www.gi.sanu.ac.rs, www.doiserbia.nb.rs
J. Geogr. Inst. Cvijic. 2021, 71(2), pp. 135–150

Original scientific paper

UDC: 911.1:551.588
https://doi.org/10.2298/IJGI2102135B

Received: January 7, 2021
Reviewed: April 21, 2021
Accepted: May 17, 2021

VEGETATION COVER EFFECTS ON SEDIMENT CONCENTRATION AND OVERLAND FLOW UNDER ARTIFICIAL RAINFALL INTENSITY

Mounia Boussaadi[1]*, *Liatim Mouzai*[1]

[1]University of Sciences and Technology Houari Boumediene, Faculty of Civil Engineering, Department of Geotechnical and Hydraulic, Algiers, Algeria; e-mails: boussadi.mounia@gmail.com; mouzail@yahoo.fr

Abstract: Soil erosion depends on a number of factors including rainfall intensity, density of plant cover, and area cover. The objective of this study is to investigate the impact of these factors on flow velocity, overland flow regimes, sediment concentration, and absolute soil detachment. The soil used in this study was sandy remolded agricultural soil. The soil is packed in a tray of 1 m^2 fixed on a slope of 3%; five different intensities were simulated under different vegetation cover (density and area). The results indicated that the overland flow velocity with vegetation cover was best described by polynomial function. The mean flow velocity varied from 0.021 to 1.244 m/s. Overland flow regime is subcritical and laminar. However, there are significant relationships between the vegetation cover density and sediment concentration and absolute soil detachment. The sediment concentration ranged from 1.38 to 5.65 kg/m^3 whereas the absolute soil detachment ranged from 0.021×10^{-3} to 1.244×10^{-3} kg/m^2/s. Finally, the vegetation cover presented a good protector to soil sediment from erosion.

Keywords: simulated rainfall; density cover; surface cover; sediment concentration; hydraulic parameters

Introduction

In Algeria, water erosion phenomenon is a serious problem, because 45% of the cultivated surfaces are located in the sensitive area to erosion; which is, more than 12 million hectares (Bouanani, 2004). Soil erosion is a major obstacle for agriculture development, either for promoted rural activity or for the management of the hydrotechnical structure (Achite, Touaibia, & Ouillon, 2006). The erosion rate changes from region to region; in the western part of the country, this phenomenon affects 47% of all lands followed by the North Center region with 27%, then the East region by 26% (Achite et al., 2006).

The vegetation cover has an important role to control the soil erosion (Zhou, Shangguan, & Zhao, 2006). The cover protects the soil by trapping and keeping a part of eroded sediments against degradation (Rey, Vallauri, & Chauvin, 2001). In addition, soil stability is ensured by the vegetation cover and the root system. First, the leaves and stems protect the soil by intercepting and reducing the rainfall intensity impact depending on various factors such as, the volume of water stored in the canopy, the distribution of water movement on the architecture of the vegetation. Secondly, the developed roots tripe the sediments and fix the soil matrix. For the high vegetation such as trees, the soil protection is different. Zhou, Wei, and Yan (2002) reported that, when rainfall

---

*Corresponding author, e-mail: boussadi.mounia@gmail.com intensities are less than 20 mm/h, the single layer eucalyptus vegetation increased significantly the kinetic energy of water drops to the land surface, and consequently, accelerated soil erosion. However, these vegetation covers have positive impacts on the reduction of soil erosion for the rainfall events of larger intensities (particularly > 40 mm/h).

From the literature review the vegetation cover effects on soil erosion is widely investigated and variable results and conclusions have been reported. Vegetation increases the resistance of soil to erosion, by reducing detachment forces of water flow. On the other hand, the nature of vegetation cover and soil are due to the aggressiveness of the rain. Also, erosion, runoff and infiltration depend on this aggressively. Fullen, Zhi, and Brandsma (1998) estimated that, when the vegetation cover established 30% of the area the erosion rates decreased to tolerable levels. So beyond 30%, it is possible to get an extinction of the gully in the ravine bed (Rey et al., 2001) since the ravines are still located on the plots with low vegetation cover (corn, sunflower in spring, barley, wheat, corn residues in fall and winter, etc.). Rogers and Schumm (1991) have set a critical vegetation cover density for a specific sandy loam soil that is 15% on a 10% slope; below this density the vegetation cover does not reduce the erosion of dry soil. The rain affects erosion in both cases, where the soil is bare and even in the presence of vegetation cover by their different hydraulic and erosive parameters. Arnaez, Lasanta, Ruiz-Flaño, and Ortigosa (2007) have observed an increase in erosion with the intensity of rain however the use of a vegetal cover is paramount in the protection of the soil from the detachment of particles. According to the literature, vegetation cover decreases soil loss and increases infiltration. Also a high density eliminates the formation of crust because the rain splash is not produced (Janeau, Mauchamp, & Tarin, 1999). While good vegetation cover reduces the effect of rainfall precipitation on erosion, because the vegetation has a direct physical impact on runoff generation, as well as, vegetation and residue cover protect the soil from raindrop impact and splash (Molina et al., 2007). The small density of wheat seedling is unable to protect the soil against the detachment by the raindrops impact by intercepting (Li, Zhang, Wang, & Yang, 2015). Bassette and Bussière (2008) mentioned that the interception is affected by several parameters which depend on the distribution of the rainfall. So, the protection of the soil from the effect of the rain depends much more on the density of the vegetation cover as well as the characteristics of the vegetation. From these variable results and conclusions, we point out that the density of vegetation is an important parameter to investigate.

