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Reducing sediment concentration and soil loss using organic and inorganic amendments at plot scale

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Abstract

Although various organic and inorganic mulches are used for soil conservation purposes, the comparative effectiveness of them on soil characteristics has not been comprehensively considered from different aspects. The present study is therefore an attempt to determine the efficiency of straw mulch, manure and TA-200 polyacrylamide with respective rates of 500, 300 and 50 g m^{-2}, respectively, in changing sediment concentration and soil loss. The experiments were conducted for sandy-loam soil (collected from the top 0–20 cm-layer) taken from a summer rangeland, the Alborz Mountains, Northern Iran under laboratory conditions with simulated rainfall intensities of 30, 50, 70 and 90 mm h^{-1} and the slope of 30 %. The results showed that the straw mulch decreased soil concentration at rate of 45.60 % compared to the control plots, and performed better than manure (8.98 % reduction) and PAM (4.74 % reduction). The results showed that the maximum reduction in sediment concentration and soil loss for all soil amendments occurred in the rainfall intensity of 90 mm h^{-1} with the rates of 58.69 and 63.24 %, for straw mulch, 14.65 and 13.14 %, for manure and 20.15 and 23.44 % for TA-200, respectively.

1 Introduction

Topsoil erosion is a global problem that causes environmental pollution of waterways and loss of soil fertility (Cerdà et al., 2013). Runoff transports organic materials and heavy metals and pollutes the water bodies. Erosion is therefore known as a serious problem in the world (Wolancho, 2010) especially in developing countries, because of land-use changes at large scales without considering land capabilities. Many methods of soil conservation with different performances and mechanisms have been developed in recent decades. For example, various natural, organic and inorganic mulches viz. crop residues, leaf litter, woodchips, bark chips, biological geotextiles, gravel and crushed stones (Gilley et al., 1986; Cerdà, 2001; Smets et al., 2008) have been

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applied for soil conservation. Mulches can increase the infiltration capacity of a soil and strongly control soil erosion (Morgan, 1986), runoff and sediment yield (Poesen and Lavee, 1991). When the vegetation cover cannot be established, organic and inorganic mulches can be used to protect the soil surface against the erosive forces of rain and runoff (Smets et al., 2008). Although, previous studies have been conducted about application of soil amendments to improve soil structure (e.g. Karami et al., 2012; Jiménez et al., 2013), change soil and water behavior (e.g. Huang et al., 2014) and reduce post-fire runoff and soil erosion in recent years (e.g. Prats et al., 2013). Straw mulch as an organic amendment reduces soil erosion but also recovers the main soil properties lost due to the agriculture (García-Orenes et al., 2010). Marmering and Meye (1963) and Adams (1966) showed that the straw mulch could reduce soil erosion in plot scale. Adekalu et al. (2007) showed that the sediment yield decreased with the amount of mulch used and increased with slope. Groen and Woods (2008) investigated the role of straw mulch in reducing post-wildfire erosion and showed that the straw mulch application was highly effective in reducing erosion in the first year after fire. Jiang et al. (2011) found that the wheat straw reduced soil erosion by 95 % compared to bare soil. Fernández et al. (2012) stated that the conserved treatments (seeding and mulching + seeding) did not significantly increase soil cover or affect runoff but soil losses were low in all cases. Li et al. (2011) found that the grass mulch significantly reduced sediment yield at large plot scale. Liu et al. (2012) successfully reported the decreasing effect of rice straw mulch at plot scale for a period of 2 years in the Xiaofuling Watershed in China. Gholami et al. (2013) studied straw mulching effect on sediment yield from eroded plots and showed that the straw mulch had a significant effect in changing soil erosion characteristics at a confidence level of 99 %. Shi et al. (2013) verified the positive effects of mulch cover on reduction of soil loss. Fernandez and Vega (2014) investigated the effects of straw mulch on erosion control after wildfire and showed that the straw mulch could decrease soil erosion. More recently, the scale effects of two plot sizes of 6 and 0.25 m^2 covered by straw mulch with rate of 0.5 $kg\,m^{-2}$ in changing the time to runoff, runoff coefficient, sediment

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concentration and soil loss under laboratory conditions were considered by Sadeghi et al. (2014). The results of the study showed that the straw mulch had more significant effect in in reducing runoff coefficient, sediment concentration and soil loss at 0.25 m^2-plot scale.

