

Università degli Studi Mediterranea di Reggio Calabria

Archivio Istituzionale dei prodotti della ricerca

Effects of length and application rate of rice straw mulch on surface runoff and soil loss under laboratory simulated rainfall

This is the peer reviewd version of the followng article:

Original

Effects of length and application rate of rice straw mulch on surface runoff and soil loss under laboratory simulated rainfall / Parhizkar, Misagh; Shabanpour, Mahmood; Lucas-Borja, Manuel Esteban; Zema, Demetrio Antonio; Li, Siyue; Tanaka, Nobuaki; Cerdà, Artemio. - In: INTERNATIONAL JOURNAL OF SEDIMENT RESEARCH. - ISSN 1001-6279. - 36:4(2021), pp. 468-478. [10.1016/j.ijsrc.2020.12.002]

Availability: This version is available at: https://hdl.handle.net/20.500.12318/77560 since: 2024-11-20T10:10:35Z

Published DOI: http://doi.org/10.1016/j.ijsrc.2020.12.002 The final published version is available online at:https://www.sciencedirect.

Terms of use:

The terms and conditions for the reuse of this version of the manuscript are specified in the publishing policy. For all terms of use and more information see the publisher's website

Publisher copyright

This item was downloaded from IRIS Università Mediterranea di Reggio Calabria (https://iris.unirc.it/) When citing, please refer to the published version.

1	This is the peer reviewed version of the following article:
2	
3	Parhizkar, M., Shabanpour, M., Lucas-Borja, M. E., Zema, D. A., Li, S., Tanaka, N.,
4	& Cerda, A. (2021). Effects of length and application rate of rice straw mulch on
5	surface runoff and soil loss under laboratory simulated rainfall. International
6	Journal of Sediment Research, 36(4), 468-478,
7	
8	which has been published in final doi
9	
10	10.1016/j.ijsrc.2020.12.002
11	
12	
13	(https://www.sciencedirect.com/science/article/pii/S100162792030127X)
14	
15	The terms and conditions for the reuse of this version of the manuscript are specified in
16	the publishing policy. For all terms of use and more information see the publisher's
17	website

18	Effects of length and application rate of rice straw mulch on surface runoff and
19	soil loss under laboratory simulated rainfall
20	
21	Misagh Parhizkar ^{a,*} , Mahmood Shabanpour ^a , Manuel Esteban Lucas-Borja ^b , Demetrio
22	Antonio Zema ^c , Siyue Li ^d , Nobuaki Tanaka ^e , Artemio Cerdà ^f
23	
24	^a Department of Soil Science, University of Guilan, 41635-1314 Rasht, Iran;
25	misagh.parhizkar@gmail.com; Shabanpour@guilan.ac.ir
26	^b Escuela Técnica Superior Ingenieros Agrónomos y Montes, Universidad de Castilla-
27	La Mancha, Campus Universitario, E-02071 Albacete, Spain;
28	manuelesteban.lucas@uclm.es
29	^c Department Agraria, Mediterranean University of Reggio Calabria, Loc. Feo di Vito,
30	I-89122 Reggio Calabria, Italy
31	^d Research Center for Ecohydrology, Chongqing Institute of Green and Intelligent
32	Technology, Chinese Academy of Sciences, Chongqing 400714, China;
33	syli2006@163.com
34	^e Ecohydrology Research Institute, The University of Tokyo Forests, Graduate School
35	of Agricultural and Life Sciences, The University of Tokyo, Seto, Japan;
36	tnk.nobu@gmail.com
37	^t Soil Erosion and Degradation Research Group (SEDER), Department of Geography,
38	University of Valencia, Blasco Ibáñez 28, 46001 Valencia, Spain;
39	artemio.cerda@uv.es
40	
41	* Corresponding author: <u>misagh.parhizkar@gmail.com</u>
42	
43	Abstract
44	
45	Forest land affected by deforestation yields high soil and water losses. Suitable
46	management practices need to be found that can reduce these losses and achieve
47	ecological and hydrological sustainability of the deforested areas. Mulch has been found
48	to be effective in reducing soil losses; straw mulch is easy to apply, contributes soil

49 organic matter, and is efficient since the day of application. However, the complex 50 effects of rice straw mulch with different application rates and lengths on surface runoff 51 and soil loss have not been clarified in depth. The current paper evaluates the efficiency 52 of rice straw mulch in reducing the hydrological response of a silty clay loam soil under 53 high intensity and low frequency rainfall events (tap water with total depth of 49 mm 54 and intensity of 98 mm/h) simulated in the laboratory. Surface runoff and soil loss at 55 three lengths of the straw (10, 30, and 200 mm) and three application rates (1, 2, and 3 56 Mg/ha) were measured in 50 (width) x 100 (length) x 10 (depth) cm plots with disturbed 57 soil samples (aggregate soil size < 4 mm) collected in a deforested area. Bare soil was 58 used as control experiment. Runoff volume and erosion were significantly (at p < 0.05) 59 lower in mulched soils compared to control plots. These reductions were ascribed to the 60 water absorption capacity of the rice straw and the protection cover of the mulch layer. 61 The minimum runoff was observed for a mulch layer of 3 Mg/ha of straw with a length 62 of 200 mm. The lowest soil losses were found with straw length of 10 mm. The models 63 developed predict runoff and erosion based on simple linear functions of mulch 64 application rate and length, and can be used for a suitable hydrological management of 65 soil. It is concluded that, thanks to rice straw mulch used as an organic soil conditioner, soil erosion and surface runoff are significantly (at p < 0.05) reduced, and the mulch 66 67 protection contributes to reduce the risk of soil degradation. Further research is, 68 however, needed to analyze the upscaling of the hydrological effects of mulching from 69 the plot to the hillslope scale.

70

Keywords: Straw mulch; Soil erosion; Mulch application rate; Mulch length; Rainfall
simulator.

73

74 **1. Introduction**

75

Soil erosion is one of the most serious problems impacting the global environment (Zhao et al., 2019). The impacts of soil erosion include land degradation, sedimentation, and nutrient transport, resulting in reduced crop production, decay of soil properties, and poor water quality (Pimentel et al., 1995). Inappropriate soil management practices and land use generally cause these impacts on soils (Lucas-Borja et al., 2019; Shabanpour et al., 2020), such as the increase of the erosion rates (Cherubin et al., 2017;
FAO, 2000).

Sustainable practices to control and mitigate soil erosion are essential worldwide and in particular in the environments that are more prone to erosion risks. For instance, deforestation removes the vegetal cover of woodlands, which usually protect the soil surface from sealing and soil detachment. In the deforested environments, soil is left bare and the lack of vegetation increases runoff and erosion rates.

88 A possible solution is the use of various types of inorganic mulch (e.g., gravel and other 89 soil particles) and organic mulch (e.g., crop residues) (Patil Shirish et al., 2013; Prats et 90 al., 2017). The term "mulch" refers to those materials - other than soil or living 91 vegetation - that function as a permanent or semi-permanent protective cover over the 92 soil surface (Jordán et al., 2011). Mulch protects the soil against raindrop impact, 93 reduces both the overland flow generation rates and velocity, allows improved 94 infiltration capacity and increases water intake and storage. These beneficial effects of 95 mulch noticeably reduce water and soil loss rates (Prosdocimi et al., 2016b).

96 The mulch types have variable levels of efficacy in controlling and mitigating soil 97 erosion and even in improving soil properties (de Lima et al., 2019). The increase in the 98 soil organic matter content can be particularly significant when vegetative residues are 99 used as mulch, as shown by García-Orenes et al. (2009) and Jordán et al. 100 (2010). Vegetal mulch types, such as leaf litter, cut-shrub barriers, wood-chips, crop 101 residues, and straw mulch (for instance, with rice or wheat) play, in general, an effective 102 influence on soil erosion rates (de Lima et al., 2019; Fernández et al., 2011; Jordan et 103 al., 2010). For example, in southern Spain Jordán et al. (2010) showed that a wheat 104 straw layer increases rain infiltration and delays runoff generation. In central China Liu 105 et al. (2012) showed that rice straw mulch significantly decreases the sediment yield. 106 Cerdà et al. (2016) showed the positive role of barley straw mulch to reduce the soil 107 erosion in persimmon plantations of eastern Spain. Prosdocimi et al. (2016a) found an 108 immediate reduction in soil losses in vineyards, when straw mulch was applied to soil. 109 However, some negative impacts of vegetal mulch on soil protection capacity have been 110 found in literature. For instance, compared to non-mulched soils, soil mulching with straw or needle casts can increase erosion under heavy rainfall (Rahma et al., 2017;
Robichaud et al., 2013a, 2013b).

