valuable assistances are greatly appreciated. The
348 valuable cooperation of Dr. F. Soleimani in providing raw vinasse, and En. A. Jafarpour, En.

349 S. Gharemahmoodli, En. S. Zare, En. M. Zabihi and En. J. Safei in conducting experiments is
350 also greatly acknowledged.

351

352 **References**

353 Awad, Y.M., Blagodatskaya, E., Ok, Y. S., Kuzyakov, Y. 2012. Effects of polyacrylamide,
354 biopolymer, and biochar on decomposition of soil organic matter and plant residues as
355 determined by ¹⁴C and enzyme activities. *Eur. J. Soil Biol.* 48, 1-10.

356 Biju, M.S., Arnepalli, D.N. 2019. Biopolymer-Modified Soil: Prospects of a Promising
357 Green Technology. In *Geotechnical Characterisation and Geoenvironmental*
358 *Engineering* (pp. 163-169). Springer, Singapore.

359 Blanco-Sepúlveda, R. 2018. An erosion control and soil conservation method for agrarian
360 uses based on determining the erosion threshold. *MethodsX*, 5, 761-772.

361 Cheng, C. H., Lehmann, J. 2009. Ageing of black carbon along a temperature gradient.
362 *Chemosphere*. 75(8), 1021-1027.

363 Czimczik, C.I., Masiello, C.A. 2007. Controls on black carbon storage in soils. *Global*
364 *Biogeochem. Cycles*, 21(3).1-8.

365 Fangueiro, D., Kidd, P. S., Alvarenga, P., Beesley, L., de Varennes, A. 2018. Strategies for
366 soil protection and remediation. In *Soil Pollution* (pp. 251-281). Academic Press.

367 Gholami, L., Karimi, N., Kavian, A. 2019. Soil and water conservation using biochar and
368 various soil moisture in laboratory conditions. *Catena*. 182, 104151.

369 Głąb, T., Palmowska, J., Zaleski, T., Gondek, K. 2016. Effect of biochar application on soil
370 hydrological properties and physical quality of sandy soil. *Geoderma*. 281, 11-20.

371 Glaser, B., Lehmann, J., Zech, W. 2002. Ameliorating physical and chemical properties of
372 highly weathered soils in the tropics with charcoal—a review. *Biol. Fertile. Soils*, 35(4),
373 219-230.

374 Graber, E. R., Harel, Y. M., Kolton, M., Cytryn, E., Silber, A., David, D. R. Elad, Y. 2010.
375 Biochar impact on development and productivity of pepper and tomato grown in
376 fertigated soilless media. *Plant Soil*. 337(1-2), 481-496.

377 Hamidi Nehrani, S., Vaezi, A. R. 2013. Effect of polyvinyl acetate on hydraulic
378 conductivity, runoff and sediment production in a Marl Soil. *J. Water Soil*. 27 (4), 792-
379 801. (In Persian)

380 Jafari Honar, A., Kiani, F. and Khormali, F. 2015. The study on the variation of some
381 physical indices of the loess soils quality along climatic transect in Golestan Province, J.
382 *Soil Manag. Sustain*. 5(3), 65-79. (In Persian)

383 Karimi, Z., Sadeghi, S.H.R., Bahrami, H. 2015. Variations of runoff generation during
384 rainfall events with different levels of powder and liquid application of polyacrylamide,
385 *J. Water Soil Res*. 46 (3), 443-453. (In Persian)

386 Kavian A., Hayavi F., Boroghani M. 2014. Polyacrylamide effects on splash erosion rate in
387 different soils using rainfall simulator. *Range Watershed Manag*. 67(2), 203-216. (In
388 Persian)

389 Keesstra, S., Pereira, P., Novara, A., Brevik, E.C., Azorin-Molina, C., Parras-Alcántara, L.,
390 Jordán, A., Cerdà, A. 2016. Effects of soil management techniques on soil water erosion
391 in apricot orchards. *Sci.Total Environ*. 551, 357-366.

392 Khadem, A., Raiesi, F. 2019. Response of soil alkaline phosphatase to biochar amendments:
393 Changes in kinetic and thermodynamic characteristics. *Geoderma*. 337, 44-54.