The effects of Manure on soil erosion have been studied by many researchers in recent decades. Mitchell and Gunther (1976) verified that the liquid manure provided a stabilizing effect on the soil surface, resulting in reduced rates of runoff and erosion. Giddens and Barnett (1980) revealed that the poultry litter could substantially reduce soil loss. Gilley and Eghball (1998) used beef cattle manure to control sediment transport and found that the manure could significantly reduce solids transport. Ginting et al. (1998) found that the application of beef manure could significantly reduce runoff and sediment. Gilley and Risse (2000) reported that the soil loss was influenced by the application of manure from 15 to 65 % compared to non-manured sites. Gossin et al. (2003) showed that, although sediment concentrations were higher in the surface-applied treatments, the runoff volume was reduced and consequently declined the total sediment load. While Martínez et al. (2004) showed that the sediment concentration was higher in treated plots with cattle manure, but Ramos and Martinez-Casanovas (2006) found that the sediment concentration in runoff was low in treated areas with cattle manure. The significant effect of poultry manure on soil loss reduction was also reported by Rees et al. (2011).

On the other hand, some researchers studied the effects of polyacrylamide on sediment concentration and soil loss. Uysal et al. (1995) found that the polyacrylamide were quite effective for reducing soil loss (Yonter, 2010). Yu et al. (2003), Shahbazi et al. (2004), Yonter (2010) and Lee et al. (2011) reported the positive effects of the polyacrylamide on soil loss, while Ai-Ping et al. (2011) found that the sediment concentration and soil loss increased significantly with the increasing polyacrylamide application rate. Tümsava and Kara (2011) revealed that the most effective rate of polyacrylamide on reducing soil losses rate were found to be 3.33 and 5 kg ha^{-1}.

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The reviewed literatures, verified variable behaviors and effectiveness of different mulches which necessitates further studies under different conditions. However, no study has been conducted to comprehensively assess the effects of three organic and inorganic amendments on sediment concentration and soil loss under different rainfall intensities.

2 Materials and methods

2.1 Soil characteristi

A sandy-loam soil (14 % clay, 24 % silt and 62 % sand) was collected from the top layer of 0–20 cm (Kukal and Sarkar, 2010) of a summer rangeland in the Alborz Mountains, Northern Iran located in latitude of 36°24′48.5″, longitude of 51°44′59.4″ and altitude of 1431 m. The mean annual precipitation and temperature were about 587 mm and 11.3 °C, respectively. The bulk density, pH, electrical conductivity and organic content of the study soil were measured as 1.376 g cm^{-3}, 7.95, 75.5 µS cm^{-1} and 2.167 %, respectively. The collected soil was carried to the lab and air-dried up to optimum moisture content to maintain the relative stability of the soil aggregates (Kukal and Sarkar, 2011; Khaledi Darvishan et al., 2013). The pebbles and plant residues were removed from the soil through passing from 8 mm sieve to obtain maximum similarity with the soil natural conditions (Defersha et al., 2011; Khaledi Darvishan et al., 2013).

Three layers of mineral pumice grains with different sizes and total thickness of 15 cm were used as a filter layer and placed at the bottom of the plots in order to simulate natural drainage condition and decreasing plot weight (Defersha et al., 2011; Khaledi Darvishan et al., 2013). A 15 cm-thick soil layer was then placed on the top and separated from the mineral pumice by a sheet of porous jute (Defersha et al., 2011; Khaledi Darvishan et al., 2013). The soil was ultimately compacted by a PVC roller filled with cement to achieve the bulk density of 1.376 g cm^{-3} almost equal to that measured for the soil under natural conditions (Khaledi Darvishan et al., 2013).

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The moisture content of the soil was also set at some 29 % similar to average amount reported for the real soil in the study area and during rainy season. The experiments duration was considered about 10–15 min corresponded with climatological records for the selected rainfall intensities.

2.2 Plot characteristics and rainfall simulation

The laboratory experiments were conducted using three 6 m × 1 m-erosion plots with the depth of 0.5 m and the slope of 30 % installed in the Faculty of Natural Resources of Tarbiat Modares University (TMU), Northern Iran.

The rainfall simulator lab consisted of a 4000 L water tank and 27 pre-calibrated nozzles at 3 parallel lines having the ability to simulate average raindrops size of 1.3 mm. The drops falling from a constant height of 4 m which ascertains the average terminal velocity of some 7.12 m s^{-1}. The rainfall intensities of 30, 50, 70 and 90 mm h^{-1} were then selected based on analysis made for the data collected from the nearest Kojour weather station (36°13′48″ NL, 51°26′24″ EL and 1550 m a.m.s.l.) with the return period less than 20 years. The duration of each precipitation was set for all treatments as 10 min after commencement of runoff.