Rice, along with corn and wheat, is a common staple crop. The total harvested area of 113 rice is 160 x 10^6 ha globally, with most of the 700 x 10^6 t world production grown in 114 Asia (640 x 10⁶ t) (IRRI, Africa Rice and CIAT, 2010; Hegde & Hegde, 2013). This 115 116 makes rice an important source of nutrition for Asia and, in general, worldwide. The 117 vegetal residues of rice cultivation (such as straw) are, therefore, abundant in several 118 countries and are becoming cheaper due to the decreasing demand for it as animal 119 fodder (Omidi-Mirzaee et al., 2017). Therefore, rice straw is a low-cost mulch substrate 120 to protect the soil and improve its fertility (Yadav et al., 2019). Rice straw can improve 121 the hydrological and physico-chemical properties of soil (Obour et al., 2019), thanks to 122 the incorporation into the soil of the ligno-cellulosic substances and the subsequent 123 degradation. Therefore, a practical use of rice straw mulch is beneficial for soil 124 conservation in deforested lands, which, as previously mentioned, are very susceptible 125 to land degradation of ecosystems once they lose the plant cover (Parhizkar et al., 126 2020). Deforestation due to clear-cutting for timber production induces unsustainable 127 runoff generation and soil erosion rates. Therefore, it is important to evaluate whether 128 soil protection with rice straw mulch can be effective in controlling forest hydrology, 129 and the deforested lands of this country may represent a suitable case study.

130 In general, the influence of straw mulch on soil hydrology and biochemistry is well 131 documented in many studies worldwide, also for rice straw (Abrantes et al., 2018; 132 Fakhari et al., 2018; Gholami et al., 2013; Prats et al., 2017). However, it is believed 133 there are several factors influencing the effectiveness of straw mulch, including rice 134 variety, straw age and length, as well as application methods, rates, and seasons 135 (Mannering & Meyer, 1963; Pearson et al., 2015). The large number of these 136 influencing factors requires a better comprehension of the effects of rice straw mulch on 137 soil erosion, considering different rice straw characteristics as well as rainfall and soil 138 conditions.

At present, few studies have been done considering the effects of rice straw mulch characteristics on runoff and soil loss (de Lima et al., 2019), particularly for a deforested region. Recently, the latter authors found in a laboratory study that mulch length affected soil loss more than runoff and that erosion decreased with the length of rice straw applied to soil. Despite this isolated study, the need remains for a better comprehension of the effects of rice straw mulch lengths and application rates on erosion of deforested soils at high rainfall intensity. Laboratory studies using rainfall simulators and soil plots under specific rain, soil, and vegetation factors are suggested in order to control the effects of each factor influencing the erosion process (Bombino et al., 2019).

To achieve these goals, the current study evaluates the hydrological effects (surface runoff and soil loss) of three lengths (10, 30, and 200 mm) and three application rates (1, 2, and 3 Mg/ha) of rice straw mulch on deforested soils using a rainfall simulator on soil plots. The soil was sampled in a deforested hillslope of the Saravan Forest Park (Northern Iran). It is hypothesized that the surface runoff and soil loss decrease with higher length and application rate of rice straw. Finally, regression models are proposed to predict runoff volume and soil loss from rice straw lengths and application rates.

The current research should give land managers insight about the most suitable soil application method of rice straw in deforested areas, where the soil erosion rates are high and the need for their reduction is compulsory, to avoid land degradation and other negative environmental impacts.

160

161 **2. Materials and methods**

162

163 2.1. Soil sampling, analysis, and characterisation

164

In Iran, deforestation is one of the most important anthropogenic factors of soil degradation and erosion, especially in the northern part of the country, where deforestation due to illegal logging is one of the major factors causing severe soil erosion (Bahrami et al., 2010; Emadodin, 2008). The soil for the laboratory experiment was selected from a deforested hillslope of the Saravan Forest Park, which is one of the oldest forestlands in Guilan province. The park is located in the south of Rasht city and the outlet coordinates are $37^{\circ}08'04''$ N and $49^{\circ}39'44''$ E (Fig. 1).



193 University. The soil samples were sieved through a 4-mm mesh, to remove the residual

194 gravel and vegetation, and then well mixed. Here, the soil was maintained under a 195 tarpaulin cover until the experiment date, when it was placed in the experimental plots 196 (see section 2.2).

The soil texture was silty clay loam (SDSD, 2017) and the aggregate stability in water, bulk density, and organic matter content of the soil were measured on representative sub-samples of the collected soil samples. Sand, silt, and clay contents of the soils were measured by sieving and hydrometers. Bulk density and aggregate stability were determined using the oven-drying and the wet-sieving methods, respectively. Soil organic matter was estimated using the potassium dichromate colorimetric method.

203

204 2.2. Soil characteristics

205

The mean clay, silt, and sand contents of the studied soil were $37.5 \pm 0.02\%$ (where the \pm is the standard deviation), $49.9 \pm 0.01\%$, and $12.6 \pm 0.01\%$, respectively. The bulk density was $1487 \pm 38 \text{ kg/m}^3$, while the soil aggregate stability, a main indicator of the ability of soil aggregates to resist degradation, was 0.21 ± 0.03 . The soil aggregate stability is lower compared to the reference values (0.70-075, Soil Quality Institute, 1998) and those measured by Parhizkar et al. (2020) in the same area (Guilan province, 0.25-0.66), who always reported a large variability of this parameter.

The sampled soil had a mean organic matter content of $1.22 \pm 0.05\%$, which is lower compared the contents (from 2.8 to 3.4%) measured in croplands and gardens in the same area (Guilan province) by Shabanpour et al. (2020), but similar to the values (from 1.28 to 1.87%) reported by Parhizkar et al. (2020) in woodland and forestland of the same park.

218

219 2.3. Plot description

220

The experimental plots consisted of timber planks (0.5-m wide, and 1-m long with 0.1m high sides) (Fig. 2a), placed on concrete blocks at a slope of 12% (Shoemaker, 2009; Singh Sidhu, 2015). The base of each plot was made of wood, which was not impervious to water. Small holes were drilled in the base, in order to facilitate water drainage and avoid unrealistic saturation of the soil. Before the experiments, the soil was air-dried until optimal water content, in order to maintain the stability of soil aggregates (Kukal & Sarkar, 2010). Then, the soil was placed in the plots and the surface was gently leveled by hand. A tarpaulin cover was put on the top, in order to avoid water evaporation from the plot. The plot was equipped with a horizontal collector placed at the downstream side, which conveyed the flows of water and sediment into a plastic tank through a PVC pipe.

232

233 2.4. Rainfall simulator

234

Runoff volume and soil loss were measured between June and July 2019, when rain was simulated on the plot using a hand-crafted simulator (Fig. 2b). The rainfall simulator consisted of two open rectangular boxes, whose bottom was made of a squared grid. The grid was equipped with 70 syringe needles with a diameter of 2.5 mm. The syringe needles, with an outer diameter of 0.7 mm and a length of 40 mm, were uniformly installed 3.1 m above the ground, to provide a rectangular 0.5 m x 1 m spray area. Dropformer rainfall simulators are widely used in the laboratory due to their accuracy.