The measurement of soil detachment in the presence of a vegetal cover has been the objective of several studies (Fattet et al., 2011; Liu, Tian, Warrington, Zheng, & Zhang, 2010). Furthermore, interrill erosion is caused by soil particles being detached by raindrops and transported by overland flow (Romero, Stroosnijder, & Baigorria, 2007). To describe the effect of vegetation cover on erosion and to understand the mechanism of erosion it is important to measure and estimate the hydraulic parameters that characterize the flow, such as, Reynolds number (*Re*), Froude number (*Fr*), and flow velocity parameters.The vegetation cover increases the resistance of the surface to erosion with increasing the roughness of the soil surface and it affects directly the flow velocity and shear stress by reducing both of them (Brookes, Hooke, & Mant, 2000). Furthermore, Liu et al. (2010) note that vegetation cover affected the hydrological characteristics of the overland flow by reducing the Froude (*Fr*) and Reynolds number (*Re*). From this context, we understand that the overland flow hydraulics could contribute to estimate soil erosion under the vegetative cover.

This study aims to investigate the effects of plant density with the area cover, on the hydraulics of overland flow generated by artificial rainfall intensity and soil erosion, under saturated agricultural soil. The main objective is focused on which factor, density cover or surface cover has an effect on soil erosion. The other objectives are: (i) find a theoretical relationship between the hydraulic parameters such as the velocity, the Reynolds (*Re*), and Froude numbers (*Fr*) on one side and sediment concentration, area cover and rainfall intensity on the otherside; (ii) relate all these cited parameters to density cover; and (iii) test the artificial stems as a support for the wild oat and use a saturated agricultural soil.

Materials and methods

Experimental set up

The artificial rainfall is generated by a rainfall simulator (ORSTOM type) (Figure 1), which has a pyramidal structure of 2.7 m height. At the top of the carriage, a nozzle spraying system is fixed to a mobile arm, which is linked to a device that allows the change of oscillation velocity. Soil tray is 2 m length, 0.5 m width and 0.15 m depth, fixed on 3% slope. The soil used in this study is brought from an agriculture station research in Algeria. It is consisted of 75.05% coarse sand, fine sand 12.15%, coarse silt 6.05%, 4.91% fine silt, and 5.05% clay. The soil is air–dried, then sieved through 2 mm mesh to remove the stones and debris in the purpose to have a homogenous soil as proposed by Espigares, Moreno-de las Heras, and Nicolau (2011).

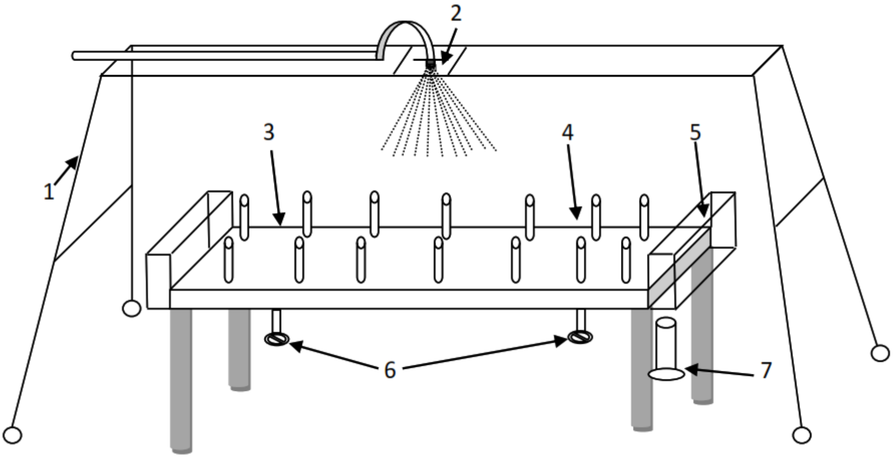

Figure 1. Schematic diagram of experimental set up. Pyramidal structure (1); spray nozzle (2); soil tray (3); vegetation cover (4); collector of waters (5); device of regulation of the flume soil slope (6); and cylinder (7).

The vegetation cover used in this investigation is the wild oats, with 150 cm in height. This vegetation is composed of many spikelets, with a size of 18 to 28 mm, which usually includes two glumes. This natural vegetation is collected from the nearside land of our department. The plants (Stems) are picked up at the end of the spring season; they are dry in this period, then selected one by one in such a way that the diameter is equal to 5 mm. After some test, the height is fixed at 50 cm because beyond this height, the stem did not resist to rainfall impact. To fix the plants into the soil, rigid plastic tubes are pushed into the soil, and used as upkeeps.

