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## Effectiveness of straw mulch on infiltration, splash erosion, runoff and sediment in laboratory conditions

Leila GHOLAMI<sup>1)</sup> ABCDEF, Kazimierz BANASIK<sup>2)</sup> DEF,  
Seyed Hamidreza SADEGHI<sup>3)</sup> AD,  
Abdulvahed KHALEDI DARVISHAN<sup>3)</sup> ABCD, Leszek HEJDUK<sup>2)</sup> DE

<sup>1)</sup> Sari University of Agriculture and Natural Resources, Faculty of Natural Resources, P.O. Box 578, Sari, Iran.

<sup>2)</sup> Warsaw University of Life Sciences – SGGW, Faculty of Civil and Environmental Engineering, ul. Nowoursynowska 159, 02-787 Warsaw, Poland; tel. +48 22 593 52 80, e-mail: [kazimierz\\_banasik@sggw.pl](mailto:kazimierz_banasik@sggw.pl)

<sup>3)</sup> Tarbiat Modares University (TMU), Faculty of Natural Resources, P.O. Box 46414-356, Noor, Iran

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### Abstract

Mulches have extraordinary potential in reducing surface runoff, increasing infiltration of water into the soil and decreasing soil erosion. The straw mulches as a biological material, has the ability to be a significant physical barrier against the impact of raindrops and reduce the detachment of soil aggregates. The present study is an attempt to determine the efficiency of straw mulch as conservation treatment in changes in the splash erosion, time-to-runoff, runoff coefficient, infiltration coefficient, time-to-drainage, drainage coefficient, sediment concentration and soil loss. The laboratory experiments have been conducted for sandy-loam soil taken from deforested area, about 15 km of Warsaw west, Poland under lab conditions with simulated rainfall intensities of 60 and 120 mm·h<sup>-1</sup>, in 4 soil moistures of 12, 25, 33 and 40% and the slope of 9%. Compared with bare treatments, results of straw mulch application showed the significant conservation effects on splash erosion, runoff coefficient, sediment concentration and soil loss and significant enhancement effects on infiltration and drainage. The results of Spearman-Rho correlation showed the significant ( $p \leq 0.05$ ) correlation with  $r = -0.873, 0.873, 0.878$  and  $0.764$  between rainfall intensity and drainage coefficient, downstream splash, sediment concentration and soil loss and with  $r = -0.976, 0.927$  and  $-0.927$  between initial soil moisture content and time-to-runoff, runoff coefficient and infiltration coefficient, respectively.

**Key words:** mulch, organic amendment, soil and water conservation, soil moisture, splash erosion

### INTRODUCTION

Soil erosion due to water and wind results in the loss of valuable top soil and causes land degradation as well as environmental quality, water management and hydro-technical problems [BANASIK *et al.* 2012; BANASIK, MITCHELL 2008; BAK, DĄBKOWSKI 2013; BHATTARAI *et al.* 2011; BOUCHELKIA *et al.* 2014; KOWALCZYK, TWARDY 2012; MIODUSZEWSKI 2012;

MITCHELL *et al.* 2001]. There are different methods for soil conservation but biological methods in bare or degraded slopes need long time for establishment [ADEKALU *et al.* 2007; CERDA 1999; SMETS *et al.* 2008a; SPALEVIC *et al.* 2014]. Mulching the soil surface with a layer of plant residue is an effective method of conserving water and soil because it reduces surface runoff, increases infiltration of water into the soil and retard soil erosion [ADEKALU *et al.* 2007;

KARABOVA *et al.* 2012; MORGAN 2004; POESEN, LAVEE 1991; WU *et al.* 2012]. Organic mulches can be used to protect quickly, when plants cannot be established, the soil surface against the erosive forces of rain and runoff [GHOLAMI *et al.* 2013; SMETS *et al.* 2008b]. Straw mulch of the remaining plants has been used to reduce evaporation and to modify soil and soil aggregates [ADAMS 1966; KUKAL, SARKAR 2010]. Several studies have shown the importance of soil organic matter content in retard time of initial runoff [GHOLAMI *et al.* 2013; LEE *et al.* 2012], increasing infiltration (e.g. DULEY, KELLY [1939]; GILLEY *et al.* [1986]), runoff reduction and soil erosion control [AUERSWALD *et al.* 2003; GHOLAMI *et al.* 2013]. The straw mulches can absorb the impact of raindrops [ADEKALU *et al.* 2007; GHOLAMI *et al.* 2013; KUKAL, SARKAR 2010; LAL 1976] and reduce the detachment of soil aggregates [ADEKALU *et al.* 2007; GHOLAMI *et al.* 2013; KUKAL, SARKAR 2010].

Describing the relationship between rainfall, infiltration, and runoff through rainfall simulation in laboratorial conditions were conducted in previous researches [GRACE *et al.* 1998; WILSON *et al.* 2004] and field [MULUMBA, LAL 2008]. MANNERING and MEYER [1963] studied the effects of six rates of surface wheat mulch on infiltration and erosion. The mulching indicated that, it could reduce soil surface sealing as evidenced by higher infiltration rates and decrease rainfall and runoff energy for particle detachment and transport as evidenced by reduced soil content in the runoff. ADAMS [1966] studied influence of rice straw mulch on runoff, erosion and soil moisture depletion in 0.4 m<sup>2</sup> plots on a 4% slope in Texas. He observed that the straw mulch could reduce runoff and erosion. He also found that, this mulch significantly increased the infiltration of clay pan soils on sloping land. LAL [1976] used the rice straw with cover of 60 and 90% in the higher intensity for loamy-sand, sandy-loam and sandy-clay-loam soils. The amount of soil erosion reduced by 70, 86 and 81%, respectively, with 60%, while with cover of 90% mulch gave an average reduction of 94, 91 and 86%, respectively.