242 The rainfall intensity was controlled by feeding the boxes with a flow of tap water 243 (drawn from the municipal aqueduct). This flow was kept constant throughout the 244 experiment via a pipe. Before starting the experiment, the rainfall simulator was 245 calibrated at a rainfall intensity of 98 ± 1.1 mm/h. The experiment was set to this very 246 high value, since extreme weather conditions result in the highest erosion rates in this 247 area. In more detail, the Rasht area has an annual mean rainfall depth of 1353 ± 279 mm 248 with historical (years 1951-2003) extremes of more than 2000 mm (Modarres, 2006; 249 Rahimzadeh et al., 2009). Considering that the climate is typically Mediterranean, 250 where few rainfall events (often two to five) lasting one to two hours account for half of 251 the total precipitation (Modarres, 2006), an intensity of 90-100 mm/h¹ is realistic, and 252 this may result in very erosive precipitations.

The walls of the laboratory prevented wind from disturbing the simulated rain. However, the plots were exposed to a moderate air stream that slightly varied the impact positions of the falling drops. The distribution uniformity of the rainfall intensity (Duke & Perry, 2006) was 83%, a value that can be considered as good in the classification of The Irrigation Association (2002).

259 2.5. Straw mulch characteristics

260



269



270

Fig. 2. The experimental plot (a); rainfall simulator (b); 10-mm length rice straw mulch
(c); 30-mm length rice straw mulch (d); 200 mm-length rice straw mulch (e), used for
the experiment.

- 274
- 275

A "water absorption capacity" of mulch was estimated on a sample of 100 g of each length (dry weight). This sample was placed on the soil of the plot and a rainfall intensity of 95 mm/h¹ was simulated for 30 min. The water absorption capacity (WAC, %) was:

$$WAC = \frac{w_w - w_d}{w_d} \times 100 \tag{1}$$

where w_w and w_d (g) are the sample weights after and before rainfall, respectively. The wet straw was immediately weighed, in order to limit the water and soil losses.

The estimated values of WAC for 10, 30, and 200-mm lengths of rice straw mulch were 30, 52, and 82%, respectively. Finally, surface cover of soil due to straw mulch application was measured by photographic method followed by image processing using common software.

287

288 2.6. The experimental design

289

290 Before the tests, the soil was saturated with tap water until ponding. Water was gently 291 and slowly poured on the plot surface to avoid runoff, splashing, and slaking. Then, the 292 soil was left to dry in the open air for 24 hours, to have a water content equal to the field 293 capacity. For each experiment, a 5-10 mm layer of was removed from the plot surface 294 and replaced by a new layer of dry soil, in order to ensure the same content of soil 295 particles. To avoid discontinuities between the old lower and fresh upper layers, the 296 upper surface of the lower layer was roughened using a manual ripper. After preparing 297 the soil with the desired straw mulch application rate and length and filling the rainfall 298 simulator with water, the experiment started, and the runoff volume and soil loss were 299 collected and measured.

300 An experiment with bare soil in the plot was considered as the "control". For the other 301 experimental runs, three application rates (1, 2, and 3 Mg/ha) and three lengths (10, 30, 302 and 200 mm) of rice straw mulch were tested (after de Lima et al., 2019). The weight of 303 rice straw mulch for 1, 2, and 3 Mg/ha application rates was 71, 142, and 213 g, 304 respectively. Each test was done in triplicate. Therefore, 30 experiments were done (3 application rates x 3 lengths x 3 replicates + 1 control x 3 replicates). Each experiment 305 306 was done for 30 min as the runoff discharge was stable in all the experiments by that 307 time (Zhao et al., 2019). After measuring the runoff volume, the collected water was 308 oven-dried at 80°C for 24 h, to measure the sediment weight. Moreover, the runoff 309 outlet time (the time when runoff water starts to drop in the collecting tanks) was 310 measured. This time gives information about the connectivity within the plot.

311 Hereinafter, each experiment will be indicated as "ARXX-LXXX", where "ARXX" is

312 related to the mulch application rate and "LXXX" to the mulch length. For instance,

313 AR1-L30 indicated the plots covered by 1 Mg/ha of straw with a length of 30 mm.

314

315 2.7. Statistical analysis

316

317 Using OO-normal plots, the normal distribution hypothesis of the samples was checked. 318 An ANalysis Of VAriance (ANOVA) was used to assess the statistical significance of 319 the differences in the runoff volume and soil loss (considered as the dependent 320 variables) among the different straw mulch application rates and lengths (independent 321 variables). Then, a Principal Component Analysis (PCA) was applied, in order to find 322 correlations (using Pearson's method) among runoff, soil loss, and mulch application 323 rate, length, and cover, as well as to identify the existence of meaningful derivative 324 variables (Principal Components, PCs) (Rodgers & Nicewander, 1988). The 325 correlations between runoff volume and soil loss (dependent variables), and mulch rate 326 and application rate (independent variables) were analyzed by linear multi-regression 327 equations. The simulations were evaluated for "goodness-of-fit" with the corresponding 328 observations. First, observed and simulated values of the water flow were visually 329 compared in scatterplots. Then, the following indicators, commonly used in the 330 hydrological literature (e.g., Legates & McCabe, 1999; Loague & Green, 1991; 331 Willmott, 1982), were applied for a quantitative evaluation: (i) the main statistics (i.e., 332 the maximum, minimum, mean, and standard deviation of both the observed and 333 simulated values); (ii) a set of summary and difference measures, such as the coefficient of determination (R^2) , coefficient of efficiency (E), and its modified form (E*, Willmott, 334 335 1982), and Root Mean Square Error (RMSE). In particular, E is more sensitive to 336 extreme values, while E* is better suited to significant over- or underprediction by 337 reducing the effect of squared terms. The related equations are reported in Zema et al. 338 (2012), Krause et al. (2005), Moriasi et al. (2007), and Van Liew & Garbrecht (2003). 339 To summarize:

- R² ranges from 0 (no agreement between model and data variance) to 1 (perfect agreement); values over 0.5 are acceptable (Santhi et al., 2001; Van Liew et al., 2003; Vieira et al., 2018);

343 - E (Nash & Sutcliffe, 1970) and E* are the most common measure of model
344 accuracy and range from -∞ to 1; the model accuracy is "good" if E and E* ≥ 0.75,
345 "satisfactory" if 0.36 ≤ E and E* ≤ 0.75, and "unsatisfactory" if E and E* ≤ 0.36
346 (Van Liew & Garbrecht, 2003);

- RMSE, which measures the standard deviation between observations and
predictions, should be as close as possible to zero (Fernandez et al., 2010); RMSE is
considered good if it predicted value is lower than 0.5 of the observed standard
deviation (Singh et al., 2004).

- All statistical analyses were done with the SPSS 17.0 and XLSTAT 9.0 software.
- 352

353 3. Results

354

355 *3.1. Analysis of the hydrological variables*

356

Table 1 lists the volumes and outlet times of runoff as well as the soil losses measured in the experimental plots under the various rice straw mulch lengths and application rates. The control plot produced the highest runoff volume $(13.2 \pm 0.23 \text{ mm})$, while the lowest value was observed in the AR3-L200 plots $(7.62 \pm 0.12 \text{ mm})$ (Table 1).

In general, for a given application rate of mulch, the runoff volume decreased and the outlet time increased when the straw length increased. The same trend (decreasing volume and increasing time) can be noticed, if the application rate of mulch increases at the same straw length (Table 1).

365 This is better explained in Fig. 3a, where it can be noticed that, if the runoff volumes are 366 averaged among the plots with the same mulch length, but different application rates, a 367 significant (p < 0.05) decreasing trend for runoff with increasing application rate is evident (11.31 \pm 0.10 mm in AR1, to 8.49 \pm 0.05 mm in AR3). Conversely, comparing 368 369 plots with the same mulch application rate, but different lengths, runoff decreased 370 (significantly for the finer straw lengths, p < 0.05) when the length increased (from 371 10.67 ± 0.12 mm in L10 to 9.04 ± 0.06 in L200) (Fig. 3a). The lowest runoff outlet time 372 was found in the control plot (49 s) and the highest in AR3-L200 plots (122 s) (Table 373 1).

Table 1. Experimental conditions (mulch application rate and length), and surface
cover, runoff volume, runoff outlet time, and soil loss evaluated at the plot scale on a
deforested soil sampled from the Saravan Forest Park (northern Iran).

