

Assessing the rice straw effects on the soil erosion rate in forest road cut slope embankments

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ABSTRACT

Applying rice straw as mulch blanket on recently-established embankment is one way to reduce the environmental impact of sediment yields from forest roads embankments. Effectiveness of straw, however, is often unknown and it is unclear how the rate of application should vary with factors such as slope. In this study, the effects of the percentage of straw cover and slope gradient in the embankment of forest roads on the runoff volume and soil erosion were studied using rainfall simulator in plots of 1 m × 1 m dimension. Straw effects were quantified in four treatments of rice straw cover (0%, 30%, 60% and 90%), three treatments of slopes (0-15%, 16-30%, and 30-45%), with three replications in each giving a total of 36 experimental plots. Runoff and sediment from each plot were recorded every two minutes during the simulated rainfall of 65 mm/h intensity for 16 minutes. The 16-min simulations divided into eight simulation periods. The results showed that an increase in straw cover (based on length and amount) resulted in an impressive decrease in the runoff volume and soil erosion. Moreover, investigating the effect of slopes indicated that the runoff volume was significantly different between 0-15% and 15-30% slope classes. In terms of sediment concentration (g mL⁻¹) and sediment (g), there were significant differences between the study slopes (various slopes and covers). The results showed that rice straw can decrease soil erosion up to 90% in road embankments and the rice straw with the length of 5 cm was the most economical choice to protect soil from erosions.

Keywords: Forest roads embankments, Rainfall simulator, Rice straw, Runoff.

INTRODUCTION

A road network in forest lands provides easy access to forest resources for harvesting, regeneration, protection, and recreation activities. Soil erosion is one of the major concerns in forest management (Akay *et al.* 2008). Forest roads is a major source of sediments and the loss of vegetation cover after forest construction increases the volume of surface runoff and sediments (Connelly *et al.* 2000; Aldrich *et al.* 2005; Miller *et al.* 2005; Pierson *et al.* 2007; Akay *et al.* 2008; Davies *et al.* 2011; Miller *et al.* 2011). Forest road embankments, after construction, are often the most important part of the runoff generation and sediment production (Megahan 1974; Jordan & Martinez 2008; Dalir *et al.* 2014). The important factors for embankment erosion are slope gradient (Jordan-Lopez *et al.* 2009; Chamizo *et al.* 2012; Naghdi *et al.* 2017), vegetation coverage (Li *et al.* 2009; Nyman *et al.* 2014), rainfall intensity and duration (Keim *et al.* 2006; Cattan *et al.* 2009; Jones *et al.* 2014), and soil properties (Zhao *et al.* 2013; Sun *et al.* 2014). The road embankments are created by excavation into the natural hillside slope. These slopes are steeper than the natural slope and it has sparse plant cover (Jordán-Lopez *et al.* 2009). The characteristics of road embankments are not usually suitable for vegetation growth (Martínez-Zavala *et al.* 2008; De Ona *et al.* 2009; Meyer *et al.* 2014), consequently soil in forest roads

embankment is very erodible (De Lima *et al.* 2003; De Ona *et al.* 2009). The effectiveness of conservational methods on soil erosion has been evaluated in a number of studies (Burroughs & King 1989; Grace 2002; Yu *et al.* 2003; Grismer & Hogan 2005; Foltz & Wagenbrenner 2010; Du *et al.* 2019). Rice straw is one of the most widely-used materials for erosion mitigation in the most forest areas (Foltz & Copeland 2009). These materials are inexpensive, easily available, easy to apply, and operative in reducing soil erosion in the available slopes (Foltz & Dooley 2003; Foltz & Copeland 2009). Surface cover provided by rice straw protects the soil from raindrop impact and the wind erosion (Chaplot & Bissonnais 2001), improves soil condition (Persyn *et al.* 2004; Moragues-Saitua *et al.* 2017), help to impound moisture at the soil surface by reduction of evaporative heat transfer (Chang *et al.* 1977; Cerda & Doerr 2008), slow and deflect runoff (Sun *et al.* 2015), and trap erodible material entrained in runoff (Yanosek *et al.* 2006).

The transfer of sediments from slope by rainfall towards downstream highly depends on the vegetation conditions on the slope surface (Bagheri *et al.* 2013). In fact, vegetation reduction causes a decrease in soil resistance to erosion. Moreover, water erosion happens when shear stress of flowing water (runoff) is higher than soil resistance. Surface roughness changes depending on vegetation changes. Due to growing vegetation and also use of rice straw, roughness coefficients are changed in comparison with the surface without vegetation (Gholami *et al.* 2015; Dianati Tilaki *et al.* 2020; Gholami *et al.* 2020).

Therefore, vegetation and straw caused a reduction of runoff generation by increasing the permeability of soil and water holding capacity of the study area (Gholami *et al.* 2008). Rice straw has a variety of features that make them suitable for erosion controls. Many studies have investigated the rates of soil erosion, runoff volume under various covers, but few have focused on runoff and soil erosion rates with different percentage of rice straw cover and slope gradient. Rainfall simulator set and field plots are commonly used to evaluate runoff generation and soil erosion on the different slopes and covers (Martinez-Zavala *et al.* 2008; Foltz & Wagenbrenner 2010; Las Heras *et al.* 2010). Sun *et al.* (2015) reported the mean rates of soil erosion that increased linearly by elevating slope gradient. De Ona *et al.* (2009) once assessing the effects of using compost on reducing erosion in road embankments, reported that when cover were applied to the plot, soil loss was reduced by 63% to as much as 90%. Foltz & Copeland (2009) compared using wood shreds against rice straw to reduce runoff and soil erosion exhibiting that erosion was reduced by 60 to 100 % depending on the type of soil, the amount of focus flow and wood shred coverage. Wood shred is a good alternative to rice straw. Yanosek *et al.* (2006) studied the influence of wood shreds on different slopes and soils and consequently found that both straw and wood strands had an equal effect on reducing the rate of soil erosion from coarse- to fine-grained soils. In addition, they found that the three- dimensional layer of the wood strands was dramatically helpful in reducing the soil loss. Foltz & Dooley (2003) found that wood strands were as effective as straw in reducing runoff and soil loss.