394 Kiani-Harchegani, M., Sadeghi, S. H., Asadi, H., 2016. Comparative analysis of the effects
395 of rainfall intensity and experimental plot slope on Raindrop Impact Induced Erosion
396 (RIIE). *J. Soil Water Res*. 46 (4), 631-640.

397 Kiani-Harchegani, M., Sadeghi, S. H., Singh, V. P., Asadi, H., Abedi, M. 2019. Effect of
398 rainfall intensity and slope on sediment particle size distribution during erosion using
399 partial eta squared. *Catena*. 176, 65-72.

400 Laird, D. A., Fleming, P., Davis, D. D., Horton, R., Wang, B., Karlen, D. L. 2010. Impact of
401 biochar amendments on the quality of a typical Midwestern agricultural soil. *Geoderma*.
402 158(3-4), 443-449.

403 Lentz, R.D., Sojka, R.E. 2009. Long-term polyacrylamide formulation effects on soil
404 erosion, water infiltration, and yields of furrow-irrigated crops. *Agron. J.* 101(2), 305-
405 314.

406 Liu, Z., Yao, Z., Huang, H., Wu, S., Liu, G. 2014. Land use and climate changes and their
407 impacts on runoff in the Yarlung Zangbo river basin, China. *Land Degrad. Dev.* 25(3),
408 203-215.

409 Maiti, S. K., Ahirwal, J. 2019. Ecological restoration of coal mine degraded lands: topsoil
410 management, pedogenesis, carbon sequestration, and Mine Pit Limnology. In
411 *Phytomanagement of Polluted Sites*. Chapter 3, 83-111. [https://doi.org/10.1016/B978-0-
412 12-813912-7.00003-X1](https://doi.org/10.1016/B978-0-12-813912-7.00003-X1).

413 Major, J., Lehmann, J., Rondon, M., Goodale, C. 2010. Fate of soil-applied black carbon:
414 downward migration, leaching and soil respiration. *Glob. Change Biol.* 16(4), 1366-
415 1379.

416 Nguyen, B.T., Lehmann, J., Hockaday, W.C., Joseph, S., Masiello, C.A. 2010. Temperature
417 sensitivity of black carbon decomposition and oxidation. *Environ. Sci. Tech.* 44(9),
418 3324-3331.

419 Omondi, M.O., Xia, X., Nahayo, A., Liu, X., Korai, P.K., Pan, G. 2016. Quantification of
420 biochar effects on soil hydrological properties using meta-analysis of literature data.
421 *Geoderma*. 274, 28-34.

422 Rumpel, C., Ba, A., Darboux, F., Chaplot, V., Planchon, O. 2009. Erosion budget and
423 process selectivity of black carbon at meter scale. *Geoderma*. 154(1-2), 131-137.

424 Sadeghi, S.H.R., Ghavimi Panah, M.H. Younesi, H. 2017a. Feasibility of reducing soil loss
425 using biochar produced from dairy factory waste. *Water Soil Conserv.* 24(4): 211-226.
426 (In Persian)

427 Sadeghi, S.H., Ghavimi Panah, M.H., Younesi, H., Kheirfam, H. 2018. Ameliorating some
428 quality properties of an erosion-prone soil using biochar produced from dairy
429 wastewater sludge. *Catena*. 171, 193-198.

430 Sadeghi, S.H.R., Gholami, L., Homae, M., Khaledi Darvishan, A. 2015. Reducing sediment
431 concentration and soil loss using organic and inorganic amendments at plot scale. *Solid*
432 *Earth*. 6(2), 445-455.

433 Sadeghi, S.H.R., Hazbavi, Z., Younesi, H.A. & Bahramifar, N. 2016a. Trade-off between
434 runoff and sediments from treated erosion plots and polyacrylamide and acrylamide
435 residues, *Catena*, 142: 213-220.

436 Sadeghi, S.H.R., Kiani-Harchegani, M., Asadi, H. 2017b. Variability of Particle Size
437 Distributions of upward/downward splashed materials in different rainfall intensities
438 and slopes. *Geoderma*. 290: 100-106.

439 Sadeghi, S. H., Hazbavi, Z., Kiani Harchegani, M. 2016b. Controllability of runoff and soil
440 loss from small plots treated by vinasse-produced biochar. *Sci. Total Environ.* 541, 483-
441 490.