	Mulch characteristics					Soil
Plot	Application rate (Mg/ha)	Length (mm)	Surface cover (%)	Runoff volume (mm)	Runoff outlet time (s)	loss (Mg/ha)
BS	0 (bare soil)	-	-	13.20 ± 0.23	49	3.02 ± 0.26
AR1-L10		10	38.9 ± 2.1	12.20 ± 0.28	60	1.33 ± 0.10
AR1-L30	1	30	27.7 ± 1.1	11.52 ± 0.12	68	1.48 ± 0.16
AR1-L200		200	24.6 ± 1.2	10.21 ± 0.10	79	2.28 ± 0.20
AR2-L10		10	47.8 ± 5.0	10.39 ± 0.10	84	0.82 ± 0.01
AR2-L30	2	30	39.9 ± 2.6	9.66 ± 0.08	89	1.11 ± 0.02
AR2-L200		200	30.8 ± 1.3	9.29 ± 0.02	100	1.65 ± 0.12
AR3-L10		10	54.8 ± 3.2	9.42 ± 0.05	107	0.42 ± 0.04
AR3-L30	3	30	48.7 ± 3.8	8.44 ± 0.14	113	0.55 ± 0.02
AR3-L200		200	41.4 ± 4.1	7.62 ± 0.12	122	0.87 ± 0.02

379 Note: BS = bare soil; in the plot indications ("ARXX-LXXX"), "ARXX" is related to the mulch application rate, and

380 "LXXX" to the mulch length.





Fig. 3. Total runoff volume (a), soil loss (b), and surface cover (c) averaged among application rates and lengths of straw mulch applied to a deforested soil and evaluated at the plot scale on a deforested soil sampled from the Saravan Forest Park (northern Iran).

388 Note: Different lowercase and capital letters indicate significant differences among mulch sizes and doses 389 at p-level < 0.05; BS = bare soil; in the plot indications ("ARXX-LXXX"), "ARXX" is related to the mulch 390 application rate and "LXXX" to the mulch length. The vertical lines on the bars indicate the standard 391 deviations.

392

Soil erosion was maximum for the bare plot $(3.02 \pm 0.2 \text{ Mg/ha})$. The lowest erosion was measured in AR3-L10 plots $(0.42 \pm 0.04 \text{ Mg/ha})$ (Table 2). It is also interesting to note that a high soil loss $(2.28 \pm 0.20 \text{ Mg/ha})$ was detected in the deforested soil (plots AR1-L200) treated with 1 Mg/ha of 200-mm rice straw, but this value is lower by about 25% compared to the bare soil, showing how mulching with an unsuitable dose and length is still able to significantly reduce soil erosion.

399 As noticed for the runoff, for a given straw length, the soil loss decreased when the 400 mulch dose increased. Instead, and differently from what observed for runoff, erosion 401 increased if the application rate was kept constant, but the straw length was increased 402 (Table 1). These trends are evident observing Fig. 3b, which shows that, under the same 403 mulch length, soil loss significantly (p < 0.05) decreased with increasing mulch rate 404 (from 1.70 ± 0.05 Mg/ha in AR1 to 0.61 ± 0.01 Mg/ha in AR3). Conversely, as the 405 mulch length decreased under a constant application rate, soil loss increased (0.86 \pm 406 0.04 Mg/ha in L10 to 1.60 ± 0.09 Mg/ha in L300), but the differences were significant 407 (p < 0.05) only between BS and L10 on one side and L30 and L200 on the other side 408 (Fig. 3b).

409 Comparing the plots with straw mulch application, the lowest and the highest surface 410 cover were measured in AR1-L200 plots ($24.6 \pm 1.06\%$) and AR3-L10 ($54.8 \pm 3.2\%$), 411 respectively (Table 1). The variability of surface cover was the opposite of the soil 412 erosion trend among mulch length and application rate, as shown by Fig. 3c, in which 413 the values of surface cover are averaged among the different mulch application rates 414 and lengths. In other words, surface cover increased with the mulch application rate 415 (from $30.4 \pm 0.62\%$ in AR1 to $48.3 \pm 0.46\%$ in AR3) and decreased with its length (44.5 416 $\pm 0.53\%$ in L10 to $32.3 \pm 1.69\%$ in L200) under the same length or application rate, 417 respectively. The differences in surface cover were always significant (p < 0.05) at 418 different mulch application rates; instead, the length L30 was significantly (p < 0.05) 419 different from L10, but not from L200 (Table 1).

- 420
- 421 422

3.2. Analysis of relations between the hydrological variables and the mulch parameters

The analysis of Pearson's matrix shows a positive correlation between total runoff on one side, and soil loss (r = 0.66) and straw length (r = 0.91). Moreover, runoff was negatively correlated with surface cover (r = -0.65) as well as mulch application rate (r= -0.51). Soil loss also was negatively correlated surface cover (r = -0.95) and mulch application rate (r = -0.87), but not with mulch length (r = 0.16) (Table 2).

428

Table 2. Pearson's correlation matrix among the hydrological variables and mulch
characteristics in plots treated with three lengths and three application rates of rice straw
mulch applied to a deforested soil sampled from the Saravan Forest Park (northern
Iran).

433

Variables	Mulch application rate	Mulch length	Surface cover	Runoff volume	Soil loss
Mulch application rate	1	0.174	0.842	-0.909	-0.872
Mulch length		1	-0.099	-0.516	0.162
Surface cover			1	-0.649	-0.948
Runoff volume				1	0.663
Soil loss					1

434

Note: Values in bold are significant at p level < 0.05.

Two principal components (PCs) were identified using PCA, and explained together
97% of the total variance of the hydrological variables and straw mulch parameters
(69% for PC1 and 26% for PC2).

The mulch application rate and surface cover as well as runoff and soil loss had high (absolute value > 0.88) positive and negative loadings, respectively, on PC1, while only mulch length significantly (p < 0.05) influenced PC2 (loading over 0.97) (Fig. 4a). In other words, runoff and soil loss were associated with low values of the mulch application rate and surface cover (Fig. 4b).



444

Fig. 4. Loadings of the original hydrological variables and straw mulch characteristics (length, application rate, and surface cover) (PC₁ and PC₂) (a) and scores on the first two Principal Components provided by PCA applied to plots (b) with deforested soils sampled from the Saravan Forest Park (northern Iran).

451 452	Note: BS = bare soil; in the plot indications ("ARXX-LXXX"), "ARXX" is related to the mulch application rate and "LXXX" to the mulch length.										
453											
454	Plotting the hydrological variables and the associated mulch parameters on the two PCs,										
455	five well differentiated clusters were evident: a first cluster grouping the control plots										
456	(associated with low values of PC1), a second group with AR1-L200, AR2-L200 and										
457	AR3-L200 plots, associated with high values of PC2) and four other clusters with the										
458	remaining plots, characterized by intermediate values of PC1 and low values of PC2										
459	(Fig. 4b).										
460											
461	3.3. Modeling runoff volume and soil loss using mulch parameters										
462 463	Table 3 lists the coefficients of the equations estimating runoff volume and soil loss										
464	from mulch application rate and length.										
465											
466	Table 3. Coefficients of the multi-regression equations between runoff volume or soil										
467	loss and straw mulch parameters (application rate, [Mg/ha]), and length, [mm]) in plots										
468	treated with different lengths and application rates of straw mulch applied to a										
469	deforested soil sampled from the Saravan Forest Park (northern Iran).										
470											
	Model Soil										

Model	Dunoffuolumo	Soil		
parameter	Kunon volume	loss		
Intercept	13.275	2.506		
Mulch application rate	-1.429	-0.760		
Mulch length	-0.008	0.002		
Mulch application rate x length	0.001	0.001		

472 The proposed equations are the following:

$$RV = -1.429 MAR - 0.008 ML + 0.001 ML \cdot MAR + 13.275$$
(2)

475 where RV = surface runoff volume (mm), SL = soil loss (Mg/ha), MAR = mulch476 application rate (Mg/ha), and ML = mulch length (mm).