Experimental procedures

The rainfall intensity is measured using 30 rain gauges (glass cylinders) 6.5 mm in diameter, spaced uniformly over the soil plot. The volume of collected water in each gauge is divided by the reception surface and by the running time gives the rainfall intensity. The uniformity is tested using Christiansen formula (Grierson & Oades, 1977). The selected rainfall intensities are 30, 70, 80, 90, and 100 mm/h. Some authors (e.g., Arnaez et al., 2007) classified the rainfall intensity as follows, low intensity (I < 40 mm/h), intermediate intensity (45–70 mm/h), and high intensity (I > 70 mm/h).

Soil preparation

A thin layer of gravel is put on the bed of the soil tray, before setting up the soil (Parsons & Stone, 2006) in the purpose to reduce the thickness and ovoid slippage of the soil. Then the soil is packed gradually, in such a way that the soil surface is flat and homogeneous, and then smoothed to decrease the effect of microtopography (Li et al., 2015). Before each run, the soil is saturated using fine spray in the purpose to do not disturb the structure of the soil surface. After each run the soil is added and mixed again with the rest of the soil to have a new soil surface (Parsons & Stone, 2006).

Five cover densities are tested, 64 stems/m², 264 stems/m², 458 stems/m², 798 stems/m², and 2500 stems/m² corresponding to vegetative covers 0.083, 0.218, 0.275, 0.294, and 0.453 respectively. Plastic tubes are pushed into the soil carefully, then, the natural plants are fixed into the artificial stems (plastic tubes) and the cover density is controlled by the space between the stems. The space of 2 cm, 3.5 cm, 4.5 cm, 6 cm, and 12 cm between the stems were used.

Surface flow velocity measurement

Flow velocity was measured by injecting dye tracer (Gilley & Finkner, 1991) at the top end of the soil tray. At each 50 cm along the tray, the time is recorded and the surface flow velocity U_s is calculated ($v = x/t$) and the mean value is calculated for each run. The run is repeated five times to represent the experiment. The mean flow velocity, U_m, is calculated using the following relationship (Equation 1):

Error! Bookmark not defined.$$U_m = K \cdot U_s \qquad (1)$$

where, K is a correction coefficient.

In the literature, variable values of K are used. Shen, Zheng, Wen, Han, and Hu (2016) reported that, the measured velocity using $KMNO_4$, is the mean velocity, and then, the value of K is 1. Other authors Liu et al. (2010) measured the surface flow velocity using $KMNO_4$, with a correction factor of 0.67. Smets, Poesen, Langhans, Knapen, and Fullen (2009) have measured flow velocity by injecting a dye tracer (brilliant blue G250 solution) and they used a correction factor K = 0.94. In this investigation, a correction factor of 0.67 is used.

Overland flow discharge and sediment concentration measurements

Overland flow discharge is measured volumetrically, using cylinders of one litre each 3 min. The running time of the experiment is 24 min and the experiment is repeated 5 times. At the end of the experiment run, the cylinders were shacked up and down to get a homogeneous mixture; the samples of 200 ml were taken and put into the oven for 24 h at 105 °C. The dry mass of sediments per volume represents the sediment concentration C_s (Romero et al., 2007).

To quantify the soil loss and take into account the eroded soil surface A, the absolute soil detachment ASD expression reported by Smets et al. (2009) has been chosen (Equation 2). For each run, an ASD is calculated and the mean value is evaluated.

Error! Bookmark not defined. $$ASD = \frac{C_s \cdot Q_m}{A} \tag{2}$$

Where, ASD kg/m^2/s; C_s is the sediments concentration kg/m^3; Q_m is the mean overland flow discharge m^3/s, and A is the soil surface m^2.

Area covers

As we know, each plant of wild oat is made of a set of fine stems holding spikelets with glumes, fixed on the main stem. The fine stems with spikelets overlap each other, form a canopy cover or a brush of vegetation, and make difficulties to measure the real cover surface. This situation leads us to measure the loosed soil without vegetation ASD_{bar} (barred soil) and the loosed soil with vegetation ASD_c for different rainfall intensities in the same conditions and Equation 3 was used to determine the area cover C_v, which varied from 0 to 1.

Error! Bookmark not defined. $$ASD_c = ASD_{bar} \cdot (1 - C_v) \tag{3}$$

From Equation 3, the C_v is deduced and presented in Equation 4:

Error! Bookmark not defined. $$C_v = 1 - (ASD_c / ASD_{bar}) \tag{4}$$

where, ASD_c is the absolute soil detachment under vegetation cover, ASD_{bar} is the absolute soil detachment of barred soil (without vegetation), and C_v is the area cover calculated using the Equation 4 that has been deduced from Equation 3 and which is developed on basis of studies.

Basic equations without vegetation

In order to investigate overland flow generated by rainfall in the presence of vegetation cover on saturated agricultural soil, the hydraulic parameters characterizing the flow need to be known. Froude number (Fr) is defined as the ratio of inertia to gravitational forces. A critical value separating subcritical and supercritical flow is 1 (Zhao, Gao, Huang, Wang, & Zhang, 2016). The Fr is expressed by:

$$Fr = \frac{U_m}{\sqrt{g \cdot h}} \tag{5}$$

where, g is gravity acceleration, 9.81 m/s^2 and h is the mean flow of depth m.