According to previous studies, the infiltration rate and the rapid movement of infiltrated water increased due to the use of straw mulch [ADAMS 1966]. The straw mulch also increased protection of the immediate soil surface due to absorption of water and the holding excess surface water of soil surface by mechanical impedance [ADAMS 1966].

According to GILLEY *et al.* [1986], sorghum mulch was more effective to reduce runoff coefficient compare with soybean and sorghum residue [SMETS *et al.* 2008a]. KHAN *et al.* [1988] investigated the influence of rice straw mulch on soil loss in the laboratory condition and showed that runoff and soil loss were significantly reduced with increasing mulch cover. They also showed that when the soil was wet, runoff was not affected by rainfall intensity and duration, slope of the plot and canopy cover variables except

for the mulch cover. LAL [1998] investigated that reductions in soil erosion by mulching were due both to decreased runoff and to lower sediment concentration in runoff. POULENARD *et al.* [2001] studied the infiltration, runoff and soil erosion under rainfall simulation for the *páramos* in Colombia effect of tillage and burning at plot scale. The results showed that the infiltration rate was very high and sediment loss was very low. Results indicated that land use change on *páramos* increased runoff flow and sediment losses from natural undisturbed *páramos* were very low. ADEKALU *et al.* [2007] also investigated *Pennisetum purpureum* mulching effect in three agricultural soils in Nigeria for two slopes. Runoff and soil loss decreased with mulch used and increased with slope. But in the highest cover, infiltration was increased and soil loss was reduced. MULUMBA and LAL [2008] studied mulching effects with wheat straw mulch at plot scale and the Waterman Farm of the Ohio State University, Columbus, on selected soil physical properties. The results demonstrated that mulch rates significantly increased available water capacity by 18–35% and soil moisture retention at low suctions from 29 to 70%. JORDÁN *et al.* [2010] checked the effect of mulching wheat straw on infiltration and runoff under semi-arid conditions in southern Spain. They found that the mulch layer contributed to increase the roughness and the interception of raindrops, delaying runoff generation, enhancing infiltration of rainwater and decreasing erosive responses during storms. Also they showed that, the delay of runoff flow enhanced the infiltration of rain water during storms. KUKAL and SARKAR [2010] also studied the effect of wheat straw mulch on splash erosion and infiltration rate in two soils under simulated rainfall in semi-arid tropics. The result showed that the effect of mulch in decreasing splash and increasing infiltration was more effective in sandy loam than in silt loam. PARLAK and ÖZASLAN PARLAK [2010] measured the splash erosion in vetch, barley and ryegrass cover crops for two slopes of 4 and 9% with three replications in Turkey. Splash erosion decreased with the increase in cover percentage and the decrease in the slope. GHAMRAMANI *et al.* [2011] studied effect of ground cover on splash and sheetwash erosion over a steep forested hillslope in the scale plot. They showed that soil splash transport occurred in hillslopes with sparse understory vegetation, the contribution of splash transport to total sediment movement depended on vegetation and the ground cover controlled the infiltration capacity and overland runoff depth by developing a litter layer and macropores in surface soil. LI *et al.* [2011] studied effects of bahia grass mulch on runoff and sediment yield of sloping red soil at 15 × 5 m plot scale in Southern China. They found that the straw mulch increased infiltration and reduced significantly runoff and sediment yield.

Annual runoff reduction ratio of 26.9% due to the use of straw mulch was reported by CHOI *et al.* [2012]. LEE *et al.* [2012] used from straw mat, PAM

(Soilfix G1, Ciba Chemical Co., Germany), rice chaff, sawdust, and gypsum for reduction of soil erosion under 10 and 20% slopes and 30 mm·h<sup>-1</sup> rainfall simulation in Korea. The average reduction of runoff under 10 and 20% slopes was 85.6% and 72.0%, respectively. The average reduction of sediment discharge from mulched plots was 99%. Also in this study infiltration increased and retard time of initial runoff. LIU *et al.* [2012] evaluated the effect of rice straw mulch for plot scale and 2 years in the Xiaofuling watershed in the Danjiangkou Reservoir area. The straw mulch treatment significantly decreased the runoff and the sediment yield from 18 up 22% and also infiltration increased. GHOLAMI *et al.* [2013] studied straw mulching effect on splash erosion, runoff and soil loss from eroded plots with simulated rainfall intensities of 30, 50, 70, and 90 mm·h<sup>-1</sup> and a slope of 30% and three replicates in Iran. The data from splash cups showed that, the maximum splash reduction occurring at a rainfall intensity of 70 mm·h<sup>-1</sup>. The results of the research also showed that the straw mulch had a significant effect in changing runoff and soil erosion characteristics at a confidence level of 99%. SHI *et al.* [2013] studied effects of mulch cover rates of 0, 15, 30, 50, 70, and 90% cover using simulated rainfall on runoff and erosion processes in 15% slope. The results showed that, mulch rates reduced the runoff coefficient values and soil loss when compared with the bare soil case. Also mulch rate of 90% had the most effect on processes.