442 Sarkar, D.J., Barman, M., Bera, T., De, M., Chatterjee, D. 2018. Agriculture: Polymers in
443 Crop Production Mulch and Fertilizer. *Encyclopedia of Polymer Applications*, First
444 Edition, 20 p. DOI: 10.1201/9781351019422-140000083

445 Sharifi Moghaddam, E., Sadeghi, S.H.R., Khaledi Darvishan, A., 2014. Small plot soil
446 hydrologic components as affected by application of Vinasse organic residue, *J. Soil*
447 *Water Res.* 45(4), 499-508. (In Persian)

448 Sojka, R.E., Entry, J.A., Orts, W.J., Morishita, D.W., Ross, C.W., Horne, D.J. 2005.
449 Synthetic-and bio-polymer use for runoff water quality management in irrigated
450 agriculture. *Water Sci. Tech.* 51(3-4), 107-115.

451 Sojka, R. E., Lentz, R. D., Ross, C. W., Trout, T. J., Bjorneberg, D. L., Aase, J. K. 1998.
452 Polyacrylamide effects on infiltration in irrigated agriculture. *J. Soil Water Conserv.*
453 53(4), 325-331.

454 Verheijen, F.G., Zhuravel, A., Silva, F.C., Amaro, A., Ben-Hur, M., Keizer, J.J. 2019. The
455 influence of biochar particle size and concentration on bulk density and maximum water
456 holding capacity of sandy vs. sandy loam soil in a column experiment. *Geoderma.* 347,
457 194-202.

458 Wang, C., Walter, M. T., Parlange, J.Y. 2013. Modeling simple experiments of biochar
459 erosion from soil. *J. Hydrol.* 499, 140-145.

460 Wang, L., Ma, B., Wu, F. 2017. Effects of wheat stubble on runoff, infiltration, and erosion
461 of farmland on the Loess Plateau, China, subjected to simulated rainfall. *Solid Earth.*
462 8(2), 281-290.

463 Yu, J., Lei, T.W., Shainberg, I., Mamedov, A.I., Levy, G.J. 2003. Infiltration and erosion in
464 soils treated with dry PAM and gypsum. *Soil Sci. Soc. Am. J.* 67(2), 630-636.

465 Yue, Y., Lin, Q., Xu, Y., Li, G., Zhao, X. 2017. Slow pyrolysis as a measure for rapidly
466 treating cow manure and the biochar characteristics. *J. Anal. Appl. Pyrol.* 124, 355-361.

467 Zhang, L., Jing, Y., Chen, G., Wang, X., Zhang, R. 2019. Improvement of physical and
468 hydraulic properties of desert soil with amendment of different biochars. *J. Soil. Sed.*
469 19(7), 2984-2996.

470 Zhao, G., Mu, X., Jiao, J., An, Z., Klik, A., Wang, F., Jiao, F., Yue, X., Gao, P., Sun, W.
471 2017. Evidence and causes of spatiotemporal changes in runoff and sediment yield on
472 the Chinese Loess Plateau. *Land Degrad. Dev.* 28(2), 579-590.

473 Zhang, F., Huang, C., Yang, M., Zhang, J., Shi, W. 2019. Rainfall simulation experiments
474 indicate that biochar addition enhances erosion of loess-derived soils. *Land Degrad.*
475 *Dev.* 30(18), 2272-2286.

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	pH	BD	Particle Size Distribution (%)		
			(%)	(ds/m)		(gr/cm ³)	Clay	Silt	Sand
Marl	51° 23'	36° 28'	1.63	0.21	7.68	1.12	42	43	15
Loess	55° 26'	37° 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 ₂ O	MgO	Al ₂ O ₃	SiO ₂	P ₂ O ₅	SO ₃	Cl	K ₂ O	CaO	TiO ₂	Cr	MnO	Fe ₂ O 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	
		PAM	0.26	0.09	0.13	0.00	0.00	0.27	0.26	
		BC	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	
		PAM	0.53	0.61	0.74	0.00	0.01	0.00	0.00	
		BC	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