2.3 Rice straw mulch, manure and TA-200 polyacrylamide treatments

In the present study, rice straw mulch and manure were used as organic amendments and TA-200 polyacrylamide was applied to the plots as inorganic amendment. Each run was conducted using new soil and straw mulch (Adams, 1966; Liu et al., 2012), manure (Gilley and Eghball, 1998) and polyacrylamide (Yu et al., 2003; Shahbazi et al., 2004; Tümsava and Kara, 2011). All amendments were spread on the soil surface 5 days before each experiment. For each plot, the rice straw mulch used with the surface cover, thickness and dry weight of about 90 % (Adekalu et al., 2007; Kukal and Sarkar, 2010; Shi et al., 2013), 8 cm and 0.5 kg m^{-2}, respectively. The manure with the cover about 90 %, dry weight of 0.3 kg m^{-2} (Ramos et al., 2006) was spread with hand (Ramos

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et al., 2006; Garcia et al., 2008) at each plot. TA-200 polyacrylamide also was used with the ground cover about 5 %, sieve of 2–4 mm and the rate of 50 g m^{-2}. Two organic amendments of straw mulch and manure were used with the rates of 0.5 and 0.3 kg m^{-2} respectively, because of significant effects in water and soil conservation in previous studied (Ramos et al., 2006), while the rate of 50 g m^{-2} for TA-200 polyacrylamide was selected because of economic justification and minimal risk of detrimental effect to the environment. Each experiment was run with the new soil and the new amendment i.e. rice straw, manure and TA-200 polyacrylamide. For each experiment, the top layer of soil were collected and replaced with new soil. The control treatment was then performed and corresponding variables viz. runoff volume, sediment concentration and soil loss were measured. Consequently, the study soil amendments were applied to the plots with eroded soil and runoff volume, sediment concentration and soil loss were ultimately measured after 5 days and running artificial rainfalls. The entire number of 24 treatments in three replicates was formulated as a factorial design (Defersha and Melesse, 2012), as shown in Table 1.

A general view of the experimented plots is shown in Fig. 1. The control plots subjected to study rain storms were also monitored under identical lab conditions on bare soils and just before applying the straw mulch, manure and TA-200 polyacrylamide to the same plots under consideration. So that, the plots with eroded soils due to study rain storms were supposed as control conditions in order to assess the relative effectiveness of study amendments on controlling soil erosion.

2.4 Runoff, suspended sediment concentration and soil loss measurements

The runoff volume was measured at the outlet of each plot for the control (i.e., before mulching) and treated plots at intervals of 2 min (Ruiz-Sinoga et al., 2010) at intensities of 30, 50, 70, and 90 mm h^{-1}. The rainfall duration was prolonged 10 min after runoff commencement for all experimental treatments (Khaledi Darvishan et al., 2013). The sediment laden runoff samples were taken from the total runoff (Khaledi Darvishan et al., 2013) at the outlet of the plots at the onset of receiving the first runoff drop with

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10 L plastic buckets. The entire experiments were conducted for the similar treatments for rainfall intensities of 30, 50, 70 and 90 mm h^{-1}. The amounts of soil loss were then measured using decantation, oven drying at 105 °C for 24 h and weighing techniques (Kukal and Sarkar, 2011; Gholami et al., 2013; Khaledi Darvishan et al., 2013). The concentrations of suspended material in runoff were consequently calculated based on the sediment mass and runoff volume data collected in each sample (Ai-Ping et al., 2011; Khaledi Darvishan et al., 2013).

2.5 Statistical analysis

The coefficient of determination was considered as a main index to select the best linear on nonlinear relationships between rainfall intensity and studied variables (average sediment concentration and soil loss). The same method was used to select the best relationships between soil conservation treatments and the studied variables.

To understand the statistical differences between studied variables in various levels of two studied factors (rainfall intensities or soil conservation treatments), one-way and two-way ANOVA were used in General Linear Model (GLM) test in SPSS 19 software package. Determination of homogeneous subgroups was then obtained for both studied factors with the help of Duncan test. In order to standard ANOVA table, all the differences with significant level less than 0.01 and 0.05 are statistically significant in confidence levels of 99 and 95 %, respectively.

3 Results

The runoff volume, sediment concentration and soil loss amounts before and after rice straw mulch, manure and TA-200 polyacrylamide in each plot are shown in Table 2. The measured mean runoff volume for plots treated by straw mulch, manure and TA-200 polyacrylamide were 46.1[4]5.71 and 45.74 for the control plots, 41.60, 45.21 and 41.93 for the treated plots (Table 2). The relative effectiveness of straw mulch, manure

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and TA-200 polyacrylamide on sediment concentration and soil loss has ultimately been summarized in Table 3. As shown in Table 3, the strongest conservation effects on average sediment concentration and soil loss in all rainfall intensities were observed for straw mulch treatment, while the conservation effects of two other conservation treatments (manure and TA-200 polyacrylamide) were relatively the same.