Reviewing of literatures clearly verified the variability of hydrological responses and effectiveness of different mulches which emphasized further studies under different conditions. A few studies have been done to study the effects of straw mulch on infiltration, runoff, soil loss and especially splash erosion in different soils. The present study has been therefore conducted to study the efficiency of straw mulch on splash erosion, time-to-runoff, runoff coefficient, infiltration, drainage, sediment concentration and soil loss for a sandy-loam soil taken from deforested area, about 15 km of Warsaw west, Poland. The study has been done under lab conditions with simulated rainfall intensities of 60 and 120 mm·h<sup>-1</sup>, soil moisture of 12, 25, 33 and 40 volumetric percent and the slope of 9%.

## METHODS

### RAINFALL SIMULATOR

The experiments were checked the effect of barley straw mulch as conservation soil on bare soil. These were done by using simulated rainfall in intensities of 60 and 120 mm·h<sup>-1</sup> at 4 soil moistures of 12, 25, 33 and 40% on infiltration, time-to-runoff, runoff amount, splash erosion and sediment yield. The rainfall simulator lab consisted of a 10 L water reservoir and 3 nozzles (BEX: 3/8 S24W).

### SOIL CHARACTERISTICS AND PREPARATION

Soil was collected from the top layer of 0–50 cm [KUKAL, SARKAR 2010] about 15 km of Warsaw west, Poland. Then soil was carried to WULS-SGGW laboratory and initial experiments were performed on that. The soil texture was of sandy-loam (12.6% clay, 30.8% silt and 56.6% sand). Also the experimented soil of bulk density, pH, EC and organic matter were 1.67 g·cm<sup>-3</sup>, 6.73, 124 µmohs·cm<sup>-1</sup> and 2.76%, respectively. The KUKAL and SARKAR [2011] method was used as basic method for preparation of soil. At first collected soil were transferred to lab and air-dried up to optimum moisture content to maintain the relative stability of soil aggregates [KUKAL, SARKAR 2011], then pebbles and plant debris were removed through passing a 4 mm sieve [TANG *et al.* 2006] to increase the homogeneity of soil layers [AGASSI, BRADFORD 1999; DEFERSHA *et al.* 2011].

### EROSION PLOT

The laboratory works were conducted using one 2 m<sup>2</sup> erosion plot, the slope of 9% [PARLAK, ÖZASLAN PARLAK 2010] and also those carried out in the Warsaw University of Life Sciences (WULS), Poland. A splash cup proposed by MORGAN [1978] was used for measurement of splash erosion. A 2.5 cm layer of artificial pumice grain was covered by a layer of 2.5 cm sand with total thickness of 5 cm as a filter layer under the experimented soil for the creation of infiltration layer [DARBOUX *et al.* 2001; DEFERSHA *et al.* 2011; GHOLAMI *et al.* 2013]. A 7 cm-thick soil as top layer was compacted by PVC roller (filled with cement and sand) to achieve the bulk density of 1.67 g·cm<sup>-3</sup> almost equal to the originated soil under natural conditions [GHOLAMI *et al.* 2013; ROMKENS *et al.* 2001].

### BARLEY STRAW MULCH

To achieve the study purpose, the soil surface was covered by the air-dried barley straw [PARLAK, PARLAK 2010] with the surface coverage of about 90% [ADEKALU *et al.* 2007; LAL 1976; SHI *et al.* 2013] and dry weight of 350 g m<sup>-2</sup> (Phot. 1). The control plot was monitored under identical lab conditions on bare soils and just before applying the straw mulch.

### LABORATORIAL MEASUREMENTS

Each run was conducted using new soil and straw mulch [ADEKALU *et al.* 2007]. For performance of experiments, a plot had the same primary conditions and also soil surface cover, which controls the detachment and transport of sediment [GHAHRAMANI *et al.* 2011; GHOLAMI *et al.* 2013], infiltration [ADEKALU *et al.* 2007; CHOI *et al.* 2012; LEE *et al.* 2012] and the generation of runoff [GHAHRAMANI *et al.* 2011; GHOLAMI *et al.* 2013].



Phot. 1. Treated plot with barley straw mulch (left) and illustration from treated splash cup (right); source: own

### • Splash erosion

A splash cup [MORGAN 1978] was used to measure splash erosion (Fig. 1). The splashed soil particles have been collected separately from upward and downward segments of cup after each experiment and measured using decantation procedure and oven drying at 105°C for 24 h and weighed by means of high-precision scales [WALLING *et al.* 2001].

### • Runoff

Time-to-runoff was recorded as the time-to-arriving the first drop of runoff to plot outlet. The 2 minutes intervals [RUIZ-SINOGA *et al.* 2010] were then considered for collecting runoff volumes in plot outlet for all experiments.

### • Infiltration and drainage

The volume of the infiltrated water was calculated in 2 minutes intervals as the difference between the volume of water rained and the runoff volume [ADEKALU *et al.* 2007]. For the first interval, the difference between dry-weight and wet-weight of the straw mulch was also measured to increase the accuracy of calculations [ADEKALU *et al.* 2007; LI *et al.* 2011]. Time-to-drainage was recorded as the time-to-arriving the first drop of drained water to plot drainage outlet. All drained waters were then collected to determine the drainage coefficient.

### • Sediment concentration and soil loss

The sediment concentration in each runoff sample was measured using decantation procedure and oven drying at 105°C for 24 h and weighing by means of high-precision scales [WALLING *et al.* 2001]. The soil loss was finally calculated as the total dry-weighted sediment losses from plot in each experiment by adding the results of multiplying sediment concentration and runoff volume in all 2 minutes intervals.