Previous studies have not focused specifically on rice straw, hence the optimum length and amount of straw for reducing runoff and sediment is unclear in Iran. So, the objectives of this study were to select a suitable cover (straw kind and amount) of the rice straw in order to reduce runoff and soil erosion as well as to find the impacts of both rice straw and the percentage of slope on runoff and sediment along with finding a suitable and available straw and the best rice straw length for erosion conservation in road embankments.

MATERIAL AND METHODS

Study area

The field studies were conducted on the side slope of a forest road embankment at Shenrood forest, Guilan Province, north of Iran between 49° 52' to 37° 5' N latitude and 49° 55' to 50° 8' E longitude (Fig. 1). The forest was comprised predominantly of Oriental beech (*Fagus orientalis* Lipsky) growing on a clay loamy soil. Mean tree height and stand density were 21 m and 180 trees per hectare respectively.

The elevation of the study area ranged between 1300 and 1600 m. The mean annual precipitation recorded at the proximate climatology station was 1200 mm. The maximum mean monthly precipitation of 120 mm usually occurred in December, while the minimum monthly rainfall of 25 mm occurred in August.

The mean annual temperature was 15 °C with the lowest values in February. Because of widespread timber harvesting in this area, there was a large network of forest roads. Weather condition was generally wet with average soil moisture content of 38 % during field studies and there were over 150 rainy days during a year. Therefore, soil erosion (water erosion) was very notable in the study area.

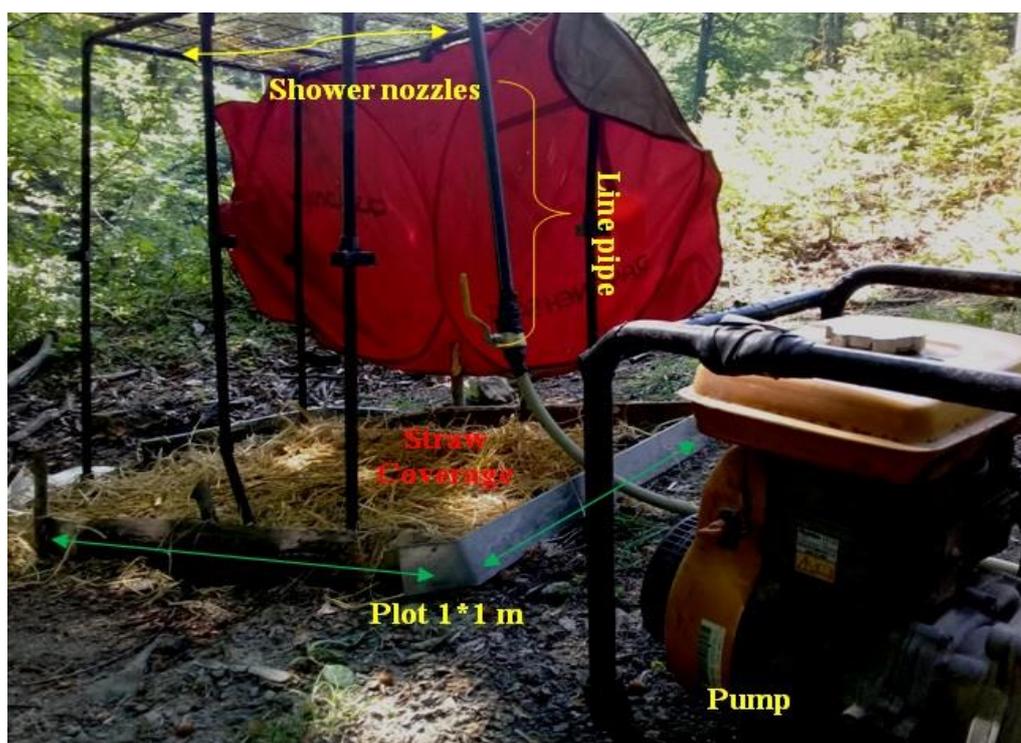


Fig. 1. The rainfall simulator.

Experimental plots characteristics

The experiments were conducted in 36 test plots measuring 1 m × 1 m each. The 36 test plots were divided into three sets of 12 plots to compare the influence of the different embankment slopes and cover percentages. Three different embankment slope classes were used: 0-15%, 15-30% and 30-45%. Side slopes which were the most widely-used slopes in the research road embankments due to geotechnical factors, and four different cover percentages with rice straw crops were used for each of the side slopes including: 0% (bare soil), 30%, 60% and 90% coverage. All plots were created in an area with homogeneous characteristics, and the soil texture was clay-loam in all plots.

For this study, rice straw was selected because that is available and a native cultivation in northern Iran. Straw length is a key selection in using straw for soil conservation. Small straws cannot conserve well soil because runoff flow transfers the small straws. Furthermore, a large length of straws will have different problems such as: (a) increase of the straw volume and their costs (b) delay on decomposition. Therefore, we used different lengths of rice straw in the study plots (1, 2, 5, 20-30 cm or complete length) for defining the optimal straw length in the soil conservation in terms of efficiency and cost. The optimal straw length will be the minimum length of rice straw that ensure soil conservation.

The coverage rate was determined by taking a digital picture. Rice straw was used in three sites in the study area on slopes of 15, 30 and 45 %. In all three cases, straw coverage percentage was exactly defined for each plot (three slopes and straw coverage). The simulator system consisted of a cistern, pump, and line pipe. The cistern water was a spring. The pump moved the water to the line pipe and through the shower nozzles to simulate rainfall. A simulated storm that generated both raindrop impact and concentrated flow was delivered to the prepared plots (Foltz & Dooley 2003; Yanosek *et al.* 2006; Foltz & Copeland 2009, Fig. 2). In Rainfall simulation process, the considered rainfall was selected by defining the initial loss rates. The initial loss (sum of infiltration, interception, depression storage) is one of the main unknown parameters in runoff estimation which are difficult to determine. When the initial loss was determined on different slopes and in different AMC (Antecedent Moisture Condition), the parameter was used to define a suitable intensity and amount of rainfall for applying rainfall simulator set (Esmaeeli Gholzom & Gholami 2012). In each plot (before rainfall simulations), soil samples from the depth interval 0-10 cm were collected with a soil hammer and cylinder. Collected samples, were promptly weighed (soil samples). Soils were dried in an oven at 105 °C (24 h) and 65 °C (48 h), respectively (Naghdi *et al.* 2016). Bulk density was calculated as the ratio between dry soil mass and

soil volume. Soil texture was determined based on the Bouyoucos hydrometer method (Kalra & Maynard 1991). Moreover, initial soil moisture was calculated as Equation (1):

$$M_s = (W_w - W_d) / W_w \quad (1)$$

where M_s is the soil moisture content (%), W_w is the moist yield of the soil (g), and W_d is the dry yield of the soil (g) (Table 1).