Figure 2 shows the average sediment concentration and soil loss for control, three amendments and four rainfall intensities. According to Table 3 and Fig. 2, it is observed that straw mulch has the powerful conservation effects on average sediment concentration and soil loss compared with manure and TA-200 polyacrylamide. Figure 3 also shows the relationships between rainfall intensity and conservation treatments on average sediment concentration and soil loss.

The average sediment concentration and soil loss in at rainfall intensities of 30, 50, 70 and 90 $mm\,h^{-1}$ (Fig. 2) showed that the straw mulch, manure and TA-200 polyacrylamide reduced sediment concentration and soil loss at all rainfall intensities.

Tables 4 and 5 show that General Linear Model (GLM) test and determination of significant differences between rainfall intensities and soil conservation treatments using post hoc analysis (Duncan test). The results of GLM test indicated that the effects of rainfall intensity, soil conservation and soil conservation × rainfall intensity on changing sediment concentration and soil loss was significant in level of 99 % (Table 4). The Duncan test showed that the subgroup of rainfall intensity was in 4 groups of 30, 50, 70 and 90 $mm\,h^{-1}$ (for sediment conservation and soil loss). The effect of TA-200 and manure on sediment concentration were similar and the effect of straw mulch on this variable was more and significantly different from 2 other soil conservation treatments and that was set in the first subgroup (Table 5).

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4 Discussion

4.1 Straw mulch

The results (Table [illegible]nd Fig. 2) showed that the straw mulch treatment essentially reduced soil loss and also sediment concentration (Marmering and Meyer, 1963; Adams, 1996; Adekalu et al., 2007; Groen and Woods, 2008; Smets et al., 2008; Jiang et al., 2011; Li et al., 2011; Gholami et al., 2013; Fernandez and Vega, 2014). This indicates that the flow could not get enough power to detach particles (Poesen and Lavee, 1991) with amount of 0.5 kg m^{-2} because the depth of the mulch trapped detaching soil aggregates. The straw mulch could decrease runoff energy for particle detachment and transport (Mannering and Meyer, 1963). The effective relationship between average sediment concentration and rainfall intensity in the control and treated plots was linear-direct, with coefficients of determination of 0.97 and [illegible]3, respectively (Fig. 3). The effective relationship between sediment yield and rainfall intensity in both treatments was also linear-direct, with coefficients of determination of 0.98 and 0.92, respectively (Fig. 3). The effective role of stubble mulch has been reported by Smets et al. (2008). The results also verified the maximum effectiveness of straw mulch on sediment concentration and soil loss at the rainfall intensity of 90 mm h^{-1} with rates of [illegible].69 and −63.23 %, respectively (Table 3). The effect of manure and TA-200 polyacrylamide on sediment yield and soil loss had more at the rainfall intensity of 90 mm h^{-1} with rates of −14.65 and −13.14 % (manure) and −20.15 and −23.44 % (TA-200 polyacrylamide), respectively (Table 3). They had minimum effects in the rainfall intensities of 70 (straw mulch), 30 mm h^{-1} (manure and TA-200 polyacrylamide). Soil loss was reduced because runoff and rainfall detachment were diminished and soil infiltration rates were increased (Jordan et al., 2010). This effect is larger for the high-intensity than for the medium-intensity rainfall as reported by Fox and Bryan (2000) and Assouline and Ben-Hur (2006).

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4.2 Manure mulch

The results of Table 2 showed that the manure could reduced sediment concentration for all raifall intensities. The reduction rates in for rainfall intensities of 30, 50, 70 and 90 mm h^{-1} was 3.26, 6.08, 11.94 and 14.65 % (for sediment concentration), 6.66, 9.56, 1086 and 13.14 % (for soil loss), respectively. Scrutinizing results (Table 2 and Fig. 2) showed that the manure treatment essentially reduced sediment concentration and soil loss (Mitchell and Gunther, 1976; Giddens and Barnett, 1980; Gilley and Eghball, 1998; Ramos and Martinez-Casanovas, 2006; Gilley and Risse, 2000; Rees et al., 2011). The manure could also reduce soil loss because runoff amount and rainfall detachment were diminished and soil infiltration rates increased. Gossin et al. (2003) showed that the application of manure could reduce the total sediment load through decreasing runoff volume. Gessel et al. (2004) also showed that the application of manure in plot scale could decrease soil loss compared to the un-manured plot. Martínez et al. (2004) showed that the manure was effective on sediment conservation in rainfall intensity of 80 mm h^{-1}. This disagreed with Mooers et al. (1948) who showed long back that the manure had less role in soil conservation. The relationships between sediment concentration and soil loss with rainfall intensity in control and treated plots with manure were entirely significant with R^2 = 0.99 ($p \leq 0.01$) and linear-direct and exponential-direct, respectively (Fig. 3). The results also verified that the maximum and minimum effectiveness of manure on sediment concentration and soil loss in rainfall intensity of 90 and 30 mm h^{-1} with rates of −14.65 and −3.26 for sediment concentration and −13.14 and −6.66 for soil loss, respectively (Table 3).