## RESULTS AND DISCUSSION

### • Splash erosion

The results of splash erosion in all experiments are shown in Table 1. The interactions between soil moisture and rainfall intensity on splash erosion are shown in Figure 1.

Table 1. Splash erosion ( $\text{g}\cdot\text{m}^{-2}$ ) for all experiments

| Initial soil moisture % | Rainfall intensity $\text{mm h}^{-1}$ | Control | Treated | Conservation ratio % |
|-------------------------|---------------------------------------|---------|---------|----------------------|
| 12                      | 60                                    | 20.55   | 13.04   | -36.52               |
| 25                      |                                       | 23.70   | 17.39   | -26.63               |
| 33                      |                                       | 31.52   | 23.97   | -23.96               |
| 40                      |                                       | 35.67   | 25.48   | -28.57               |
| 12                      | 120                                   | 64.81   | 26.85   | -58.57               |
| 25                      |                                       | 74.61   | 32.89   | -55.92               |
| 33                      |                                       | 89.50   | 36.42   | -59.31               |
| 40                      |                                       | 92.99   | 49.68   | -46.58               |

Source: own study.

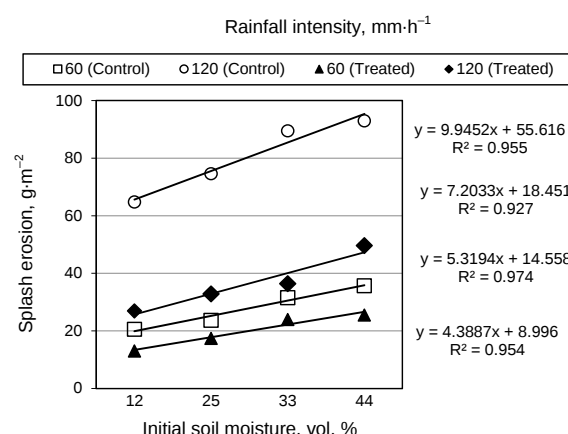


Fig. 1. Relationship between initial soil moisture and splash erosion in various rainfall intensities before (blank symbols) and after (solid symbols) straw mulching; source: own study

According to Table 1 and Figure 1, the minimum conservation ratio of straw mulch on splash erosion (23.96%) was in the soil moisture of 33% and the rainfall intensity of 60  $\text{mm}\cdot\text{h}^{-1}$  while the maximum conservation ratio of straw mulch was in the soil moisture of 33% and the rainfall intensity of 120  $\text{mm}\cdot\text{h}^{-1}$ . The results were in agreement with the previous studies (e.g. GHOLAMI *et al.* [2013]) which confirmed the conservation effects of straw mulch on splash erosion in various rainfall intensities and initial soil moistures and confirmed more conservation effect in higher rainfall intensities. Figure 1 showed the linear relationship ( $R^2 \geq 0.93$ ) between splash erosion and initial soil moisture in various rainfall intensities.

The straw mulch can intercept raindrop impact on soil surface and also maintained soil surface structure [ADAMS 1966; GHOLAMI *et al.* 2013; POESEN, LAVÉE 1991]. In agreement with KUKAL and SARKAR [2010], the results showed that the straw mulch reduces raindrop impacts on soil surface and then eliminates splash erosion. In other words, the results verified that the straw mulch protects soil aggregates from direct impact energy of raindrops and prevents soil detachment [GHOLAMI *et al.* 2013; JORDÁN *et al.* 2010; KUKAL, SARKAR 2010] and also increases the roughness of soil surface [GHOLAMI *et al.* 2013]. The conservative effects of straw mulch on soil splash was more significant at higher rainfall intensities than the lowers, because of physically protecting effect of straw mulch in soil surface against raindrop impacts specially in high rainfall intensities [ADAMS 1966]. The conservation ratio of straw mulch in splash erosion was decreased with increasing rainfall intensity and soil moisture, because of reducing the resistance of soil aggregates against the raindrops in near satu-

rated or saturated conditions. The amount of bare soil particles in contact with raindrops decreased with straw mulch and consequently, soil particles splash and transport were decreased [GHOLAMI *et al.* 2013; KHAN *et al.* 1988].

### • Runoff

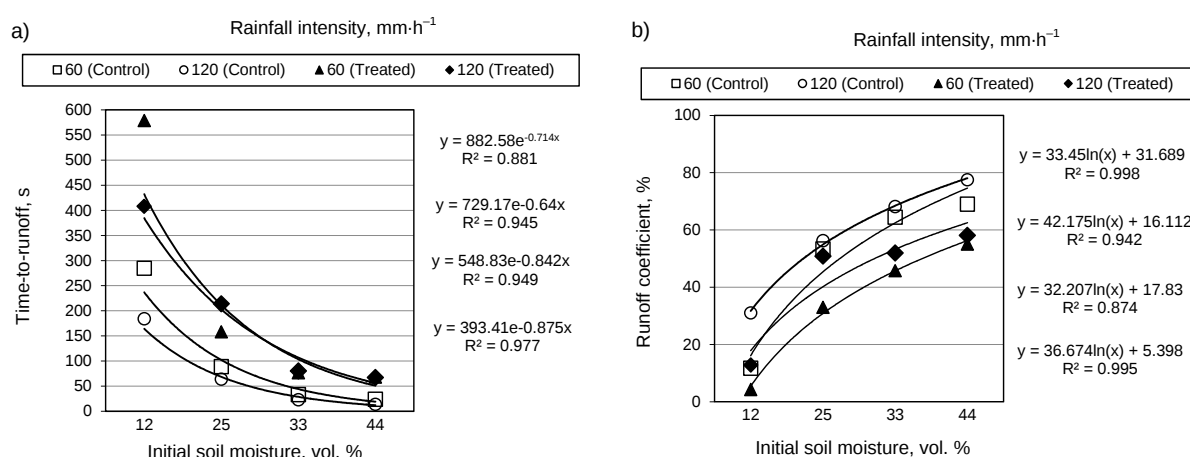
The time-to-runoff and runoff coefficient before and after straw mulching are shown in Table 2. The relationships between initial soil moisture and time-to-runoff are shown in Figure 2a and runoff coefficient in Figure 2b in various rainfall intensities before (blank symbols) and after (solid symbols) straw mulching.