The Reynolds number (Re) is defined as the ratio of inertia to viscous forces. Järvelä (2005) expresses Re as follows:

$$Re = \frac{Q_m}{\nu} \tag{6}$$

where, ν is the Kinematic viscosity of water ($\nu = 1.14 \times 10^{-6}$ m^2/s).

Basic equations under vegetation cover

The action of raindrop impact on the sheet of flowing water further complicates the overland flow characteristics. It disturbs the hydraulic of overland flow such as depth and velocity and thus all the parameters related to these two factors. It creates turbulence and clouds within the overland flow layer which greatly increases its detachment and transport and producing more erodible soil.

The flowing water generated by rainfall simulator on remolded agricultural soil is charged of a mixture, sediments and water. Thus, the unit overland flow discharge collected at the end of the soil tray mentionned by the relation bellow will be developed to establish an Equation 7 for finding a relation between hydraulic parameter and vegetation cover.

$$q_m = q_w + q_s \tag{7}$$

Where, q_m is the unit flow discharge of the mixture m^2/s, q_w is the unit flow discharge of water m^2/s, and q_s is the unit sediment discharge kg/s. The sediment flow discharge q_s is related to sediment concentration and water discharge (C_s) by the following expression:

$$q_s = q_w \cdot C_s \tag{8}$$

Substituting Equation 8 into Equation 7, we get Equation 9:

$$q_m = q_w \cdot (1 + C_s) \tag{9}$$

In this study the soil is always renewed and saturated using a fine rainfall intensity, before each experimental run, this is to say that, the flowing water starts earlier, and the water discharge could be calculated from this relation.

$$q_w = I \int dx \tag{10a}$$

In this integral, x represents the distance at which the water discharge is measured. In this present study, the length of the soil tray until the collector is L, then, we can write Equation 10a:

$$q_w = I \cdot L \tag{10b}$$

where, I is the rainfall intensity generated by the simulator mm/h; L is the length of the soil plot m.

The effect of vegetation cover on rainfall intensity is considered in this investigation. The rainfall intensity in the presence of vegetation cover is related to the effective rainfall by this relationship (Abrahams, Krishnan, & Atkinson, 2001):

$$I_{eff} = I \cdot (1 - C_v) \tag{11}$$

where, I_{eff} is the effective rainfall mm/h or the through fall rainfall touching the soil and C_v is the vegetation cover varied from 0 to 1.

Combining Equation 9, 10b, and 11, we can get Equation 12 and then, overland flow discharge of the mixture under vegetation cover and saturated soil could be expressed as:

$$q_m = I \cdot L \cdot (1 - C_v) \cdot (1 + C_s) \tag{12}$$

The hydraulic parameters, such us Reynolds number (Re) and Froude number (Fr) are expressed basing on Equation 12.

Overland flow is a sheet of water moving down slope; it is variable with time and space, since it is supplied by rainfall, depleted by infiltration. The overland flow could be influenced by roughness and vegetation and his flow regime may change from subcritical to supercritical.

Reynolds number (*Re*) of a flow generated by rainfall intensity, which is a measure of turbulence, normally represents laminar flow, but the flow is not truly laminar because of disturbance by falling raindrops. Such a disturbed flow is capable of eroding and transporting sediments (Emmett, 1970). The density of vegetation cover, which is related to surface cover and the type of vegetation, could also complicate the flow regime. This is the reason, why the Reynolds (*Re*) and the Froude (*Fr*) numbers are calculated in this study. Combining Equation 12 with Equation 5 and Equation 6, *Re* and *Fr* are obtained as follows:

$$Re = \frac{I \cdot L \cdot (1 - C_v) \cdot (1 + C_s)}{\nu} \tag{13}$$

According to this expression, the C_s contributes to the cloud of the flow, C_v perturbs the flow, I disturbs and creates the cloud by detaching soil particles from the soil matrix and L, the shear velocity increases with increasing L, thereforethe soil become more erosive.

$$Fr = \frac{U_m^3}{q \cdot I \cdot L \cdot (1 - C_v) \cdot (1 + C_s)} \tag{14}$$

In this expression, *Fr* number is a function of C_s, C_v, and I. The mean flow velocity has an effect three times (power 3) than the other factors, and is related to soil plot length. This means that more the length is long more the velocity is important and the regime can change from subcritical to supercritical.

Results

All the data measured such as overland flow velocity (U_m), overland flow discharge (Q_m), sediment concentration (*Cs*), and the calculated hydraulics parameters such as the Reynolds number (*Re*) and the Froude number(*Fr*), were analyzed statistically, and presented on Figures and Tables.