4.3 TA-200 polyacrylamide amendment

Table 2 and Fig. 2 showed that the TA-200 polyacrylamide decreased soil loss and sediment concentration (Uysal et al., 1995; Shahbazi et al., 2004; Tang et al., 2006; Ai-Ping et al., 2011; Lee et al., 2011) with rate of 50 g m^{-2}. Table 2 indicated that the reduction rates in rainfall intensities of 30, 50, 70 and 90 mm h^{-1} was 2.86,

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4.50, 3.53 and 20.15 % (for sediment concentration) and 7.63, 14.64, 11.98 and 23.44 % (for soil loss), respectively. The relationships between rainfall intensity with sediment concentration and soil loss were exponential with respective coefficients of determination of 0.97 and 0.99 for untreated and treated plots (Fig. 3). This amendment had more effect in rainfall intensity of 90 mm h^{-1}, for sediment concentration and soil loss, with rates of −20.15 and −23.44, respectively (Table 3). Sojka et al. (1998) and Sepaskhah and Bazrafshan-Jahromi (2006) showed that the polyacrylamide had more effect at soil loss control for high rainfall intensity toward low rainfall intensity.

4.4 Cross comparison of study treatments performance

4.4.1 Runoff

The results comparison showed that the straw mulch was effectively effective on reducing runoff toward two other amendments (Smets et al., 2008; Shi et al., 2013). This amendment could be more effective in rainfall intensity of 30 mm h^{-1}. But the TA-200 polyacrylamide had less impact on runoff changes compared to those for straw mulch and manure (Prats et al., 2014). The runoff volume decreased because straw mulch pieces (Duley and Kelly, 1939; Liu et al., 2012), Manure (Ginting et al., 1998; Rasoulzadeh and Yaghoubi, 2010) and TA-200 (Uysal et al., 1995; Yu et al., 2003; Tang et al., 2006; Pajuohesh et al., 2008) could store more runoff. But the greater depth of the straw mulch increased protection of the immediate soil surface with absorption of water and holding excess surface water on the soil surface by mechanical impedance (Adams, 1966; Khan et al., 1988).

4.4.2 Sediment concentration and soil loss

The straw mulch, manure and TA-200 polyacrylamide could also decrease sediment concentration and soil loss in rainfall intensities of 30, 50, 70 and 90 mm h^{-1}. All study treatments could reduce sediment concentration and soil loss in rainfall intensity of

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90 mm h^{-1} more than other intensities. This means that the significant declines in soil loss should be attributed to the organic and inorganic recovery of the plots rather than to variations of the rainfall intensities. The measured soil loss for straw mulch, manure and TA-200 polyacrylamide were 412.50, 418.98 and 396.25 for the control plots, and 187.60, 370.94 and 322.68 for the conserved plots (Table 2). Almost similar results have been reported by Wagenbrenner et al. (2006).

The results also verified that the straw mulch could reduce sediment concentration and soil loss at all of rainfall intensities more than two other treatments of manure and TA-200 polyacrylamide. García-Orenes et al. (2010) and Prats et al. (2014) showed that the straw mulch was effective on soil loss control. It might be because of low rate of the soil clay (almost 14 %) which could not facilitate better performance of TA-200. Yonter (2010) and Tümsava and Kara (2011) stated that the polyacrylamide had effective role on soil loss in soils with clay > 30 %. However, some previous studies (e.g. Fox and Bryan, 1999; Assouline and Ben-Hur, 2006) indicated that the effect of slope on soil loss was dependent on rainfall intensity. This effect is larger for the high intensity rainfall than for the medium intensity rainfall. Results showed that the straw mulch had more appropriate and better effect on sediment concentration and soil loss control. Smets et al. (2008) approved that the straw mulch had an effective role on soil loss control. The better effect of straw mulch was due to great coverage (Gholami et al., 2013; Shi et al., 2013; Fernandez and Vega, 2014), physical role of straw pieces as a resistant barriers against detachment (Marmering and Meyer, 1963; Poesen and Lavee, 1991), reducing runoff amount and speed and also increasing infiltration (Jordan et al., 2010). Loch and Donnollan (1988) stated that the sediment concentration.