Maraveh-Tapeh



Marzan-Abad



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 Miraven-Tapeh Sites, Iran

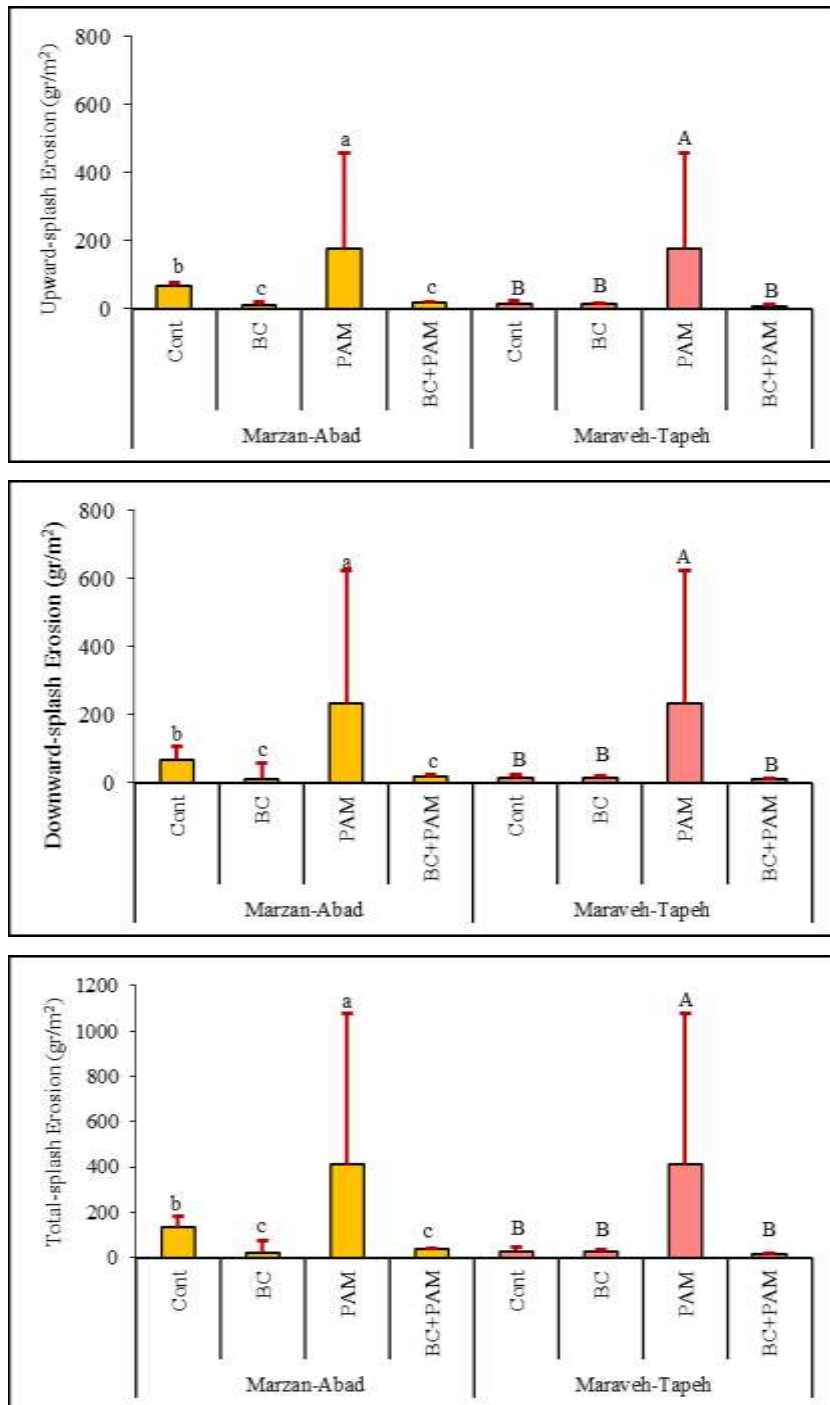


Fig. 3. Comparing pairwise of splash erosion variables by paired-samples t-test

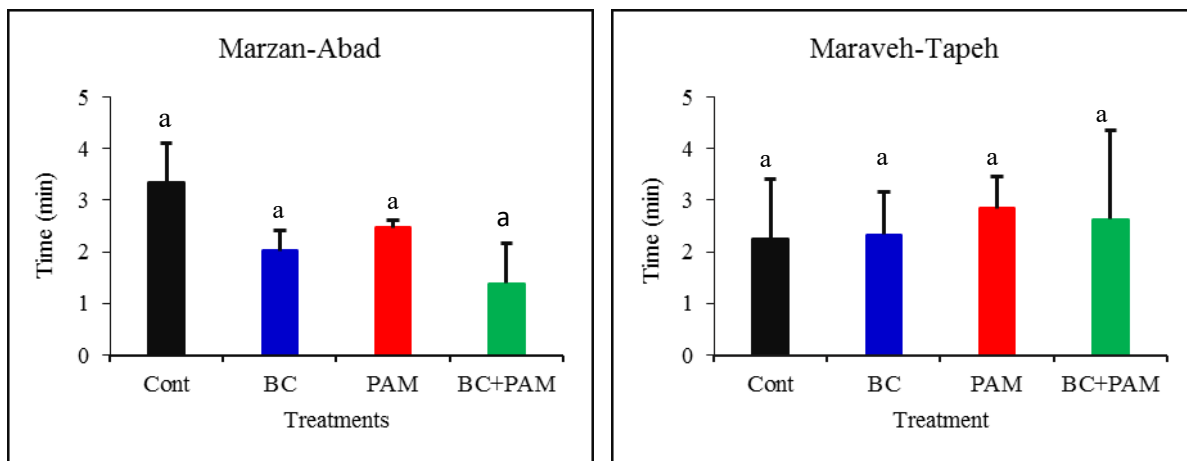


Fig. 4. Average and standard deviation of time to runoff generation from treated plots