Impact of vegetation cover on the mean flow velocity

The data of mean flow velocity and density and surface cover are plotted on Figure 2a and 2b, and analyzed statistically. The results have shown that the best fit of the relationship is a polynomial function. The coefficients of determination varied between 0.853 and 0.993 for the effect of density cover and between 0.539 and 0.794 for the effect of the cover area on flow velocity. We point out that, there is a slight difference in the coefficients. The regression equations in the form of Equation 15 and Equation 16 and the corresponding coefficients of determination are presented on Table 1.

$$U_m = a \cdot \lambda^2 + b \cdot \lambda + c \tag{15}$$

$$U_m = a \cdot C_v^2 + b \cdot C_v + c \tag{16}$$

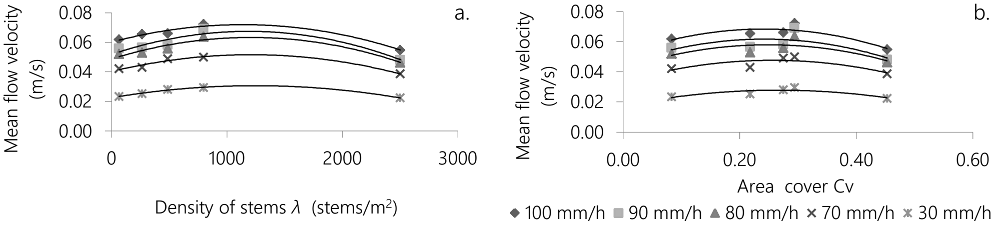

Figure 2. Effect of vegetation cover on flow velocity for different rainfall intensities. Relationship between mean flow velocity and density of stems (a); Relationship between mean flow velocity and area cover (b).

Table 1
Regression analysis of the relationships between mean flow velocity and vegetation cover

I (mm/h)	Density of stems		Area cover	
	Function	R^2	Function	R^2
30	$U_m = -5.25\times10^{-9}\lambda^2 + 1.30\times10^{-5}\lambda + 0.022$	0.993	$U_m = -0.145C_v^2 + 0.077C_v + 0.017$	0.780
70	$U_m = -7.79\times10^{-9}\lambda^2 + 1.88\times10^{-5}\lambda + 0.040$	0.942	$U_m = -0.215C_v^2 + 0.110C_v + 0.033$	0.681
80	$U_m = -1\times10^{-8}\lambda^2 + 2.41\times10^{-5}\lambda + 0.048$	0.906	$U_m = -0.254C_v^2 + 0.126C_v + 0.042$	0.576
90	$U_m = -1.11\times10^{-8}\lambda^2 + 2.63\times10^{-5}\lambda + 0.051$	0.853	$U_m = -0.280C_v^2 + 0.135C_v + 0.045$	0.539
100	$U_m = -9.16\times10^{-9}\lambda^2 + 2.079\times10^{-5}\lambda + 0.06$	0.961	$U_m = -0.288C_v^2 + 0.139C_v + 0.051$	0.794

Impact of vegetation cover on Reynolds number and Froude number

The relationship between Reynolds number (*Re*) and density of stems cover are illustrated on Figure 3. This relationship is best described by an exponential function in the form of Equation 17. Table 2 summarizes the equations and the coefficients of determination. R^2 varied from 0.782 to 0.895. From the equations, the constant *a* of Equation 17 evolves quite fast from 31.47 to 246.7; whereas the exponent *b* varied slowly from 0.00022 to 0.00033 with different rainfall intensities.

$$Re = a \cdot e^{b.\lambda} \tag{17}$$

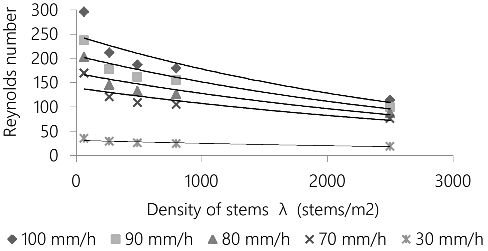

Figure 3. Relationship between Reynolds number and density of stems for different rainfall intensities.

Table 2
Regression analysis of the relationships between Reynolds number and density of stems

I (mm/h)	Function	R^2
30	$Re = 31.47 \cdot e^{-0.00022\,\lambda}$	0.871
70	$Re = 139.47 \cdot e^{-0.00026\,\lambda}$	0.782
80	$Re = 169.27 \cdot e^{-0.00028\,\lambda}$	0.824
90	$Re = 205.5 \cdot e^{-0.00030\,\lambda}$	0.895
100	$Re = 246.7 \cdot e^{-0.00033\,\lambda}$	0.861

Figure 4 shows the relationship between the Froude number (*Fr*) and density of stems. The coefficients of determination values are between 0.868 and 0.991. The polynomial functions in the form of Equation 18 are presented on Table 3. The Froude number (*Fr*) reacted differently from Reynolds number (*Re*) with density cover; even the R^2 values are a bit higher.

$$Fr = a \cdot \lambda^2 + b \cdot \lambda + c \tag{18}$$

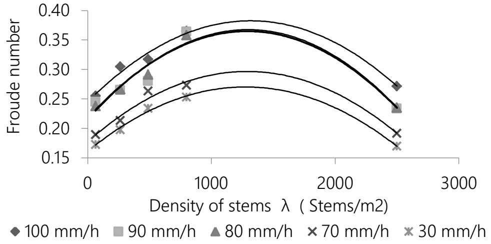

Figure 4. Relationship between Froude number and density of stems for different rainfall intensities.