477

478 The explanatory capacity of these equations was very high for both the modeled 479 hydrological variables (R^2 equal to 0.96 for surface runoff and 0.87 for soil loss). The 480 predictions of both surface runoff and soil loss were very close to the line of perfect 481 agreement (Fig. 5).





Observed soil loss (Mg/ha)

485 Fig. 5. Scatterplots of runoff volume (a) or soil loss (b) observed and predicted using 486 the multiregression models based on rice straw mulch parameters (application rate and 487 length) in plots with a deforested soil sampled from the Saravan Forest Park (northern 488 Iran).

- 489
- 490

491 Not only are the statistics of the observed and predicted variables very close (maximum 492 difference of 33.5% for the maximum values of soil loss), but also the indexes gave 493 values exceeding the acceptance limits suggested by the literature (Santhi et al., 2001; 494 Singh et al., 2004; Van Liew et al., 2003; Vieira et al., 2018; Van Liew & Garbrecht, 495 2003). In more detail, E was good for runoff and soil loss (0.96 and 0.87, respectively), 496 while E^* was good for runoff (0.80) and satisfactory (0.65) for soil loss. The values of 497 RMSE were always lower than 50% of the observed standard deviations (Table 4). 498

499 Table 4. Values of the criteria adopted for evaluating the accuracy of equations (2) and 500 (3) to predict the soil loss and runoff volume from mulch parameters in plots treated 501 with different lengths and application rates of straw mulch applied to deforested soils 502 sampled from the Saravan Forest Park (northern Iran).

503

Hydrological variable		Statistic				Index			
		Mean	Min	Max	Std. Dev.	R ²	E	E*	RMSE
Runoff	Observed	10.2	7.5	13.4	1.7	0.96	0.96	0.80	0.33
volume	Predicted	10.2	7.7	13.3	1.6	0190	0120	0.00	0.00
Soil	Observed	1.35	0.39	3.29	0.78	0.87	0.87	0.65	0.28
loss	Predicted	1.35	0.26	2.51	0.73				

504

Note: Min = minimum; Max = maximum; Std. Dev. = Standard Deviation; R^2 = coefficient of determination; E and 505 E* = coefficients of efficiency of Nash and Sutcliffe (1970) in the original (E) and modified (E*) form; and RMSE = 506 root mean square error (expressed in mm for runoff volume and Mg/ha for soil loss). 507

508

509 4. Discussion

510

511 4.1. The influence of mulching conditions on runoff volume and soil loss

513 Previous studies have evaluated how much straw influences the hydrological response 514 of the soil under different experimental conditions (e.g., de Lima et al., 2019; Gholami 515 et al., 2013, 2014; Keesstra et al., 2019; Lucas-Borja et al., 2018; Sadeghi et al., 2015). 516 However, the research done in the field is highly affected by other factors, such as the 517 rainfall intensity, spatial variability of soil properties, plant cover, and soil moisture. In 518 the current study, the straw mulch cover has been isolated to assess its effect through 519 controlled experiments in the laboratory. Therefore, the effects of mulch application 520 rates and lengths on the variability of the soil loss and runoff volume can be directly 521 evaluated at the plot scale.

522 The presence of straw mulch reduced by 8% (plots AR1-L10) to 42% (plots AR3-L200) 523 the runoff volume and by 25% (plots AR1-L200) to 86% (plots AR3-L10) the soil 524 erosion rate. The lower runoff volumes in the straw-mulched experiments compared to 525 bare soil (control plots) are consistent with findings of several authors (e.g., Adams, 526 1966; ; Gholami et al., 2013; Liu et al., 2012). In every case, mulching soil with straw, 527 also with low application rates and coarse sizes, is beneficial for improving the 528 hydrological response of deforested soils, since the current study has demonstrated that 529 runoff decreases at least by 7-10% and soil erosion by 25% or much more. These 530 positive effects on soil hydrology support other hydrological and ecological advantages, 531 such as the increase in water capacity retention and infiltrability as well as the 532 improvement of some important physico-chemical properties (Prosdocimi et al., 2016b), 533 which, however, go beyond the specific aims of the current paper. The current study 534 confirms the immediate impact of straw mulch to reduce the runoff generation capacity 535 and erosion of soils, such as Prosdocimi et al. (2016a) found in field experiments in 536 eastern Spain under vineyard cultivation. Surface runoff and soil loss decrease in 537 mulched soils due to three main factors. First, straw mulch has a capacity to absorb 538 water (from 30 to 82% of the precipitation, depending on the mulch length). This water 539 volume is retained by the straw, reducing the runoff volume. Second, the presence of 540 straw over the soil represents an obstacle against the overland flow, which decreases the

flow velocity. Third, the mulch layer protects the soil surface against raindrop impact,acting as a protection against the precipitation erosivity.

543 The significant capacity of straw to absorb water is beneficial, since the mulching layer 544 decreases the share of precipitation that turns into runoff, and, therefore, the detachment 545 capacity of the overland flow.

546 The decrease in the flow velocity due to the presence of straw over the soil is demonstrated by the reduction of the runoff outlet time (the lowest in the control plot 547 548 and the highest in the AR3-L200 plots), which increases upon mulch length and 549 application rate. This reduction is in accordance with findings of many authors (e.g., de 550 Lima et al., 2019; Keesstra et al., 2019; Yanosek et al., 2006), who concluded that straw 551 mulch is effective in delaying the runoff outlet time or runoff initiation. It is also 552 important to noe that, when the mulch application rate and length increase, the runoff 553 generation capacity significantly (p < 0.05) decreases and then the runoff outlet time is 554 delayed. Therefore, an application rate of 3 Mg/ha with a length of 200 mm is suggested 555 for the highest runoff reduction. These results are consistent with those of de Lima et al. 556 (2019), who found that 10-mm mulch yielded the highest runoff.

557 The protection effect of straw against the precipitation erosivity helps to reduce the 558 hydrological response of mulched soil, reducing erosion. The mulch layer protects the 559 soil surface against raindrop impact, which is one of processes determining erosion, in 560 addition to the transport capacity of runoff. In the current study, the lowest erosion was 561 detected for the AR3-L10 plots, that is, in the plots with the highest mulch application 562 rate (as for surface runoff), but the lower length. This lowest soil loss may be due to the 563 fact that these mulch conditions lead to the highest surface cover, and, thus, the 564 maximum soil protection. The reduced erosion with the lower surface runoff and the 565 higher soil protection due to mulch characteristics are also confirmed by the positive 566 correlations between total runoff, soil loss, and mulch application rate and the negative 567 relations with surface cover as well as straw length. In other words, runoff and soil loss 568 are associated with low values of the mulch application rate and surface cover.

569 The two smaller lengths of rice straw mulch (10 and 30 mm) present much more 570 complex pathways for runoff. These pathways should enhance deposition of suspended 571 sediments to be deposited when the flow rates decrease, while the overland flow was 572 not influenced. In the case of the 200-mm straw, the mulch seems to increase soil 573 erosion due to the straighter pathways. This is consistent with Rahma et al. (2017), who 574 reported that straw mulch can induce greater soil losses compared to non-mulched soils 575 under extreme rainfall conditions, such as those of the current study. As a matter of fact, 576 the longer straw length resulted in greater soil losses, because the straw layer provides 577 straighter pathways that can accelerate flow velocity and concentrate surface flow. This 578 effect should be considered with caution when the straw length must be identified for 579 mulching, and crushing the straw as fine as possible before land spreading for soil 580 protection should be done.

581 It is interesting to note that soil erosion is not directly dependent on mulch length (that 582 is, there is not a clear trend in soil loss reduction with straw size), but only to mulch 583 application rate, which influences surface cover. This is confirmed by PCA, which 584 shows direct associations among four of the five variables analyzed (runoff, soil loss, 585 surface cover, and mulch application rate) and the first PC (which can be considered a 586 synthetic measure of the soil hydrological response). The latter, in turn, is weakly 587 associated with straw length. Moreover, the evident clustering of experiments provided 588 by PCA clearly associate causes (length and application rate of straw mulch, and surface 589 cover) and effects (runoff and soil loss). The very high correlations between the 590 hydrological variables measured in the current study and the mulch application rate 591 indicate that the latter is the factor with the greatest influence on the hydrological 592 response of a deforested soil, while mulch length is more important for runoff reduction 593 than for erosion control. For this purpose, rice straw application is beneficial to increase 594 the surface cover, which is very effective to reduce soil loss, as shown by the high 595 correlation between these two variables. As regards in particular the experiments done 596 using rice straw as mulching material, de Lima et al. (2019) found in a sandy loam soil 597 that an increase in mulch length leads to a decrease in surface cover and then in soil 598 erosion rates.