The rainfall was simulated at a continuous rate of 65 mm h⁻¹ for duration of 16 min. According to the IDF (Intensity-Duration-Frequency) curve, an event of this intensity and duration has a return period of 25 years in the study area. The rainfall duration and intensity were chosen not to represent a particular design storm, but rather to exceed the initial loss rate and ensure that the entire plot area contributed to runoff. Initial loss rates ranged between 3 and 8 mm in the study plots. Initial loss rate was changed based on A.M.C, slope and land cover. The initial loss were estimated rates using rainfall simulator set and field studies (the begging of runoff flow). The 16-min simulations were divided into eight simulation periods, and collected runoff was measured in 1000 mL- graduated cylinders every two minutes after its generation. The collected runoff samples, were brought to the laboratory from study area, dried in an oven at 105 °C (24 h) and 65 °C (48 h). Sediment weights of any samples were determined by balance (precision digital scale 0.01 g).

Table 1. Soil moisture, Soil texture classes at a depth of 0–10 cm for each plots. The range of particle length was < 0.002, 0.002–0.05 and 0.05–2 mm for clay, silt, and sand, respectively.

Soil particle distributions (g 100 g ⁻¹)					
Soil Sample	Clay%	Silt%	Sand%	Soil texture	Initial soil moisture (%)
1	29	40	31	Clay Loam	29
2	28	41	31	Clay Loam	29
3	27	39	34	Clay Loam	30
4	26	42	32	Clay Loam	29
5	27	40	33	Clay Loam	28
6	28	40	32	Clay Loam	28
7	30	39	31	Clay Loam	30
8	28	42	30	Clay Loam	29
9	28	41	31	Clay Loam	28
10	29	40	31	Clay Loam	29
11	28	41	31	Clay Loam	30
12	29	41	30	Clay Loam	29

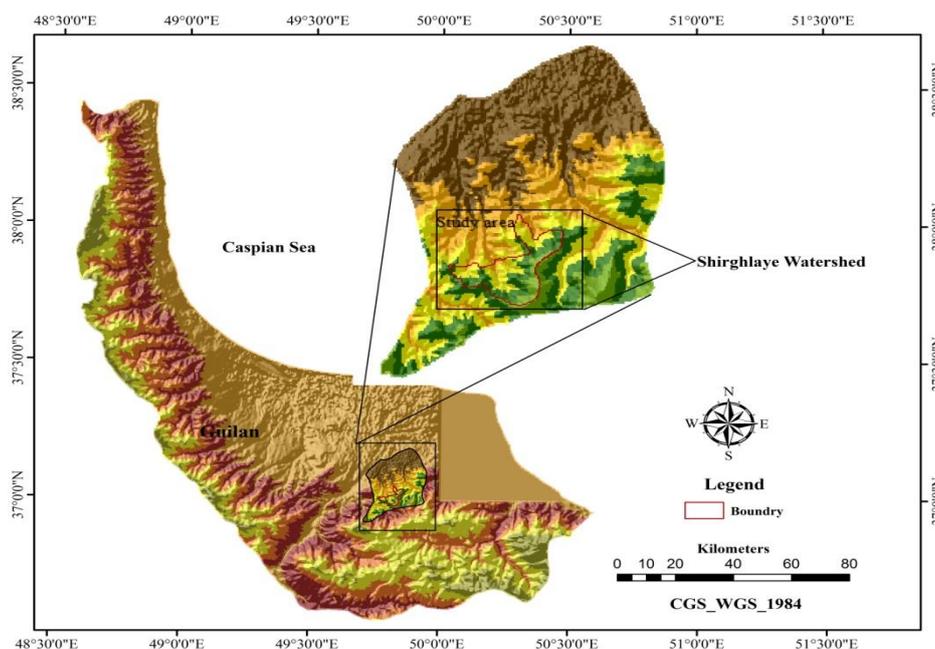


Fig. 2. Location of the study area in the northern Iran.

Statistical analysis

After normalizing the data the statistical analysis of the slope and cover percentage results was performed by means of analysis of variance (ANOVA), on a quantitative dependent- and independent variables (factors). Analysis of variance is used to test the hypothesis that several means are not the same. In our analyses, we performed several Two-Way ANOVA for different response variables. In addition to determining that differences between the means exist, several post-hoc LSD tests were considered on factor levels. Moreover, SPSS (version 16.0) software was used to analyze and also for modeling the relations of the straw cover as well as slope changes with runoff and sediment rates. At first, data were normalized and randomized. Then, multivariate regression method was used for modeling soil erosion and runoff process along with the relations between the straw cover and slope values with sediment and runoff generation on the forest road embankments. 70% of data were used for modeling and the rest were used to validate the model. Finally, two linear models were presented to simulate sediment yield and runoff generation based on the changes of the cover and slope on the forest road embankments.

RESULTS

The effect of the straw coverage

The results showed that runoff, sediment and sediment concentration were reduced by increased rice straw percentage. Comparison of the various treatments (straw cover and slope) is given in Fig. 3. In this study, the One- Way ANOVA results exhibited that runoff volume decreased significantly by the elevated percentage of the rice straw coverage. There were statistically significant differences ($p < 0.01$; LSD test) on the survival coverage (0%, 30%, 60% and 90%) in any comparisons between the factor's levels.