Table 3
Regression analysis of the relationships between Froude number and density of stems

I (mm/h)	Function	*R*^{2}
30	$Fr = -6.72 \times 10^{-8}\lambda^2 + 0.00017\,\lambda + 0.161$	0.991
70	$Fr = -7.17 \times 10^{-8}\lambda^2 + 0.00018\,\lambda + 0.177$	0.959
80	$Fr = -9.11 \times 10^{-8}\lambda^2 + 0.00024\,\lambda + 0.214$	0.946
90	$Fr = -8.90 \times 10^{-8}\lambda^2 + 0.00023\,\lambda + 0.217$	0.868
100	$Fr = -7.93 \times 10^{-8}\lambda^2 + 0.00021\,\lambda + 0.245$	0.966

Impact of vegetation cover on sediment concentration

Many authors have found a difference in soil losses between a partly covered and uncovered land surface, and the importance of the vegetative cover in protecting the soil against erosion. In the purpose to enhance the understanding of the importance of soil protection in this study the density and the surface cover were investigated. The relationship between sediment concentration as a dependent parameter and the density and surface cover as independent parameters were plotted on Figures 5a and 5b. For both relationships, we point out that sediment concentration decreased with increasing vegetation (density λ and surface C_v) following an exponential function in the form of Equation 19 and Equation 20. The regression equations and the corresponding coefficients of determination were presented on Table 4.

$$C_s = a \cdot e^{b \cdot \lambda} \tag{19}$$

$$C_s = a \cdot e^{b \cdot Cv} \tag{20}$$

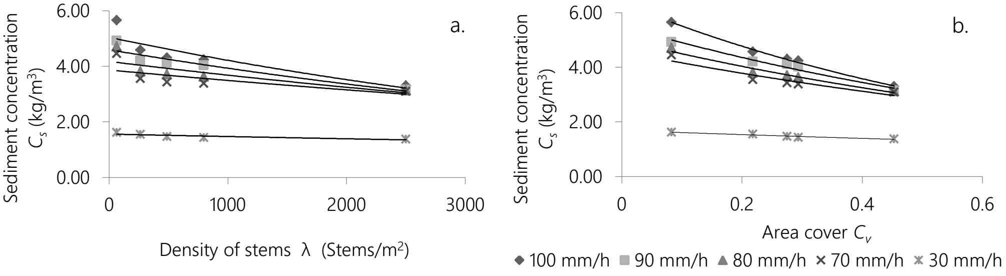

Figure 5. Effect of vegetation cover on sediment concentration for different rainfall intensities. Relationship between sediment concentration and density of stems (a); Relationship between sediment concentration and Area cover (b).

Table 4
Regression analysis of the relationships between sediment concentration and vegetation cover

I (mm/h)	Density of stems		Area cover	
	Function	R^2	Function	R^2
30	$Cs = 1.559 \cdot e^{-0.000056\lambda}$	0.720	$Cs = 1.686 \cdot e^{-0.02Cv}$	0.933
70	$Cs = 3.876 \cdot e^{-0.0001\lambda}$	0.541	$Cs = 4.582 \cdot e^{-0.04Cv}$	0.897
80	$Cs = 4.174 \cdot e^{-0.00013\lambda}$	0.699	$Cs = 5.008 \cdot e^{-0.05Cv}$	0.967
90	$Cs = 4.595 \cdot e^{-0.00016\lambda}$	0.903	$Cs = 5.520 \cdot e^{-0.06Cv}$	0.970
100	$Cs = 5.045 \cdot e^{-0.000181\lambda}$	0.832	$Cs = 6.360 \cdot e^{-0.07Cv}$	0.996

Impact of vegetation cover on absolute soil detachment

According to Equation 2, *ASD* is the ratio between C_s times Q_m and the soil surface *A*. The difference between the previous relationship and C_s, is to show the effect of the presence of soil surface on soil detachment. The data of absolute soil detachment and data of the surface and density covers are analyzed statistically and the relationships between them are illustrated on Figure 6a and 6b. The statistical analyses and the shape of the curves have shown that the relationships follow the exponential function (Equation 21 and 22) with high coefficient determination. The results are presented on Table 5.

$$ASD = a \cdot e^{b \cdot \lambda} \tag{21}$$

$$ASD = a \cdot e^{b \cdot Cv} \tag{22}$$

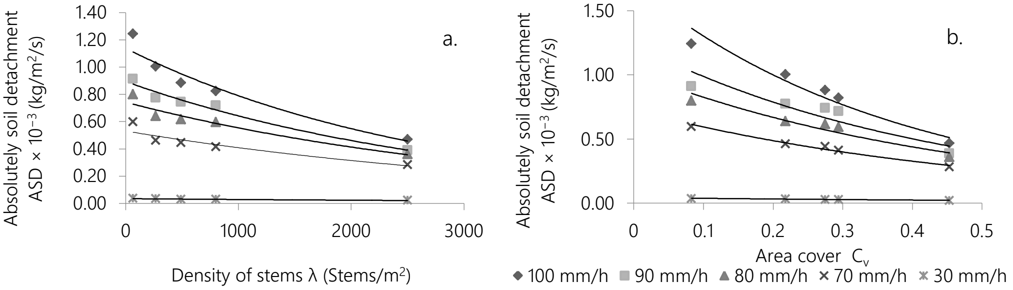

Figure 6. Effect of vegetation cover on absolutely soil detachment for different rainfall intensities. Relationship between absolutely soil detachment and density of stems (a); relationship between absolutely soil detachment and area cover (b).