The one way ANOVA results (Table 4) showed that the sediment concentration and soil loss increases with increasing rainfall intensity in both the control and the soil conservation treatments and the effect of rainfall intensity was significant on study variables (R^2 = 0.99). But the conservation treatments could reduce sediment concentration and soil loss and this effect was significant on study variables (R^2 = 0.99).

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Determination of significant differences between rainfall intensities and soil conservation treatments using Post-Hoc analysis (Table 5) showed that the rainfall intensities of 30, 50, 70 and 90 mm h^{-1} were classified in 4 different subgroups. The separation of soil conservations was found that, for sediment concentration were in 3 subgroups of straw mulch, TA-200, manure and control. The amounts of TA-200 and manure were close to control treatment. While, for soil loss, the soil conservation treatments grouped were in 4 different subgroups. They were separated to straw mulch, TA-200, manure and control, respectively, but the straw mulch had significant difference with two other soil conservation treatments.

5 Conclusion

The present study was conducted to study the effects of straw mulching, manure and TA-200 polyacrylamide application on sediment concentration and soil loss control under different rainfall intensities under lab experimented conditions at medium sized plot scale. It can be concluded from the results that the straw mulching, manure and TA-200 polyacrylamide at respective rates of 500, 300 and 50 g m^{-2}, and 6 m^2 plots with 30 % slope could significantly decrease the sediment concentration and soil loss with different rates. The straw mulch decreased soil concentration at rate of 45.60 % compared to the control plots, and performed better than manure (8.98 % reduction) and PAM (4.74 % reduction). Also the straw mulch reduced soil loss in 52.35 % compared to the control plots, and performed better than manure (10.05 % reduction) and PAM (14.42 % reduction). The straw mulch, manure and TA-200 polyacrylamide could reduce sediment concentration and soil loss in rainfall intensity of 90 mm h^{-1} more than other study intensities. However, further detailed studies with different levels of straw mulches, manures, polyacrylamide and slopes and even under different conditions are needed to allow drawing comprehensive conclusion.

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Table 1. Details on experimental setup and study treatments.

Soil conservation treatment		Rainfall intensity treatment ($mm\,h^{-1}$)	
Symbol	Specific treatment	Symbol level	Treatment level
C	Control treatment	I_1, I_2, I_3 and I_4	30, 50, 70 and 90
T	Conservation treatment with rice straw mulch, manure and TA-200 polyacryamide	I_1, I_2, I_3 and I_4	30, 50, 70 and 90

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Table 2. Runoff volume, sediment concentration and soil loss from control and treated plots under different rainfall intensities.

Treatment	Plots	Rainfall intensity	Runoff volume (L)		Sediment concentration ($g L^{-1}$)		Soil loss (g)	
		($mm h^{-1}$)	Control	Treated	Control	Treated	Control	Treated
Rice Straw Mulch	1	30	21.06	19.04	7.07	3.98	146.55	72.64
		50	36.90	33.74	6.13	3.87	226.27	131.38
		70	58.82	51.05	9.36	5.83	551.87	290.89
		90	74.24	65.79	10.28	4.39	756.69	286.37
	2	30	20.46	15.66	5.94	3.53	121.72	54.24
		50	35.95	35.05	7.43	3.69	266.64	128.94
		70	51.79	47.79	9.17	5.07	473.69	234.16
		90	74.05	70.65	10.71	4.47	787.94	315.10
	3	30	19.08	16.32	6.78	3.97	128.17	54.87
		50	36.73	34.91	8.27	4.70	302.82	161.62
		70	51.18	49.17	8.79	5.92	449.45	281.53
		90	72.99	60.04	10.15	4.01	738.20	239.42
		Mean	46.10	41.60	8.34	4.45	412.50	187.60
		Standard Error	1.61	2.36	0.56	0.38	32.46	24.32
Manure	1	30	19.69	21.9	6.21	6.10	120.59	127.66
		50	34.65	35.35	7.97	7.18	273.61	253.71
		70	56.98	56.84	8.70	7.83	492.64	444.52
		90	72.55	75.63	11.36	8.64	819.74	664.73
	2	30	22.22	22.06	6.03	6.52	131.62	138.41
		50	33.50	31.51	7.34	6.56	245.78	204.98
		70	52.38	50.25	9.38	7.90	489.38	395.42
		90	75.78	73.53	11.47	10.35	870.08	779.40
	3	30	21.53	18.34	5.73	4.80	121.07	83.54
		50	37.99	35.41	7.07	7.24	265.11	252.37
		70	50.43	53.23	9.09	8.17	452.26	435.99
		90	70.86	68.49	10.66	9.58	745.85	670.52
		Mean	45.71	45.21	8.42	7.57	418.98	370.94
		Standard Error	2.38	2.83	0.37	0.58	26.35	36.92
TA-200 Polyacrylamide	1	30	20.77	20.18	5.75	6.66	117.62	139.44
		50	37.65	29.65	6.76	6.86	151.69	133.77
		70	58.75	50.42	6.49	4.81	120.34	84.67
		90	73.41	71.04	7.42	6.72	278.41	196.33
	2	30	22.31	18.84	6.40	7.24	204.15	233.57
		50	32.04	32.40	7.31	6.06	257.81	183.43
		70	53.78	48.49	7.92	8.09	457.46	406.47
		90	68.94	70.07	9.09	7.89	485.41	381.49
	3	30	18.69	16.48	7.70	7.74	405.37	391.63
		50	35.18	30.72	10.73	8.59	784.07	605.47
		70	52.71	50.55	9.88	8.77	673.30	614.65
		90	74.62	64.36	11.05	7.82	819.42	501.24
		Mean	45.74	41.93	7.04	7.27	396.25	322.68
		Standard Error	2.71	2.01	0.61	0.60	43.53	32.93