Figs. 3

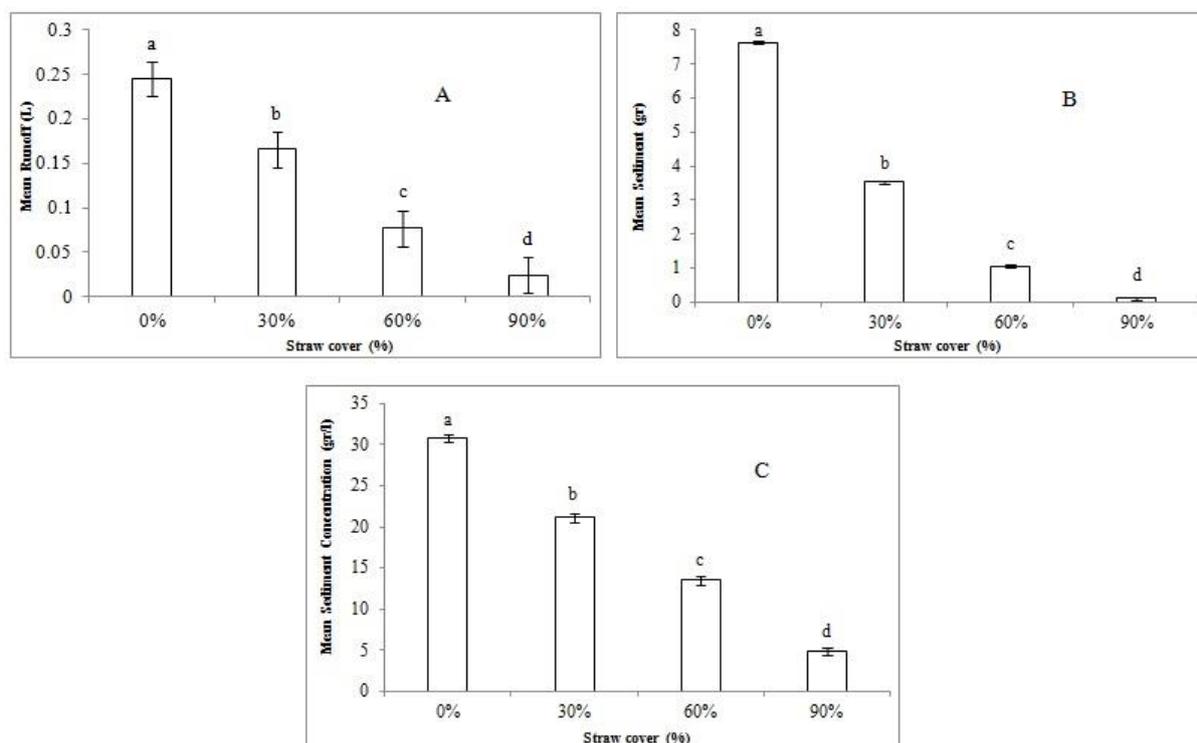


Fig. 3. The effect of the straw coverage rate (%) on mean runoff volume (A), mean sediment (B) and sediment concentration (C).

Results of mean sediments yield comparison in four different covers revealed a significant difference between them. LSD test between mean sediments yield also indicated that by increasing in the coverage of the embankment, the amounts of sediment among all groups (0%, 30%, 60% and 90% coverage's) were reduced significantly and all groups were significantly different ($p < 0.01$) together, except between those of 60% and 90% which were significantly different at 95% confidence level. Table 2 presents the mean sediment in different

cover percentages. Moreover, Fig. 4 illustrates the amounts of sediments in different covers in terms of increasing the time of rainfall simulations. Notably, by increasing in the simulation time, the amounts of sediments were also upraised.

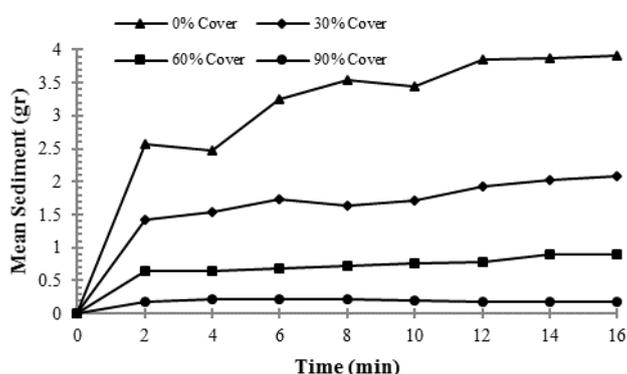


Fig. 4. The mean soil erosion in the different straw covers (and increase in the rainfall duration).

Table 2. The mean of the generated sediments in different cover percentages (0%, 30%, 60% and 90%).

Plot number	Straw Coverage (%)	Mean sediment (gr)	LSD
1	0%	6.83	
2	0%	8.12	0% **
3	0%	7.92	
4	30%	2.77	
5	30%	3.36	30% **
6	30%	3.24	0%
7	60%	0.84	
8	60%	1.02	60% **
9	60%	0.95	
10	90%	0.1	
11	90%	0.11	90% **
12	90%	0.1	

Asterisks (*) and (**) significant at the 0.05 and 0.01 probability levels, respectively.

Results of ANOVA test revealed that by increasing the amount of straw cover on the embankment, the sediment concentration was reduced significantly. LSD test results (Table 3) also indicated that there were significant differences ($p < 0.01$) among all straw cover groups (0%, 30%, 60% and 90%). Table 4 shows the mean sediment concentration in different straw covers. By increasing the coverage from 0% to 30%, from 30% to 60% and from 60% to 90%, sediment concentrations decreased by 31.4%, 56.1% and 84.4%, respectively. Fig. 5 illustrates the amount of runoff volume, soil erosion and sediment concentration in three slope treatments. It was found that by increasing the slope from 30% to 45%, the runoff volume, soil erosion and sediment concentration did not change considerably.

Table 3. The LSD test results between the mean sediment concentrations in the all classes of straw covers (0%, 30%, 60% and 90%).

— (I)	(J)	Mean Difference	Std. Error	Sig.	99% Confidence Interval	
					Lower Bound	Upper Bound
LSD 0%	30%	9.75**	.918	0.000	7.87	11.63
	60%	17.27**	.918	0.000	15.39	19.15
	90%	26.05**	.918	0.000	24.17	27.93
30%	60%	7.51**	.918	0.000	5.63	9.39
	90%	16.30**	.918	0.000	14.41	18.18
60%	90%	8.78**	.918	0.000	6.9013	10.66

Asterisks (*), (**) and (***) significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

Table 4. The mean sediment concentration in the different covers of rice straw.