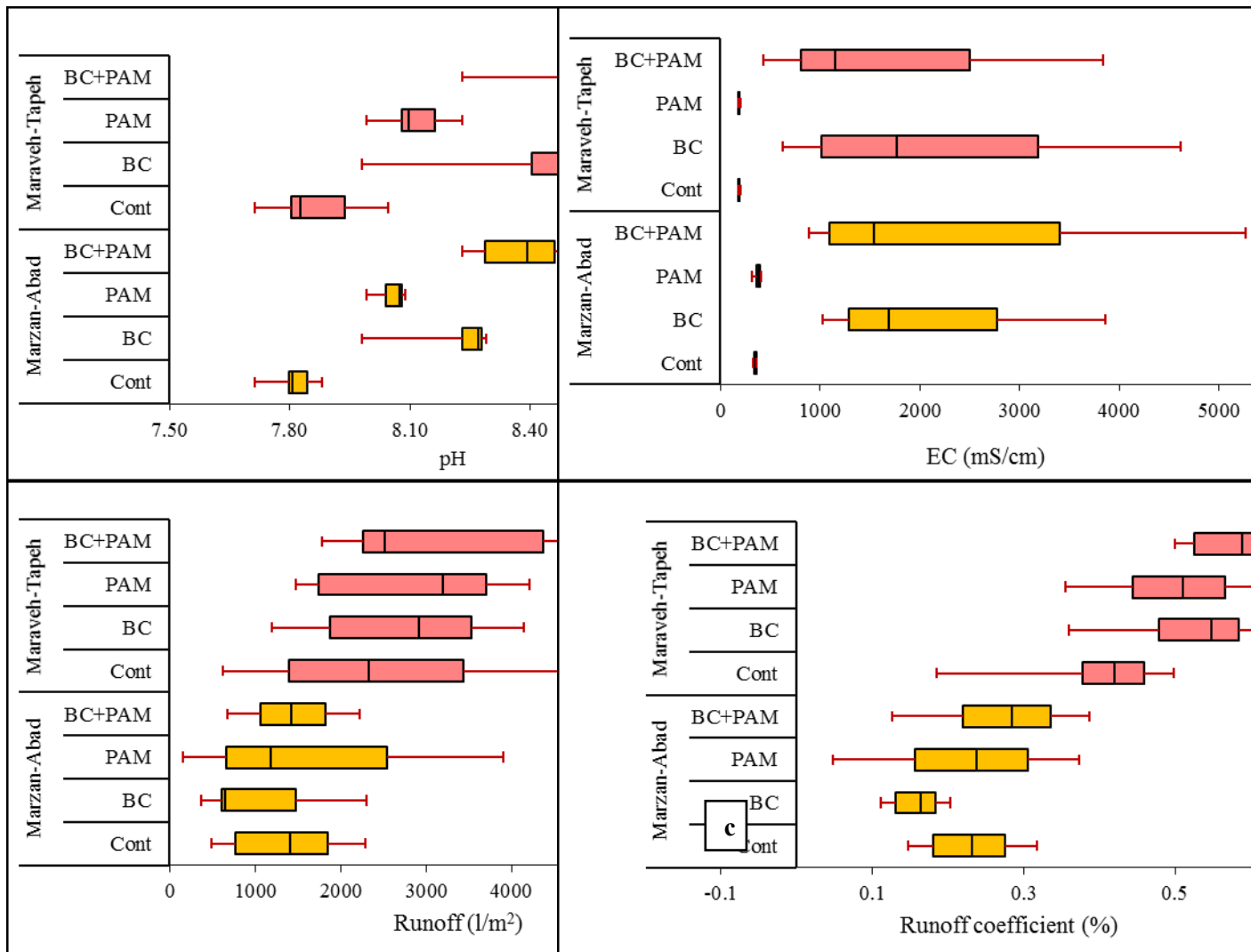


Fig. 5. Box plots of interrill erosion results. a: pH; b: EC; c: runoff; d: runoff coefficient, minimum, second quartile, median, third quartile and the maximum values