The results of Table 2 showed that the time-to-runoff and the runoff coefficient increased and decreased, respectively after straw mulching, due to the ability of straw mulch pieces to store a significant amount of runoff and increase infiltration [CHOI *et al.* 2012; DULEY, KELLY 1939; GHOLAMI *et al.* 2013; LIU *et al.* 2012; POESEN, LAVÉE 1991].

**Table 2.** Time-to-runoff and runoff coefficient for all experiments

| Initial soil moisture % | Rainfall intensity mm·h <sup>-1</sup> | Time-to-runoff, s |         |                     | Runoff coefficient, % |         |                      |
|-------------------------|---------------------------------------|-------------------|---------|---------------------|-----------------------|---------|----------------------|
|                         |                                       | control           | treated | enhancement ratio % | control               | treated | conservation ratio % |
| 12                      | 60                                    | 285               | 579     | 103.16              | 11.68                 | 4.30    | -63.18               |
| 25                      |                                       | 89                | 158     | 77.53               | 53.39                 | 32.98   | -38.23               |
| 33                      |                                       | 33                | 77      | 133.33              | 64.42                 | 45.79   | -28.92               |
| 40                      |                                       | 24                | 68      | 183.33              | 68.99                 | 55.08   | -20.16               |
| 12                      | 120                                   | 184               | 408     | 121.74              | 31.05                 | 12.73   | -59.00               |
| 25                      |                                       | 64                | 214     | 234.38              | 56.26                 | 50.88   | -9.56                |
| 33                      |                                       | 23                | 80      | 247.83              | 68.19                 | 51.95   | -23.82               |
| 40                      |                                       | 14                | 67      | 378.57              | 77.56                 | 58.11   | -25.08               |

Source: own study.



**Fig. 2.** Relationship between initial soil moisture and time-to-runoff (a) and runoff coefficient (b) in various rainfall intensities before (blank symbols) and after (solid symbols) straw mulching; source: own study

Although the runoff depend on the straw mulching [JORDÁN *et al.* 2010], but the rate of changes were different in various rainfall intensities and initial soil moisture contents. The maximum enhancement ratio of time-to-runoff due to straw mulch in both rainfall

intensities of 60 and 120 mm·h<sup>-1</sup> was in the initial soil moisture of 40% (Tab. 2).

The results showed that in all studied rainfall intensities and initial soil moistures contents, the runoff coefficient reduced due to straw mulching. The maximum enhancement ratio of runoff coefficient due to

straw mulch in both rainfall intensities of 60 and 120 mm·h<sup>-1</sup> was in the initial soil moisture of 12%. It might be due to water absorbing effects of straws. The results were in the same line with those reported by DULEY and KELLY [1939], LAL [1976] and POESEN and LAVEE [1991] (Tab. 2).

The results presented in Figure 2 showed that the relationships between initial soil moisture and time-to-runoff (a) in all treatments were exponential while the relationships between initial soil moisture and runoff coefficient (b) in all treatments were logarithmic. A similar nonlinear relationships have been reported by SMETS *et al.* [2008a] for treated plots by different soil surface covers. GHOLAMI *et al.* [2013] also showed that the relationship between runoff coefficient and rainfall intensity in mulch treated plot is logarithmic.

According to the results, it seems that, in agreement with KHAN *et al.* [1988], in high levels of initial soil moisture contents, runoff was more affected by mulch cover.

### • Infiltration and drainage

The results of infiltration and drainage coefficient are showed in Table 3 and the interactions between initial soil moisture and rainfall intensity on infiltra-

tion and drainage coefficient in control and treated plots are showed in Figure 3.