Coverage (%)	Mean sediment concentration (gr/liter)	Reduction percent (%)
0%	30.8	
30%	21.1	31.4
60%	13.5	56.1
90%	4.8	84.4

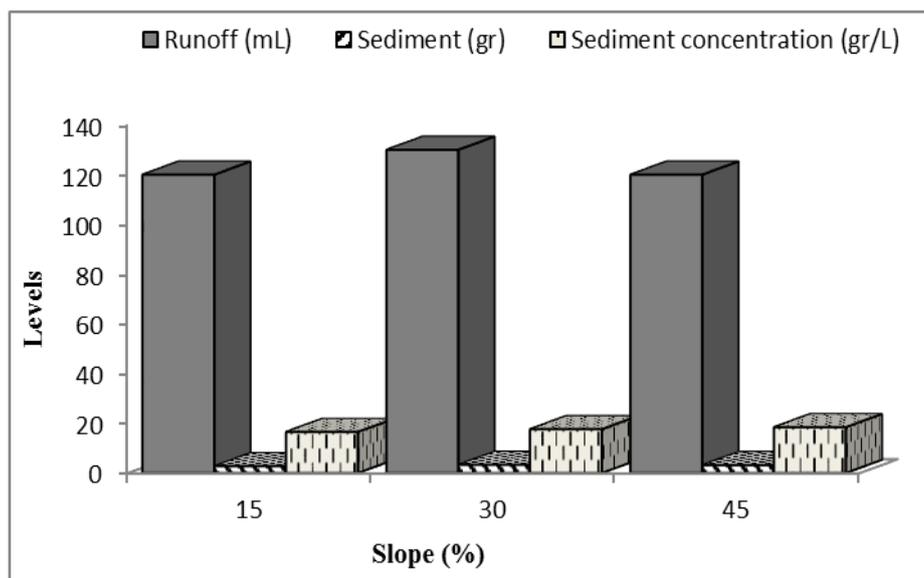


Fig. 5. The amount of runoff volume, sediment and sediment concentration in three slope treatments (15% to 30% and 45%).

Results of analysis of variance test on the sediment in slope treatments revealed that there were significant differences between the means ($p < 0.05$).

Alterations of the ingenerated sediment means in the three slope treatments and also different coverage percentages exhibited that there was a significant difference only between the slopes of 15% and 30% ($p < 0.05$). However, there were no significant differences between the other treatments. The sediment increased from the slope of 15% to 30%, but reduced from 30% to 45% (Fig. 6).

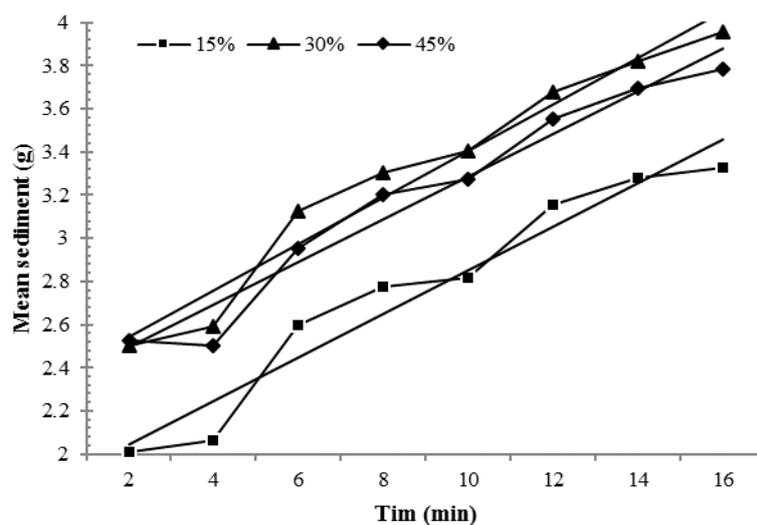


Fig. 6. The mean sediment in different slopes and time.

The effect of the straw length on runoff generation and sediment

The results showed that straw length is a determinative factor in runoff volume and sediment rate. Comparison of the different treatments (straw length) in terms of runoff generation is given in Fig. 7. A non-linear relation is observed between straw length and runoff and also sediment. There were statistically significant differences ($p > 0.01$; LSD test) in the straw lengths (1, 2, 5 cm, and complete length) once comparing between the factors levels. The optimal length of rice straw was defined based on the efficiency in decreasing runoff and sediment (Fig. 8).

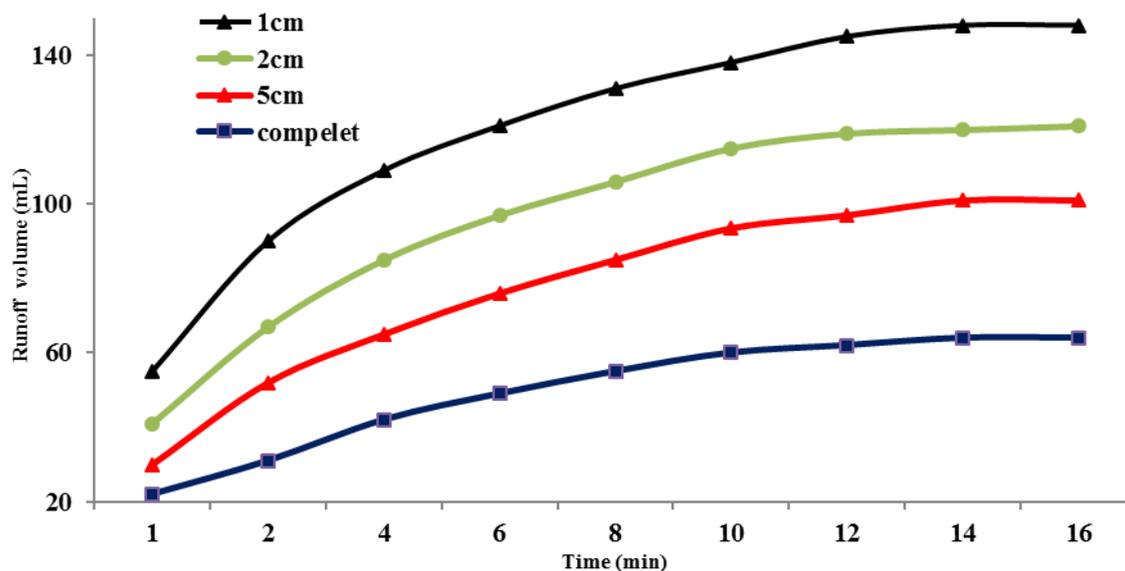


Fig. 7. Comparison of runoff volume in the different treatments (straw length: 1, 2, 5 cm and complete length).