The direct associations among the hydrological variables (runoff and soil loss), mulch parameters and soil cover found in the current study are consistent with numerous results (e.g., Donjadee & Tingsanchali, 2016; Won et al., 2012; Yanosek et al., 2006), which showed that, in soils with lower surface cover (generally with increasing mulch length), erosion expectedly increases.

605 4.2. Modeling runoff volume and soil loss using mulch parameters

606

607 The current study went further in the evaluation of runoff and soil loss after rainfall 608 simulation under different mulch conditions, proposing prediction models of these 609 hydrological variables. The multiple-regression analysis has indicated that surface 610 runoff and soil loss can be estimated from the mulch parameters using simple but 611 powerful equations with a linear mathematical form. The input data of these models are 612 simply the mulch application rates and lengths. Therefore, for a given precipitation 613 depth and intensity (as that used for these experiments), the models predict both the 614 runoff volume and soil loss. The values of the regression coefficients of the developed 615 equations show that the mulch application rate has much more influence than straw 616 length (the ratio between these parameters is equal to about 200 for runoff and 400 for 617 soil loss) and the interaction factor (that is, the product of mulch application rate by 618 length) has a very low influence on the predicted variables. This result is consistent with 619 the findings of Lal (1976), who demonstrated that the mulch application rate can be 620 assumed as predictor of surface runoff and soil loss, both being significantly (p < 0.05) 621 influenced by the mulch parameters. Clearly, the intercepts of the two equations are the 622 runoff and soil loss expected under bare soil conditions. The model coefficients of ML 623 and MAR are negative for runoff, since the latter decreases when the mulch application 624 rate increases. Instead, these coefficients are discordant (negative for MAR and positive 625 for ML) for soil loss, as erosion increases with coarser particles of straw and decreases 626 for higher doses of mulch.

627 The developed equations are related to the precipitation variables (rainfall depth and 628 intensity) that have been used under the simulated rainfall experiments. Therefore, for 629 broader applications of these prediction models, a set of equations must be developed 630 for different precipitation characteristics. For instance, having an intensity-duration-631 frequency curve, which gives the rainfall depth and intensity with a given return interval 632 (that is, with a desired probability), the values of the regression coefficients can be 633 calibrated. This helps land managers in soil conservation issues, which are pressing 634 particularly in deforested areas, as those of the current study.

635 The developed models could be applied by two approaches. First, the most suitable 636 application rate and length of mulch needed to keep the modeled hydrological variables 637 under a tolerance limit, which, for soil loss, is in the range $3 - 11.2 \text{ Mg/ha} \cdot \text{yr}$ (Bazzoffi, 638 2009; Wischmeier & Smith, 1978). Setting up, for instance, this tolerance limit, the 639 prediction model gives the application rate and length of rice straw mulch, which have 640 to be applied to the soil. Second, these models can be used in combination with other 641 erosion prediction tools, such as the well-known Universal Soil Loss Equation (USLE, 642 Wischmeier, 1973). For instance, Eq. 3 can be used to evaluate the effect of the soil 643 management (mathematically modeled by the USLE C-factor) on the annual soil loss, 644 using experimental plots with the same geomorphological and climatic characteristics, 645 but different application rates and length of rice straw mulch. The current modeling 646 approach should go further with comparison of different straws (such as oat, barley, 647 wheat) and under different slope and soil conditions.

648 In view of transferring the results of the current study to common soil conservation 649 practice, some issues should be taken into account, such as the upscaling effects of the 650 mulch efficacy when increasing the plot length to the hillslope scale. For instance, 651 higher erosion rates can be observed on longer slopes, due to concentration of overland 652 flow with increased sediment transport capacity (Rahma et al., 2017), while Prats et al. 653 (2016), although working on soils deforested by fire, showed that smaller plots can 654 overestimate runoff and erosion when compared to a hillslope scale. Another important 655 issue that is likely to affect land management using straw mulch may be the risk of 656 mulch failure over long hillslopes due to the removal effect of runoff. This risk could be 657 evaluated by applying a modeling approach helping to identify the maximum length of 658 slope that can be effectively protected by mulch without increased runoff and erosion 659 rates.

661 **5. Conclusions**

662

663 Under simulated rainfall on a deforested soil treated with rice straw mulch with 664 different application rates and lengths, runoff and soil loss in mulched soils were significantly (p < 0.05) lower than the corresponding variables observed for bare soil. 665 666 The lowest runoff was observed for a mulch layer of 3 Mg/ha of straw with length of 667 200 mm. The lowest soil loss was found with the same application rates but with 10 mm 668 length. These outcomes confirm one of the working hypotheses that higher application 669 rates of rice straw generate less runoff and soil erosion, but reject, at least for the soil 670 loss, the other hypothesis that to reduce the soil loss the length of rice straw must be 671 long. The multiple-regression equations, developed to predict runoff and erosion as a 672 function of mulch application rate and length, show very good accuracy and can be used 673 as prediction models for identifying the most suitable mulch parameters for effective 674 soil protection. 675

Acknowledgments: The authors thank the Faculty of Agricultural Sciences, University
of Guilan for their support and experimental assistance and two anonymous Reviewers,
whose suggestions really helped to improve the paper.

679

680 **References**

681

Abrantes, J. R. C. B., Prats, S. A., Keizer, J. J., & de Lima, J. L. M. P. (2018).
Effectiveness of the application of rice straw mulching strips in reducing runoff and
soil loss: Laboratory soil flume experiments under simulated rainfall. *Soil & Tillage Research, 180*, 238–249.

- Adams, J. E. (1966). Influence of mulches on runoff, erosion and soil moisture
 depletion. *Soil Science Society of America Journal*, 30(1), 110–114.
- Bahrami, A., Emadodin, I., Ranjbar Atashi, M., & Bork, H. R. (2010). Land-use change
 and soil degradation: A case study, North of Iran. *Agriculture and Biology Journal of North America*, 4, 600–605.
- Bazzoffi, P. (2009). Soil erosion tolerance and water runoff control: Minimum
 environmental standards. *Regional Environmental Change*, *9*,169-79.

- Bombino, G., Denisi, P., Gómez, J. A., & Zema, D. A. (2019). Water infiltration and
 surface runoff in steep clayey soils of olive groves under different management
 practices. *Water*, 11(2), 240.
- 696 Cerdà, A., González-Pelayo, Ó., Giménez-Morera, A., Jordán, A., Pereira, P., Novara,
 697 A., Brevik, E. C., Prosdocimi, M., Mahmoodabadi, M., Keesstra, S., Orenes, F. G.,
- 698 & Ritsema, C. J. (2016). Use of barley straw residues to avoid high erosion and
- 699 runoff rates on persimmon plantations in Eastern Spain under low frequency–high
- magnitude simulated rainfall events. *Soil Research*, *54*(2), 154-165.
- Cherubin, M. R., Tormena, C. A., & Karlen, D. L. (2017). Soil quality evaluation using
 the soil management assessment framework (SMAF) in brazilian oxisols with
 contrasting texture. *Revista Brasileira de Ciência do Solo*, *41*, 1806–9657.
- de Lima, J. L. M. P., Santos, L., Mujtaba, B., & de Lima, M. I. P. (2019). Laboratory
 assessment of the influence of rice straw mulch size on soil loss. Advances. *Geosciences*, 48, 11–18.
- Donjadee, S., & Tingsanchali, T. (2016). Soil and water conservation on steep slopes by
 mulching using rice straw and vetiver grass clippings. *Agriculture and Natural Resources*, 50, 75-79.
- Duke, M., & Perry, C. (2006). Uniformity testing of variable-rate center pivot irrigation
 control systems. *Precision Agriculture*, 7(3), 205-218.
- 712 Emadodin, I. (2008). Human-induced soil degradation in Iran. In: *Ecosystem Services*713 *Workshop*; Salzau Castle: Kiel, Germany.
- Fakhari, M. A., Lotfalian, M., <u>Hosseini</u>, S. A., & Khaledi Darvishan, A. (2018). Effect
 of rice straw and wood chips on soil erosion and seedling growth on the fill slope of
- forest roads. *Quarterly Journal of Environmental Erosion Research*, 8, 104–118.
- 717 Fernández, C., Vega, J. A., Jiménez, E., & Fonturbel, T. (2011). Effectiveness of three
- post-fire treatments at reducing soil erosion in Galicia (NW Spain). *International Journal of Wildland Fire, 20*, 104–114.
- Fernández, C., Vega, J.A., Vieira, D.C.S. (2010). Assessing soil erosion after fire and
 rehabilitation treatments in NW Spain: performance of RUSLE and revised
 Morgan–Morgan–Finney models. *Land degradation & development, 21*(1), 58-67.