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Table 3. Reduction rates in average sediment concentration and soil loss (%) resulted from application of straw mulch, manure and TA-200 polyacrylamide and various rainfall intensities.

Treatment	Impressible variable	Rainfall intensity ($mm\,h^{-1}$)			
		30	50	70	90
Straw Mulch	Average sediment concentration ($g\,L^{-1}$)	−41.91	−43.47	−38.31	−58.69
	Soil loss (g)	−54.36	−46.74	−45.07	−63.24
Manure	Average sediment concentration ($g\,L^{-1}$)	−3.26	−6.08	−11.94	−14.65
	Soil loss (g)	−6.66	−9.56	−10.86	−13.14
TA-200 Polyacrylamide	Average sediment concentration ($g\,L^{-1}$)	−2.86	−4.50	−3.53	−20.15
	Soil loss (g)	−7.63	−14.64	−11.98	−23.44

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Table 4. GLM test for one-way and two-way ANOVA to know the effects of rainfall intensity and soil conservation treatments on sediment concentration and soil loss.

Source	Dependent variables	df	Mean square	*F* value	Significant level
Rainfall Intensity	Sediment concentration ($g L^{-1}$)	3	18.21	65.50	0.00*
	Soil loss (g)		529 517.02	554.87	0.00*
Soil Conservation	Sediment concentration ($g L^{-1}$)	3	33.78	121.53	0.00*
	Soil loss (g)		112 278.653	117.66	0.00*
Rainfall Intensity × Soil Conservation	Sediment concentration ($g L^{-1}$)	9	6.62	1.84	0.00*
	Soil loss (g)		22.91	21 860.86	0.00*

* shows differences in significant level of 0.01.

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Table 5. Determination of significant differences between rainfall intensities and soil conservation treatments using Post-Hoc analysis (Duncan test).

Variable	Subgroup 1	Subgroup 2	Subgroup 3	Subgroup 4
	Subgroups for Rainfall Intensity			
Sediment concentration ($g L^{-1}$)	30	50	70	90
Soil loss (g)	30	50	70	90
	Subgroups for Soil Conservation			
Sediment concentration ($g L^{-1}$)	Straw Mulch (4.45)	TA-200 and Manure (7.27 and 7.57)	Control (8.27)	–
Soil loss (g)	Straw Mulch (187.60)	TA-200 (322.68)	Manure (370.94)	Control (409.24)

Figures given in brackets show mean values.

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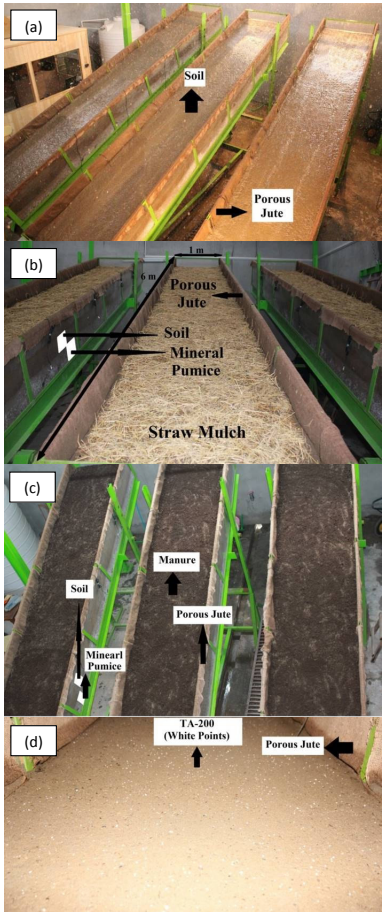

Figure 1. A view of untreated plots **(a)**, treated plots with rice straw mulch **(b)**, manure **(c)** and TA-200 polyacrylamide **(d)** under the lab condition.