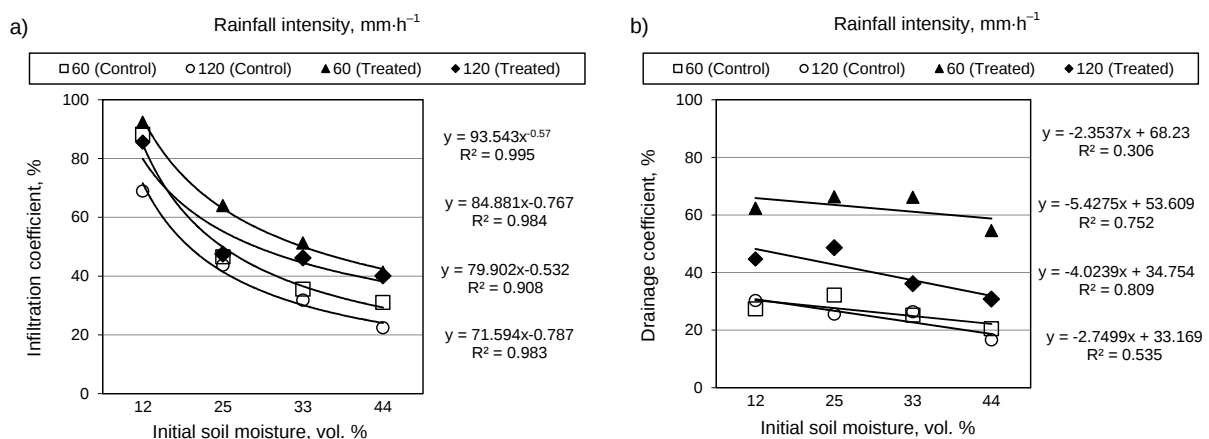
The results in Table 3 showed that the straw mulch increased the infiltration with the enhancement ratio from 4.59 to 78.61% in various treatments. Although the time-to-drainage reduced and drainage coefficient increased due to straw mulch effects on infiltration in all studied treatments, the enhancement ratio in drainage coefficient in the rainfall intensity of 60 mm·h<sup>-1</sup> was more than the 120 mm·h<sup>-1</sup>. Figure 3 shows the effects of initial soil moisture on infiltration coefficient, time-to-drainage and drainage coefficient before and after straw mulch in both rainfall intensities. The interaction of initial soil moisture and rainfall intensity on infiltration and drainage variables was poor (Fig. 3).

The maximum increasing effects of straw mulch on infiltration coefficient appeared in higher intensity and soil moisture. The maximum effects of straw mulch on infiltration in higher rainfall intensity and higher initial soil moisture content was in agreement with ADAMS [1966] and MULUMBA and LAL [2008], respectively. The results also verified a large enhancement in the drainage coefficient after treated treatments due to straw mulch.

**Table 3.** Infiltration coefficient, time-to-drainage and drainage coefficient for all experiments

| Initial soil moisture % | Rainfall intensity mm·h <sup>-1</sup> | Infiltration coefficient, % |         |                     | Time-to-drainage, s |         |                      | Drainage coefficient, % |         |                     |
|-------------------------|---------------------------------------|-----------------------------|---------|---------------------|---------------------|---------|----------------------|-------------------------|---------|---------------------|
|                         |                                       | control                     | treated | enhancement ratio % | control             | treated | conservation ratio % | control                 | treated | enhancement ratio % |
| 12                      | 60                                    | 88.32                       | 92.37   | 4.59                | 974                 | 631     | -35.22               | 27.32                   | 62.35   | 128.22              |
| 25                      |                                       | 46.61                       | 63.95   | 37.20               | 685                 | 275     | -59.85               | 32.18                   | 66.34   | 106.15              |
| 33                      |                                       | 35.58                       | 51.27   | 44.10               | 634                 | 203     | -67.98               | 25.18                   | 66.12   | 162.59              |
| 40                      |                                       | 31.01                       | 41.29   | 33.15               | 1090                | 367     | -66.33               | 20.49                   | 54.57   | 166.33              |
| 12                      | 120                                   | 68.95                       | 85.55   | 24.08               | 565                 | 418     | -26.02               | 30.26                   | 44.69   | 47.69               |
| 25                      |                                       | 43.74                       | 47.50   | 8.60                | 382                 | 291     | -23.82               | 25.58                   | 48.57   | 89.87               |
| 33                      |                                       | 31.81                       | 46.15   | 45.08               | 697                 | 274     | -60.69               | 26.34                   | 36.16   | 37.28               |
| 40                      |                                       | 22.44                       | 40.08   | 78.61               | 1393                | 291     | -79.11               | 16.60                   | 30.74   | 85.18               |

Source: own study.



**Fig. 3.** Relationships between initial soil moisture and infiltration coefficient (a) and drainage coefficient (b) in various rainfall intensities before (blank symbols) and after (solid symbols) straw mulching; source: own study

Straw mulch operated physical barrier against runoff moving and let it more time to infiltrate into the soil surface [JORDÁN *et al.* 2010].

#### • Sediment

The sediment concentration and soil loss amounts before and after straw mulch are shown in Table 4. Figure 4 shows the interaction between initial soil moisture and rainfall intensity on sediment concentration (a) and soil loss (b) before and after straw mulching.

The results of Table 4 and Figure 4 showed that soil loss reduced due to the conservation treatment