The effect of slope on sediment

ANOVA test did not display a significant difference between the mean sediments in different slopes. The

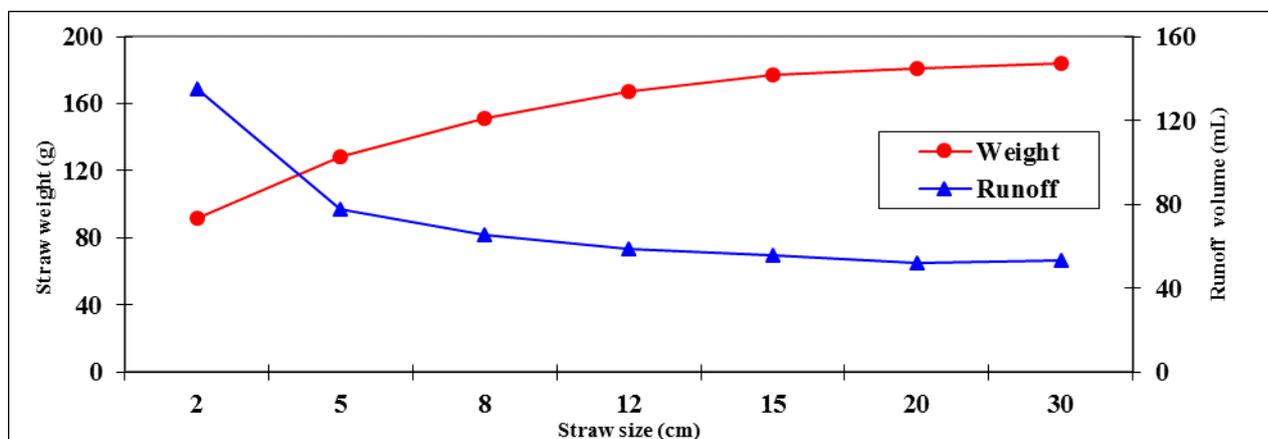


Fig. 8. Comparison of runoff volume in the different treatments of straw length for defining optimal length of straw.

Process of the simulation revealed that by elevating the rainfall time, sediment in the test plots increased (Fig. 9). The mean sediment in slope treatments were 2.7, 3.3 and 3.1 g, respectively. By increasing in slope from 15% to 30%, the mean sediment in plots was upraised. Moreover, the results indicated that the mean sediment concentration in slope classes was significantly different ($p < 0.05$). LSD test (at the 0.05 level) showed that there were significant differences between increasing in slope from 15% to 30% and from 15% to 45% but not from 30% to 45%. Fig. 9 illustrates the mean concentration of sediments in different coverage's (0, 30, 60 and 90%) due to changes in slope (15, 30 and 45%).

The mean amount of sediment concentration during the simulation time showed that over time the sediment concentration increased in different slopes and in slopes of 15% and 45%, at the beginning of the simulation the

concentration was high (splash erosion) then increased with a constant trend. At first, the rain simulation (2nd minute) washed the unfounded material and then the amount of sediment became normal after 4th minute.

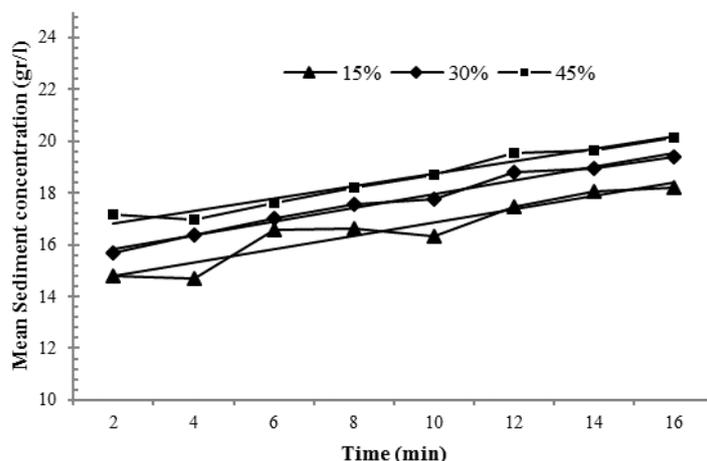


Fig. 9. The mean sediment concentration in different slopes and time.

The interaction of coverage and slope

The results of two-way analysis of variance (factors: slope and coverage) on each of the measurements (the runoff volume, sediment and sediment) showed that the interaction between the cover and slope ($p < 0.05$) on mean volume of runoff was significant. However, the test showed no significant difference in the case of runoff and sediment (Fig. 10 and 11). Pearson coefficients between straw cover and slope with runoff and sediment are given in Table 5. The equation 2 and 3 are given for estimating based on filed plots data and regression analysis:

$$R = 0.240 - .002 (CV) + 2.87 (S) \tag{2}$$

$$\sqrt{E} = 2.83 + .012 (\sqrt{S}) - 274 (\sqrt{CV}) \tag{3}$$

where R is runoff volume (lit), CV is the cover rate (%), S is slope (%) and E is soil erosion or sediment weight (g). The presented models were significant ($Rsq > 0.8$ and $Sig. < 0.05$). The models validation was proved their efficiency in simulating runoff and sediment on the embankments. In the validation stage, the comparison between the actual- and simulated values presented a good result ($Rsq > 0.7$).

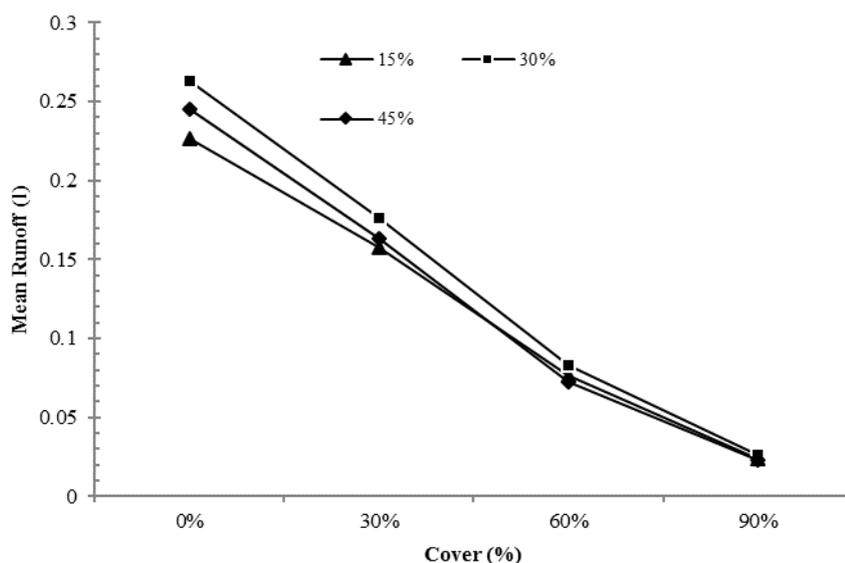


Fig. 10. The interaction of the straw cover and slope in the mean runoff (liter).