- Food and Agriculture Organization of the United Nations (FAO). (2000). *Manual on Integrated Soil Management and Conservation Practices* (FAO Land and Water
 Bulletin). Rome, Italy: Food and Agriculture Organization of the United Nations.
- García-Orenes, F., Cerdà, A., Mataix-Solera, J., Guerrero, C., Bodí, M. B., Arcenegui,
 V., Zornoza, R., & Sempere, J. G. (2009). Effects of agricultural management on
- surface soil properties and soil water losses in eastern Spain. Soil Tillage Research,
 106, 117-123.
- <u>Gholami</u>, L., <u>Banasik</u>, K., <u>Sadeghi</u>, S. H., Khaledi Darvishan, A., & <u>Hejduk</u>, L. (2014).
 Effectiveness of straw mulch on infiltration, splash erosion, runoff and sediment in
 laboratory conditions. *Journal of Water and Land Development*, 22, 51–60.
- Gholami, L., Sadeghi, S. H. R., & Homaee, M. (2013). Straw mulching effect on splash
 erosion, runoff and sediment yield from eroded plots. *Soil Science Society of America Journal*, 77, 268–278.
- Hegde, S., & Hegde, V. (2013). Assessment of global rice production and export
 opportunity for economic development in Ethiopia. *International Journal of Science and Research*, 2, 257-260.
- 739 International Rice Research Institute (IRRI), Africa Rice, & The International Center
 740 for Tropical Agriculture (CIAT). (2010). *Global Rice Science Partnership (GRiSP)*.
 741 November 2010.
- 742 Islamic Republic of Iran Meteorological Organization (IRIMO). 2016. Annual Rainfall
 743 Report. Available online: www.irimo.ir (accessed on 20 September 2019).
- Jordán, A., Zavala, L. M., & Gil, J. (2010). Effects of mulching on soil physical
 properties and runoff under semi-arid conditions in southern Spain, *Catena*, *81*, 77–
 85.
- Jordán, A., Zavala, L. M., & Muñoz-Rojas, M. (2011). Mulching, effects on soil
 physical properties. In: J. Gliński, J. Horabik, J. Lipiec (Eds) *Encyclopedia of Agrophysics*. Encyclopedia of Earth Sciences Series. Springer. Dordrecht; The
 Netherlands.
- Keesstra, S. D., Rodrigo-Comino, J., Novara, A., Giménez-Morera, A., Pulido, M., Di
 Prima, S., & Cerdà, A. (2019). Straw mulch as a sustainable solution to decrease
 runoff and erosion in glyphosate-treated clementine plantations in Eastern Spain.
 An assessment using rainfall simulation experiments. *Catena*, 174, 95–103.

- Kottek, M., Grieser, J., Beck, C., Rudolf, B., & Rubel, F. (2006). World Map of the
 Köppen-Geiger climate classification updated. *Meteorologische Zeitschrift*, 15,
 259–263.
- Krause, P., Boyle, D., & Báse, F. (2005). Comparison of different efficiency criteria for
 hydrological model assessment. *Advances in Geosciences*, *5*, 89–97.
- Kukal, S. S., & Sarkar, M. (2010). Splash erosion and infiltration in relation to
 mulching and polyviny alcohol application in semi-arid tropics. *Archives of Agronomy and Soil Science*, 56(6), 697–705.
- Lal, R. (1976). Soil erosion on alfisols in Western Nigeria II: Effect of mulch rates. *Geoderma*, 16, 377–387.
- Legates, D. R., & McCabe, G. J. Jr, (1999). Evaluating the use of "goodness-of-fit"
 measures in hydrologic and hydroclimatic model validation. *Water Resources Research. 35* (1), 233–241.
- Liu, Y., Tao, Y., Wan, K. Y., Zhang, G. S., Liu, D. B., Xiong, G. Y., & Chenearch, F.
 (2012). Runoff and nutrient losses in citrus orchards on sloping land subjected to
 different surface mulching practices in the Danjiangkou Reservoir area of China. *Agricultural Water Management*, 110, 34-40.
- Loague, K., & Green, R. E. (1991). Statistical and graphical methods for evaluating
 solute transport models: Overview and application. *Journal of Contaminant Hydrology*. 7, 51–73.
- Lucas-Borja, M. E., Zema, D. A., Carrà, B. G., Cerdà, A., Plaza-Alvarez, P. A., Cózar,
 J. S., & de las Heras, J. (2018). Short-term changes in infiltration between straw
 mulched and non-mulched soils after wildfire in Mediterranean forestland
 ecosystems. *Ecological engineering*, *122*, 27–31.
- Lucas-Borja, M. E., Zema, D. A., Plaza-Álvarez, P. A., Zupanc, V., Baartman, J., Sagra,
 J., & de las Heras, J. (2019). Effects of different land uses (abandoned farmland,
 intensive agriculture and forestland) on soil hydrological properties in Southern
 Spain. *Water*, 11, 503.
- Mannering, J. V., & Meyer, L. D. (1963). The effects of various rates of surface mulch
 on infiltration and erosion. *Soil Science Society of America Journal*, 27, 84–86.
- Modarres, R. (2006). Regional precipitation climates of Iran. *Journal of Hydrology*(*New Zealand*), 45(1), 13-27.

- Moriasi, D. N., Arnold, J. G., Van Liew, M. W., Bingner, R. L., Harmel, R. D., &
 Veith, T. L. (2007). Model evaluation guidelines for systematic quantification of
 accuracy in watershed simulations. *Transactions of the ASABE*. 50, 885–900.
- Nash, J. E., & Sutcliffe, J. V. (1970). River flow forecasting through conceptual models
 part I-a discussion of principles. *Journal of Hydrology*, *10*, 282–290.
- Obour, P. B., Danso, E. O., Yakubu, A., Abenney-Mickson, S., Sabi, E. B., Darrah, Y.
 K., & Arthur, E. (2019). Water retention, air exchange and pore structure
 characteristics after three years of rice straw biochar application to an acrisol. *Soil Science Society of America Journal*, 83(6), 1664-1671.
- Omidi-Mirzaee, H., Ghasemi, E., Ghorbani, G. R., & Khorvash, M. (2017). Chewing
 activity, metabolic profile and performance of high-producing dairy cows fed
 conventional forages, wheat straw or rice straw. *South African Journal of Animal Science*, 47(3), 342-351.
- Parhizkar, M., Shabanpour, M., Khaledian, M., Cerdà, A., Rose, C. W., Asadi, H.,
 Lucas-Borja, M. E., & Zema, D. A. (2020). Assessing and modeling soil
 detachment capacity by overland flow in forest and woodland of northern Iran. *Forests*, 11 (1), 65.
- Patil Shirish, S., Kelkar Tushar, S., & Bhalerao Satish, A. (2013). Mulching: A soil and
 water conservation practice. *Research Journal of Agriculture and Forestry Sciences*, 1, 26–29.
- Pearson, B. J., Richard, C., & Beeson, J. R. (2015). Influence of mulch type and depth
 on stormwater runoff and leachate from runoff boxes containing simulated urban
 landscape soils. *Florida Scientist*, 78, 37–46.
- Pimentel, D., Harvey, C., Resosudarmo, P., Sinclair, K., Kurz, D., McNair, M., Crist,
 S., Shpritz, L., Fitton, L., Saffouri, R., & Blair, R. (1995). Environmental and
 economic costs of soil erosion and conservation benefits. *Science*, *267*, 1117-1123.
- 813 Prats, S. A., Wagenbrenner, J. W., Martins, M. A. S., Malvar, M. C., & Keizer, J. J.
- 814 (2016). Mid-term and scaling effects of forest residue mulching on post-fire runoff
 815 and soil erosion. *Science of the Total Environment*, *573*, 1242-1254.
- Prats, S. A., Abrantes, J. R., Crema, I. P., Keizer, J. J., & de Lima, J. L. M. P. (2017).
 Runoff and soil erosion mitigation with sieved forest residue mulch strips under
- 818 controlled laboratory conditions. *Forest Ecology and Management*, 396, 102–112.