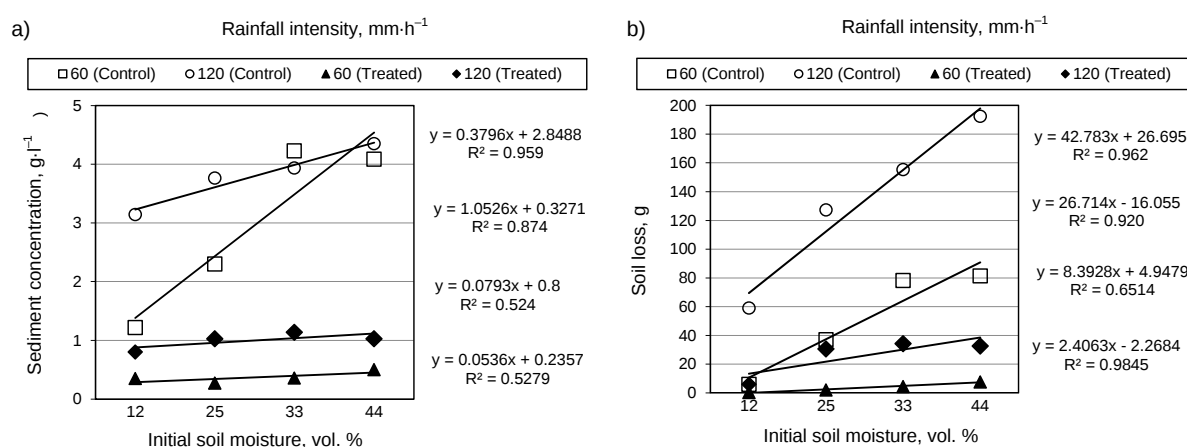
with straw mulch which is in agreement with previous researches vis. ADAMS [1966] and POESEN and LAVEE [1991]. The results indicates that there is no enough power runoff flow to detach or transport particles which is in agreement with MANNERING and MEYER [1963], LAL [1998] and GHOLAMI *et al.* [2013].

Figure 4 shows that the relationship between initial soil moisture and sediment concentration (a) and soil loss (b) were linear ( $R^2 \geq 0.52$  and  $0.65$ , respectively). The conservation ratios of straw mulch on sediment concentration were from 71.14 to 91.55%, while for soil losses were from 75.89 to 94.22%.

**Table 4.** Sediment concentration and soil loss for all experiments

| Soil moisture % | Rainfall intensity mm·h <sup>-1</sup> | Sediment concentration, g·l <sup>-1</sup> |         |                      | Soil loss, g |         |                      |
|-----------------|---------------------------------------|-------------------------------------------|---------|----------------------|--------------|---------|----------------------|
|                 |                                       | control                                   | treated | conservation ratio % | control      | treated | conservation ratio % |
| 12              | 60                                    | 1.22                                      | 0.35    | -71.31               | 6.04         | 0.44    | -92.72               |
| 25              |                                       | 2.30                                      | 0.27    | -88.26               | 37.23        | 2.31    | -93.80               |
| 33              |                                       | 4.23                                      | 0.36    | -91.49               | 78.25        | 4.53    | -94.21               |
| 40              |                                       | 4.09                                      | 0.50    | -87.78               | 81.41        | 7.72    | -90.52               |
| 12              | 120                                   | 3.14                                      | 0.80    | -74.52               | 59.26        | 5.92    | -90.01               |
| 25              |                                       | 3.76                                      | 1.03    | -72.61               | 127.40       | 30.72   | -75.89               |
| 33              |                                       | 3.94                                      | 1.14    | -71.07               | 155.42       | 34.42   | -77.85               |
| 40              |                                       | 4.35                                      | 1.03    | -76.32               | 192.53       | 32.66   | -83.04               |

Source: own study.



**Fig. 4.** Relationship between initial soil moisture and sediment concentration (a) and soil loss (b) in various rainfall intensities before (blank symbols) and after (solid symbols) straw mulching; source: own study

#### • Statistical analysis

Because of nonlinear relationships and non-normal data, the Spearman-Rho correlation coefficient was used to estimate correlations between the quantitative characteristics of splash, runoff, infiltration, sediment concentration and soil loss [SEEGER 2007]. Tables 5 and 6 shows the results of Spearman-Rho correlations and Paired Samples T-test, respectively.

The results of statistical analysis showed the significant ( $p \leq 0.05$ ) Spearman-Rho correlation coefficients of  $-0.873$ ,  $0.873$ ,  $0.878$  and  $0.764$  between rainfall intensity and drainage coefficient, downstream splash, sediment concentration and soil loss and also  $-0.976$ ,  $0.927$  and  $-0.927$  between initial soil moisture content and time-to-runoff, runoff coefficient and infiltration coefficient, respectively (Tab. 5). According to Table 6, there are significant differences between studied parameters due to straw mulching.

**Table 5.** Spearman-Rho coefficient between different studied factors

| Factors                                   | Rainfall intensity<br>mm·h <sup>-1</sup> | Initial soil moisture<br>% | Time-to-runoff<br>s | Runoff coefficient<br>% | Infiltration coefficient<br>% | Time-to-drainage<br>s | Drainage coefficient<br>% | Down-stream splash<br>g·m <sup>-2</sup> | Sediment concentration<br>g·l <sup>-1</sup> | Soil loss<br>g |
|-------------------------------------------|------------------------------------------|----------------------------|---------------------|-------------------------|-------------------------------|-----------------------|---------------------------|-----------------------------------------|---------------------------------------------|----------------|
| Rainfall intensity, mm·h <sup>-1</sup>    | 1                                        |                            |                     |                         |                               |                       |                           |                                         |                                             |                |
| Initial soil moisture, %                  | 0                                        | 1                          |                     |                         |                               |                       |                           |                                         |                                             |                |
| Time-to-runoff, s                         | 0                                        | -0.976**                   | 1                   |                         |                               |                       |                           |                                         |                                             |                |
| Runoff coefficient, %                     | 0.327                                    | 0.927**                    | -0.881**            | 1                       |                               |                       |                           |                                         |                                             |                |
| Infiltration coefficient, %               | -0.327                                   | -0.927**                   | 0.881**             | -1.000**                | 1                             |                       |                           |                                         |                                             |                |
| Time-to-drainage, s                       | 0                                        | -0.442                     | 0.491               | -0.347                  | 0.347                         | 1                     |                           |                                         |                                             |                |
| Drainage coefficient, %                   | -0.873**                                 | -0.293                     | 0.262               | -0.548                  | 0.548                         | -0.132                | 1                         |                                         |                                             |                |
| Splash, g·m <sup>-2</sup>                 | 0.873**                                  | 0.488                      | -0.476              | 0.738*                  | -0.738*                       | -0.216                | -0.905**                  | 1                                       |                                             |                |
| Sediment concentration, g·l <sup>-1</sup> | 0.878**                                  | 0.344                      | -0.275              | 0.611                   | -0.611                        | -0.157                | -0.898**                  | 0.934**                                 | 1                                           |                |
| Soil loss, g                              | 0.764*                                   | 0.586                      | -0.524              | .810*                   | -0.810*                       | -0.299                | -0.833*                   | 0.952**                                 | 0.946**                                     | 1              |