Table 5
Regression analysis of the relationships between absolutely soil detachment and vegetation cover

I (mm/h)	Density of stems		Area cover	
	Function	R^2	Function	R^2
30	$ASD = 1.24 \cdot e^{-0.000192\lambda}$	0.993	$ASD = 1.479 \cdot e^{-1.26Cv}$	0.816
70	$ASD = 5.76 \cdot e^{-0.00015\lambda}$	0.793	$ASD = 7.023 \cdot e^{-1.21Cv}$	0.981
80	$ASD = 7.04 \cdot e^{-0.000144\lambda}$	0.831	$ASD = 8.463 \cdot e^{-1.14Cv}$	0.979
90	$ASD = 8.60 \cdot e^{-0.000175\lambda}$	0.938	$ASD = 10.42 \cdot e^{-1.27Cv}$	0.933
100	$ASD = 9.76 \cdot e^{-0.0002045\lambda}$	0.902	$ASD = 12.31 \cdot e^{-1.55Cv}$	0.967

Discussion

Soil erosion is affected by several factors among them there are rainfall intensity, slope, soil texture, vegetation cover (crop technique, root, etc.). Vogel, Deumlich, and Kaupenjohann (2015) proposed that to better protect the soil against erosion, it is necessary to reduce the flow velocity and increase the vegetation cover and soil roughness. So, the aim of this section is to discuss the influence of five (05) different rainfall intensities on a vegetation cover with a variation of five (05) densities under a fixed slope of 3% with a total of 125 experiments.

Impact of vegetation cover on mean flow velocity under different rainfall intensities

In this study we found that flow velocity values with different vegetation cover varied from 0.0224 to 0.0721 m/s (Figure 2a and 2b), which are different from that reported by Zhao et al. (2016), who found that the mean flow velocities ranged from 0.24 to 0.42 m/s. The difference could be related to experimental conditions, where cylinders were used to simulate the vegetation stems and slope was fixed at 9° under five overland flow discharges. Our results have indicated that the relationship between the mean flow velocity and vegetation cover follows a polynomial function (Table 1). The coefficient of determination varied from 0.853 to 0.993 for U_m = f(λ) and from 0.539 to 0.794 for U_m = f(C_v), hence the flow velocity is greatly influenced by the stems density λ than the area cover C_v. Contrarily, Pan, and Shangguan (2006) found that in the grassplots with different cover at a slope of 26.8%, the flow velocities decreased with an increase in grass cover. Investigating interrill erosion of vegetation cover (pasture) with variable slopes 15%, 25%, 35%, and 45% under simulated rainfall intensity 90 mm/h on plot of 2 m^2, Cantalice et al. (2016) reported that the flow velocity varied between 0.0232 and 0.0401 m/s. These values are close to those of this study. From the shape of the curves presented on Figure 2a, we point out that the flow velocity increased until a critical point, 1238, 1207, 1205, 1185, and 1135 stems/m^2 corresponding to rainfall intensity of 30, 70, 80, 90, and 100 mm/h respectively; then decreased until the last point. The critical points deduced mathematically from the regression equations. The explanation of this phenomenon could be related to the distribution of the plants. From point one to point four, the velocity increased, because the flow was concentrated between the rows of vegetation, so the flow of water was following a straight direction parallel to the row, which make a channel; and more the channel is narrow more the velocity is increased for the same rainfall intensity. For the last point, the vegetation is dense, the distance between stems is very short, the velocity is broken down, and the dense cover intercepts most of the rainfall intensity.

From these findings, we can conclude that, the mean flow velocity, U_m is better related to the density stems λ than area cover C_v following a polynomial function. More than this, the density cover could increase mean flow velocity until one critical point; once this point is overstepped, the velocity starts to decrease with increasing density and the rainfall intensity is gradually intercepted.

Impact of vegetation cover on Reynolds and Froude numbers under different rainfall intensities

The Reynolds number (*Re*) calculated by Equation 13 is less than 500, so the overland flow is laminar. The finding results have shown that Reynolds number (*Re*) versus stems density follows an exponential function (Figure 3, Table 2). In Equation 13 Reynolds number (*Re*) is directly related to the unit overland flow discharge, which depends on rainfall intensity, decreases with vegetation cover density. From the curves presented on Figure 3 and regression equations, we point out that Reynolds number (*Re*) is following an exponential function with cover density, and the curve shapes confirm the regression equations. The coefficients of determination varying from 0.782 to 0.895 without respecting the rainfall intensity show that the density cover influences Reynolds number (*Re*) as did the vegetation cover area as mentioned in Equation 13. From the graph, we can discuss the effect of rainfall on Reynolds (*Re*) and the effect of cover density on Reynolds (*Re*) is the same time. For cases, when the vegetation cover density is kept constant (e.g., 2500 stems/m^2), Reynolds number (*Re*) decreased as intensity rainfall decreased, from 114.27 for the intensity of 100 mm/h to 18.96 for the intensity of 30 mm/h. For cases, when the rainfall intensity is kept constant (e.g., 100 mm/h), Reynolds number (*Re*) decreased as vegetation cover density increased, from 295.77 for the vegetation cover of 64 stems/m^2 to 114.27 for the vegetation cover of 2500 stems/m^2. These results confirm the general findings of several authors (Liu et al., 2010; Pan & Shangguan, 2006). They reported that the overland flow in presence of vegetation cover is laminar. From the regression equations, we point out that the exponent *b* is not clearly variable, whereas the coefficient *a* varied from 31.47 to 246.7 corresponding to 30 and 100 mm/h respectively. Rainfall impact could influence the flow regime, as mentioned by Kilinc and Richardson (1973). They reported that raindrops continuously disturb the flow; it is not a turbulent flow, because the Reynolds number (*Re*) is low and the perturbations of flow by the raindrops die out as soon as raindrop impact is diminished.