- Prosdocimi, M., Jordán, A., Tarolli, P., Keesstra, S., Novara, A., & Cerdà, A. (2016a).
 The immediate effectiveness of barley straw mulch in reducing soil erodibility and
 surface runoff generation in Mediterranean vineyards. *Science of the Total Environment*, 547, 323-330.
- Prosdocimi, M., Tarolli, P., & Cerdà, A. (2016b). Mulching practices for reducing soil
 water erosion: A review. *Earth-Science Reviews*, *161*, 191-203.
- Rahimzadeh, F., Asgari, A., & Fattahi, E. (2009). Variability of extreme temperature
 and precipitation in Iran during recent decades. *International Journal of Climatology*, 29(3), 329-343.
- Rahma, A. E., Wang, W., Tang, Z., Lei, T., Warrington, D. N., & Zhao, J. (2017). Straw
 mulch can induce greater soil losses from loess slopes than no mulch under extreme
 rainfall conditions. *Agricultural and Forest Meteorology*, 232, 141-151.
- Robichaud, P. R., Lewis, S. A., Wagenbrenner, J. W., Ashmun, L. E., & Brown, R. E.
 (2013a). Postfire mulching for runoff and erosion mitigation. Part I: Effectiveness
 at reducing hillslope erosion rates. *Catena*, 105, 75–92.
- Robichaud, P. R., Wagenbrenner, J. W., Lewis, S. A., Ashmun, L. E., Brown, R. E., &
 Wohlgemuth, P. M. (2013b). Post-fire mulching for runoff and erosion mitigation.
 Part II: Effectiveness in reducing runoff and sediment yields from small
 catchments. *Catena*, 105, 93–111.
- Rodgers, J. L., & Nicewander, W. A. (1988). Thirteen ways to look at the correlation
 coefficient. *The American Statistician*, 42, 59–66.
- Sadeghi, S. H., Gholami, L., Sharifi, E., & Khaledi Darvishan, A. (2015). Scale effect
 on runoff and soil loss control using rice straw mulch under laboratory conditions. *Solid Earth*, 6, 1–8.
- Santhi, C., Arnold, J. G., Williams, J. R., Dugas, W. A., Srinivasan, R., & Hauck, L. M.
 (2001). Validation of the SWAT model on a large river basin with point and
 nonpoint sources. *Journal of American Water Resources Association*. 37 (5), 1169–
- 846 1188.
- Soil Science Division Staff (SDSD). (2017). Soil Survey Manual, C. Ditzler, K.
 Scheffe, & H. C. Monger, (Eds) U.S. Department of Agriculture. Handbook 18,
 Washington, DC, USA.

- 850 Shabanpour, M., Daneshyar, M., Parhizkar, M., Lucas-Borja, M. E., & Zema, D. A.
- 851 (2020). Influence of crops on soil properties in agricultural lands of northern Iran.
 852 Science of the Total Environment. 711, 134694.
- Shoemaker, A. L. (2009). Evaluation of anionic polyacrylamide as an erosion control *measure using intermediate-scale experimental procedures*. (Master's Thesis), Civil
 Engineering, Auburn University, Auburn, AL.
- Singh, J., Knapp, H. V., & Demissie, M. (2004). Hydrologic modeling of the Iroquois
 River watershed using HSPF and SWAT. Champaign, IL, U, S.: *Illinois State Water Survey Contract Report CR 2004-08*.
- 859 Singh Sidhu, R. (2015). Effectiveness of selected erosion control covers during
 860 vegetation establishment under simulated rainfall. (Master's Thesis), Biosystems
 861 Engineering, Auburn University, Auburn, AL.
- Soil Quality Institute. (1998). Soil quality test kit guide. Soil Quality Institute, Soil
 Science Division Staff, National Resources Conservation Service, U.S. Department
 of Agriculture.
- 865 The Irrigation Association. (2002). *Certified irrigation contractor workbook*. Falls
 866 Church, VA: The Irrigation Association Publications.
- Van Liew, M. W., Arnold, J. G., & Garbrecht, J. D. (2003). Hydrologic simulation on
 agricultural watersheds: Choosing between two models. *Transactions of the ASAE*.
 46(6), 1539-1551.
- Van Liew, M. W., & Garbrecht, J. (2003). Hydrologic simulation of the Little Washita
 River experimental watershed using SWAT. *Journal of the American Water Resources Association. 39*, 413-426.
- Vieira, D. C. S., Serpa, D., Nunes, J. P. C., Prats, S. A., Neves, R., & Keizer, J. J.
 (2018). Predicting the effectiveness of different mulching techniques in reducing
 post-fire runoff and erosion at plot scale with the RUSLE, MMF and PESERA
- 876 models. *Environmental Research*. *165*, 365-378.
- 877 Willmott, C. J. (1981). On the validation of models. *Physical Geography*. 2, 184-194.
- Wischmeier, W. H. (1973). Conservation tillage to control water erosion. *Proceedings, National Conference of Conservation Tillage*. (pp. 133-140), Soil Conservation
 Society of America, Ames, Iowa, U.S.

- 881 Wischmeier, W. H., & Smith, D. D. (1978). Predicting rainfall erosion losses: A guide
- to conservation planning. USDA Agriculture Handbook No. 537. Washington, DC:

883 U.S. Department of Agriculture.

- Won, C. H., Choi, Y. H., Shin, M. H., Lim, K. J., & Choi, J. D. (2012). Effects of rice
 straw mats on runoff and sediment discharge in a laboratory rainfall simulation. *Geoderma*, 189–190, 164-169.
- Yadav, S. K., Benbi, D. K., & Toor, A. S. (2019). Effect of long-term application of rice
 straw, farmyard manure and inorganic fertilizer on potassium dynamics in soil. *Archives of Agronomy and Soil Science*, 65(3), 374-384.
- Yanosek, K. A., Foltz, R. B., & Dooley, J. H. (2006). Performance assessment of wood
 strand erosion control materials among varying slopes, soil textures and cover
 amounts. *Journal of Soil and Water Conservation*, *61*, 45–51.
- Yousefian, M., Soltani, A., Dastan, S., & Ajamnoroozi, H. (2019). Documenting
 production process and the ranking factors causing yield gap in rice fields in Sari,
 Iran. *Iran Agricultural Research*, 38(1) 101-109.
- Zema, D. A., Bingner, R. L., Govers, G., Licciardello, F., Denisi, P., & Zimbone, S. M.
 (2012). Evaluation of runoff, peak flow and sediment yield for events simulated by
 the AnnAGNPS model in a Belgian agricultural watershed. *Land Degradation and Development*, 23(3), 205-215.
- 900 Zhao, B., Zhang, L., Xia, Z., Xu, W., Xia, L., Liang, Y., & Xia, D. (2019). Effects of
- 901 rainfall intensity and vegetation cover on erosion characteristics of a soil containing
 902 rock fragments slope. *Advances in Civil Engineering*, *4*, 1–14.