Source: own study.

**Table 6.** Results of Paired Samples *T*-test for studied factors before and after straw mulching

| Item                                      | 95% confidence interval of the difference |                    |                     |          |         |          |           |                 |
|-------------------------------------------|-------------------------------------------|--------------------|---------------------|----------|---------|----------|-----------|-----------------|
|                                           | mean                                      | standard deviation | standard error mean | lower    | upper   | <i>T</i> | <i>DF</i> | sig. (2-tailed) |
| Time-to-runoff, s                         | -116.875                                  | 96.010             | 33.945              | -197.141 | -36.609 | -3.443   | 7         | 0.011           |
| Runoff coefficient, %                     | 14.965                                    | 5.690              | 2.012               | 10.208   | 19.722  | 7.440    | 7         | 0.000           |
| Infiltration coefficient, %               | -12.463                                   | 5.768              | 2.039               | -17.285  | -7.640  | -6.111   | 7         | 0.000           |
| Time-to-drainage, s                       | 458.750                                   | 323.783            | 114.475             | 188.060  | 729.440 | 4.007    | 7         | 0.005           |
| Drainage coefficient, %                   | -25.699                                   | 11.840             | 4.186               | -35.597  | -15.800 | -6.139   | 7         | 0.000           |
| Splash, g·m <sup>-2</sup>                 | 25.954                                    | 19.796             | 6.999               | 9.404    | 42.503  | 3.708    | 7         | 0.008           |
| Sediment concentration, g·l <sup>-1</sup> | 2.694                                     | 0.962              | 0.340               | 1.889    | 3.498   | 7.917    | 7         | 0.000           |
| Soil loss, g                              | 77.353                                    | 48.756             | 17.238              | 36.592   | 118.113 | 4.487    | 7         | 0.003           |

Explanations: *T* – *t*-statistic value, *DF* – degrees of freedom, sig. – statistical significance (*p*-value).

Source: own study.

## CONCLUSIONS

The present study was conducted in plot scale and laboratory conditions to determine the efficiency of 350 g·m<sup>-2</sup> straw mulch in splash erosion, runoff, infiltration, sediment concentration and soil loss under simulated rainfall intensities of 60 and 120 mm·h<sup>-1</sup>, 4 soil moistures of 12, 25, 33 and 40% and the constant slope of 9%. A sandy-loam soil originated from about 15 km Warsaw west, Poland. The results verified the significant conservation abilities of straw mulch to reduce splash erosion, soil sealing, runoff, sediment concentration and soil loss and increase infiltration and drainage rates.

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**Leila GHOLAMI, Kazimierz BANASIK, Seyed Hamidreza SADEGHI, Abdulvahed KHALEDI DARVISHAN, Leszek HEJDUK**

**Wpływ pokrycia gleby ściółką na infiltrację, erozję rozbryzgową, spływ i rumowisko określony w warunkach laboratoryjnych**

**STRESZCZENIE**

**Słowa kluczowe:** *erozja rozbryzgową, materiał organiczny, ochrona wody i gleby, ochronne działanie ściółki, wilgotność gleby*

Ściółka ze słomy może znacząco zmniejszać spływ powierzchniowy, powodując zwiększenie wsiąkania wody oraz zmniejszając erozję gleby. Ściółka jako materiał organiczny jest barierą redukującą także energię kinetyczną kropli deszczu, zmniejszając odspojenie i ograniczając transport agregatów glebowych. W prezentowanych badaniach podjęto próbę określenia wpływu ściółki ze słomy, jako środka ochronnego, na erozję rozbryzgową, czas do wystąpienia spływu, współczynnik spływu, koncentrację rumowiska i ilość zmywanej gleby. Doświadczenia laboratoryjne przeprowadzono w odniesieniu do piaszczystej gliny, pobranej z miejsca wylesionego, około 15 km na zachód od Warszawy, w symulowanych warunkach natężenia deszczu wynoszącego 60 i 120 mm·h<sup>-1</sup>, wilgotności początkowej gleby 12, 25, 33 i 40% oraz spadku powierzchni 9%. Porównując te wyniki z wynikami doświadczenia przeprowadzonego w tych samych warunkach z glebą pozbawioną ściółki, wykazano znaczący wpływ redukujący w odniesieniu do erozji rozbryzgowej, współczynnika odpływu, koncentracji rumowiska i ilości zmywanej gleby oraz znaczący wpływ zwiększający wsiąkanie i odpływ podpowierzchniowy.