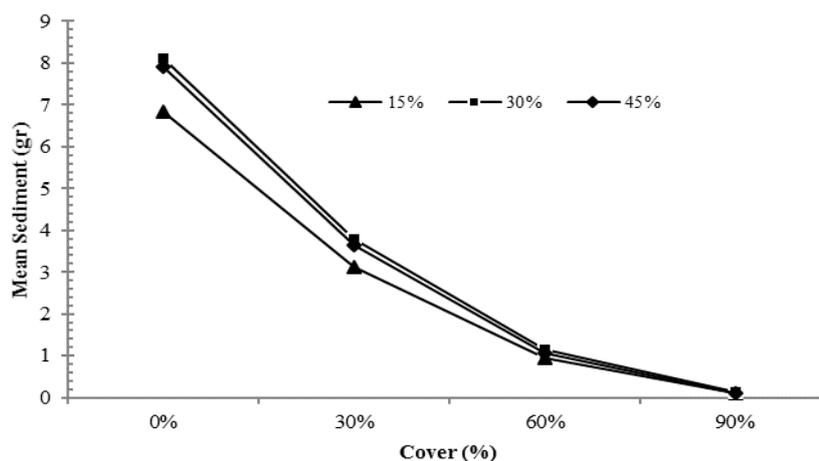


Fig. 11. The interaction of the straw cover and slope in the mean sediment (g).

Table 5. Pearson coefficients between straw cover and slope with runoff and sediment.

	Slope (%)	Cover (%)
Pearson Correlation	.015	-0.978**
Runoff (mL) Sig. (2-tailed)	.885	0.000
N	98	98
Pearson Correlation	.056	-0.931**
Sediment (g) Sig. (2-tailed)	.584	0.000
N	98	98

DISCUSSION

The results of field studies showed that the straw cover reduces runoff generation (Chang *et al.* 1977; Lorens & Domigo 2007), increase infiltration (Foltz & Copeland 2009), and reduce the kinetic energy of the raindrops relative to naked soil (Grismer & Hogan 2005; Lorens & Domigo 2007; Sun *et al.* 2014). Therefore, straw cover tends to reduce soil erosion (Huang *et al.* 2013). The straw cover above the ground intercept a substantial amount of rain water and can store some of the water, thereby reduce runoff and sediment (Chang *et al.* 1977; De Ona *et al.* 2009; Sun *et al.* 2015). Fig. 3 depicts that rice straw as a mulching material reduce runoff in bare treatments. It is reasonably effective in reducing erosion (Foltz & Copeland 2009). According to Figs. 4, the presence of the cover crop layers significantly reduced the rates of sediment (Yanosek *et al.* 2006; De Ona *et al.* 2009; Sun *et al.* 2015). Table 2 presents the mean sediments rate in the different cover percentages of rice straw. As shown in this table, by increasing the cover of the embankment from 0 to 30%, the amount of sediment decreased by 59%, while those of 60% and 90% were 78.5% and 98.5%, respectively. Burroughs & King (1989) estimated that straw mulch at 70% coverage would reduce soil loss by 72% for the covered soil. Rice straw is the commonplace method for conserving soil and water, because it can change the structure of the soil, and increase soil porosity and organic matter content. Soil infiltration would therefore increase and enhance the ability of the soil to resist erosion. The rice straw above the ground intercept a substantial amount of rainwater, and can store some of the water, thereby reducing runoff and erosion. They can also prevent raindrops from falling directly on the soil, effectively reducing the kinetic energy of the raindrops and the splash erosion. Rice straw is thus an important contributor to soil and water conservation (Chaplot & Bissonnais 2001; Sun *et al.* 2015, Du *et al.* 2019).

The amount of sediment in different cover conditions differs in the different rainfall times (Fig. 4). Notably, by increased simulation time, the amount of sediment also upraises. At the first moments, rainfall amount is less than initial loss rate (sum of the infiltration and interception). Therefore, we do not observe runoff. Hence, splash erosion is the main factor in sediment. Runoff occurs when the soil is unable to absorb or store rainfall (rainfall amount exceed from initial loss) and can subsequently result in surface and rill erosion. Hence, runoff will increase by elevating rainfall duration or amount. In a saturated soil, runoff coefficient will be 100% and

initial loss will be close to zero. In this condition, all of rainfall flows on the ground surface (convert to runoff). This trend in coverage of 0% and 30% increases to 14th minute with a faster speed than it increases with much slower speed. In cover of 0% and 90%, it declines after the 14th minute and the amount of sediment decreases over time. Jordan & Martinez (2008) and Jordan *et al.* (2009) concluded that sediment reduces after 8 minutes. At first, the rain simulation washes the unfounded stuff and then the amount of sediment becomes normal (Foltz & Wagenbrenner 2010).

As shown in Fig. 4, sediment has been significantly decreased at 60% and 90% covers. Foltz & Wagenbrenner (2010) also got the same results (Foltz & Wagenbrenner 2010). However, the amount of sediment over time in any cover time is always increasing. Different lengths of rice straw were used in the study plots. The results showed that the straws 5 cm in length play more roles in soil conservation (Figs. 7 and 8), because, the smaller lengths of the rice straw was transferred by runoff flow and those could not notably decrease sediment. Moreover, the bigger lengths of the rice straw increase its suitability and as a result, cost of soil conservation. Therefore, the experiments were conducted using the rice straws about 5 cm.

Table 4 shows the mean sediment concentration in different covers. By increasing the coverage from 0% to 30%, from 30% to 60% and from 60% to 90%, sediment concentrations decreased by 31.4%, 56.1% and 84.4%, respectively. By increasing the cover on the embankment of forest roads, the sediment generation decreased, leading to reduction in the sediment concentration in the runoff volume (De Ona *et al.* 2009; Foltz & Wagenbrenner 2010). Increasing in the slope of the road embankment and thus reducing the contact area with the rainfall reduces runoff (Govers 1990; Fox *et al.* 1997; Chaplot & Bissonais 2001; Assouline & Ben-Hur 2006).