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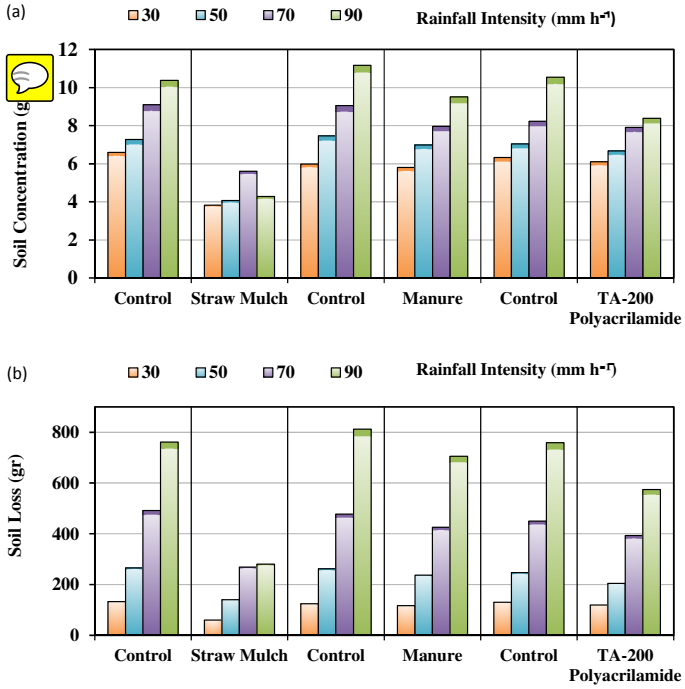

Fig. 2. Average sediment concentration **(a)** and soil loss **(b)** at four rainfall intensities.

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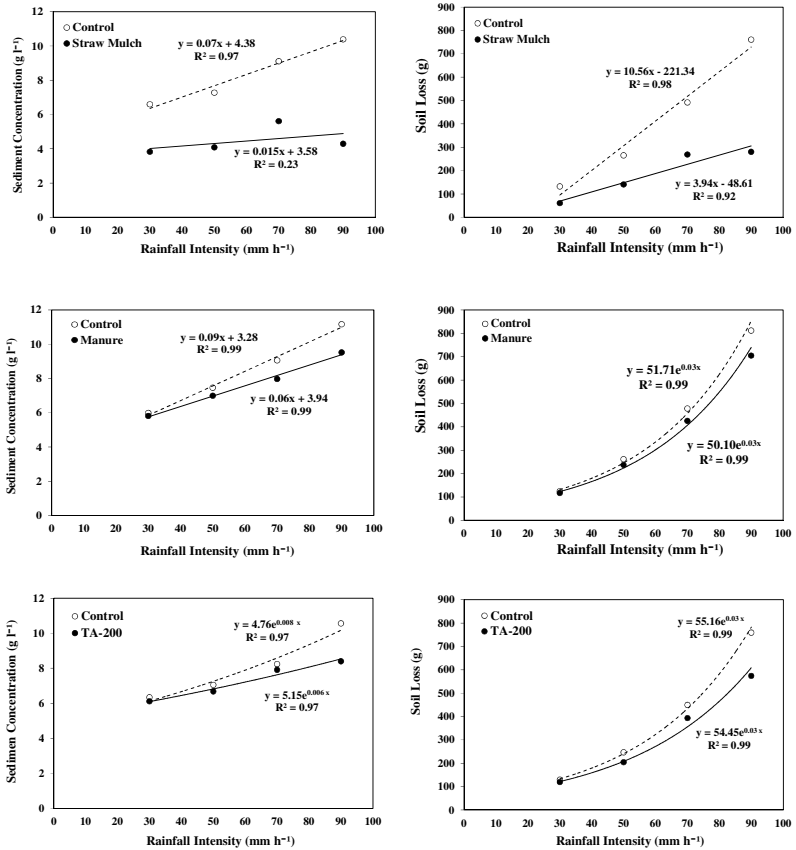

Figure 6. Relationships between rainfall intensity and organic and inorganic treatments on average sediment concentration (left column), soil loss (right column), rice straw mulch (top), manure (middle) and TA-200 polyacrylamide (bottom).

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