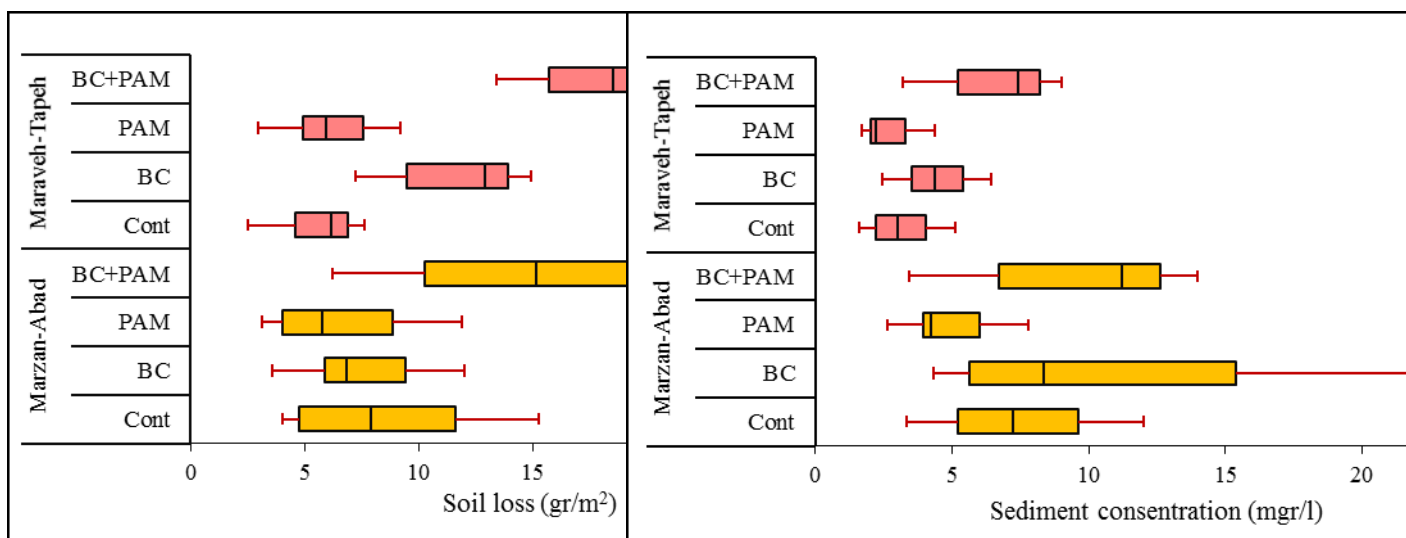


Fig. 6. Box plots of interrill erosion results. a: soil loss; b: sediment concentration, minimum, second quartile, median, third quartile and the maximum values