The length of the area affected by rain and other experimental conditions can also influence the simulated sediment (Wang *et al.* 2009; Chamizo *et al.* 2012; Kaltenbrunner *et al.* 2012). Cumulative infiltration and the time for runoff generation have been reported to decrease as gradients elevates, and the gradient positively influenced runoff coefficients and sediment. By increasing in the slope, the infiltration and runoff production times are reduced, so increased slope upraises runoff and sediment (Chamizo *et al.* 2012).

The mean sediment in slope treatments was 2.7, 3.3 and 3.1 g, respectively. By increasing the slope from 15% to 30%, the mean sediment in plots was raised. However, by elevating it from 30% to 45%, the amount of sediment reduced. Mean sediment yield, similar to the results of Wang *et al.* (2005) simulated in a soil box, negatively correlated with slope gradients. According to previous explanations in dynamic force, by increase slope and reduced runoff, sediment will be reduced (Wang *et al.* 2009; Chamizo *et al.* 2012; Kaltenbrunner *et al.* 2012). Notably, the plot length (1 m × 1 m) is not suitable for evaluating the effect of slope alterations in sediment. In the case of slope, when slope gradient upraises, the shear stress of runoff flow will be elevated and as a result, soil erosion arises. The shear stress of runoff flow increases downward slope. Therefore, we cannot evaluate exactly the effect of slope alterations in a 1 m × 1 m-plot.

Fig. 9 shows the mean concentration of sediments in different coverages (0, 30, 60 and 90%) and changes in slope (15, 30 and 45%). Bare soil creates the highest concentration of sediment in various coverage, This difference decreases by arising coverage, hence, the lowest amount of sediment concentration can be seen in 90% coverage. Increase in cover was the result of critical gradient that was <10°. Sediment rate did not increase with slope degree above it (Wang *et al.* 2009; Sun *et al.* 2015). The mean amount of sediment concentration during the simulation time showed that the sediment concentration increased in different slopes over time and in slopes of 15% and 45%, at the beginning of the simulation, the concentration was high. Increased slope of the embankments arises the mean sediment concentration. Statistical analysis using SPSS software presented the non-linear equations to simulate runoff and sediment rates on the embankment of forest roads. These simple models can be applied to estimate runoff and soil loss on the embankments with different the straw cover and slope conditions. Furthermore, those can be used as a tool for designing and managing forest roads in the northern Iran.

CONCLUSIONS

Straw cover on the embankment of forest roads significantly reduces the amount of runoff volume, the soil erosion and the sediment concentration, and it can be used as an effective tool to reduce erosion in the embankment of forest roads. Cover crops has a direct influence on the amount of sediment, similar to those reported by previous studies (Foltz & Dooley 2003; De Ona *et al.* 2009; Foltz & Copeland 2009; Sun *et al.*

2015). Recent studies have even proven that these materials have suitable protection effects. Use of straw cover in the forest roads embankments can reduce runoff production, and reducing runoff production reduces sediment and sediment production in this embankments. Hence, it is important to select a suitable straw length for sediment conservation. The use of straw can decrease sediment on the embankment, but this decrease is more related to splash erosion. In the 1×1 m-plots covered by straw, runoff cannot flow in a short reach (velocity flow and shear stress). Therefore, the shear stress of runoff will play the weaker role in sediment. However, we observed that the tiny straws flow with runoff flow in the steeper slopes. Hence, further study with the use of other straw is needed to use of biologic methods in soil conservation, and also a longer plot length is suggested to be used for evaluating the effects of shear stress (water erosion) on the hill slopes. The results of this study can be used as an efficient tool for the managers of forest areas to reduce the harmful effects of the newly established roads.

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بررسی تاثیر کاه و کلش برنج در میزان فرسایش دیواره‌های خاکبرداری جاده جنگلی

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چکیده

استفاده از کاه و کلش برنج به عنوان مالچ در خاکریزهای تازه ایجاد شده یکی از راه‌های کاهش اثرات زیست محیطی حاصل از رسوبات از خاکریزهای جاده‌های جنگلی است. با این وجود، تأثیر این نوع پوشش کاملاً شناخته شده نیست و مشخص نیست که میزان استفاده از آن با عواملی مانند شیب چگونه تغییر می‌کند. در این مطالعه، تأثیر درصد پوشش کاه و کلش و شیب در بر حجم رواناب و فرسایش خاک با استفاده از شبیه‌ساز باران در قطعات ۱ متر در ۱ متر در خاکریزهای جاده‌های جنگلی بررسی شد. اثرات چهار تیمار پوششی کاه و کلش برنج (۰٪، ۳۰٪، ۶۰٪ و ۹۰٪)، سه تیمار شیب دامنه (۰-۱۵٪، ۱۶-۳۰٪ و ۳۰-۴۵٪)، با سه تکرار بطور کامل در یک طرح آزمایشی با ۳۶ پلات مورد بررسی قرار گرفت. در هر دو دقیقه یک بار مقادیر رواناب و رسوب در طی شبیه‌سازی بارش با شدت ۶۵ میلی‌متر در ساعت به مدت ۱۶ دقیقه ثبت شد برداشت گردید. ۱۶ دقیقه شبیه‌سازی بارش به هشت دوره ۲ دقیقه‌ای تقسیم شد. نتایج نشان داد که افزایش پوشش کاه و کلش (بر اساس طول و مقدار) منجر به کاهش معنی‌داری در حجم رواناب و فرسایش خاک می‌شود. علاوه بر این، بررسی اثر شیب دامنه‌ها نشان داد که میزان رواناب بین کلاس‌های شیب ۰ الی ۱۵ درصد و ۱۵ الی ۳۰ درصد تفاوت معنی‌داری دارد. از نظر غلظت رسوب (گرم بر میلی‌لیتر) و وزن رسوب (گرم)، بین پلات‌ها مورد مطالعه (شیب‌های مختلف و پوشش‌های مختلف) تفاوت معنی‌داری وجود داشت. نتایج نشان داد که کاه و کلش کشاورزی می‌تواند فرسایش خاک را تا ۹۰٪ در خاکریزهای جاده جنگلی کاهش دهد و از نظر سایز، کاه به طول ۵ سانتی‌متر اقتصادی‌ترین انتخاب برای محافظت از خاک در برابر فرسایش می‌باشد.

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