From all these findings and the supporting literature, we can conclude that the Reynolds number (*Re*) could be affected by rainfall intensity, the cloud of sediments concentration, vegetation cover (area and density), slope, and length of slope. Furthermore, in particular case the Reynolds number (*Re*) follows an exponential function with the vegetation cover density, whatever the rainfall intensity.

As regards the Froude number (*Fr*), the regime of overland flow of this present study was subcritical, with Froude number (*Fr*) values ranged from 0.365 to 0.17 corresponding to 64 stems/m^2 and to 2500 stems/m^2 respectively. From Equation 14, Froude number (*Fr*) is a function of mean flow velocity, rainfall intensity, plot length, sediment concentration, and surface cover. From the shape of the curves presented on Figure 4 we point out that the Froude number (*Fr*) evolves with the density cover as did the mean flow velocity, and the best function describing the relationship is polynomial with high coefficient of determination of 0.868 and 0.991 (Table 3). The results of this study differ from the findings reported by Zhao et al. (2016) in which the flow is supercritical, whereas, some results supported our findings, such as those of Cantalice et al. (2016). They found that the overland flow under cover is laminar and subcritical. From these findings, we can concludethat the Froude number (*Fr*) still depends on soil and overland flow surface characteristics and rainfall properties.

Effect of vegetation cover on soil detachment and sediment concentration under different rainfall intensities

Zhou et al. (2016) suggested that, rainfall intensity has a positive effect on soil erosion. From the results shown on Figure 5a and 5b, we point out that the sediment concentration is increasing with the increasing of rainfall intensity for different vegetation cover and density. This result has been confirmed by Pan and Shangguan (2006). These increases are due to the impact of raindrops and amount of precipitation, which increased with rainfall intensity (Sun et al., 2016). In opposite to this, Defersha and Melesse (2012) reported that the sediment concentration did not show any discernable trend with rainfall intensity.

From the literature review, many investigations have concluded that vegetation cover has an important effect on detachment rates (Liu et al., 2016). Based on this, the relationship between *ASD* and the vegetation cover (Figure 6a and 6b; Table 5) have shown that the *ASD* is decreasing with increasing vegetation cover (λ and C_v) following an exponential function. The coefficients of determination varied between 0.793 and 0.993 for $ASD = f(\lambda)$ and between 0.816 and 0.981 for $ASD = f(C_v)$. These values indicate that there is a high relationship between *ASD* and the vegetation cover. This effect is supported by Liu et al. (2010). For comparison purposes, the relationship between sediment concentrations versus vegetation cover is plotted and the data were analyzed statistically (Figure 5a and 5b; Table 4). The results have shown that the sediment concentration is following an exponential function as did the *ASD*, and the coefficient of determination varied between 0.541 and 0.903 for $C_s = f(\lambda)$ and between 0.897 and 0.996 for $C_s = f(C_v)$. From these results we point out that *ASD* is better related to λ then C_s and less related to C_v then C_s. Liu et al. (2010) found that the soil loss ratios follows an exponential function with C_v, which confirm the finding of this study. Whereas, Liu et al. (2016) indicated that the soil detachement rate follows a linear function with C_v. The vegetation cover has an effective role to control soil erosion. Thrones (1988) (as cited in Nunes, de Almeida, & Coelho, 2011) found that the vegetation over 45% is seen as protector of soil while Snelder and Brayan (1995) observed that, 25–55% is potentially an effective density to control the erosion. Moreover, Snelder and Brayan (1995) have explained that the reduction of sediment concentration with increasing vegetation cover is due mainly to a reduction in particle training and splash. The coefficient *a* and exponent *b* values given in Equation 19 and 20 for different rainfall intensity are expressed on Table 4. The coefficient *a* and the exponent *b* values decreased with decreasing rainfall intensity. The coefficient *a* varied between 5.05 and 1.56 for $C_s = f(\lambda)$ and between 6.36 and 1.69 for $C_s = f(C_v)$. The exponent *b* ranges from 1.8×10^{-4} to 5.6×10^{-5} for $C_s = f(\lambda)$ and from 0.07 to 0.02 for $C_s = f(C_v)$. There is no significant differences in values of the coefficient *a* between λ and C_v, but there is a significant differences in values of exponent *b* between λ and C_v. Our values are less than those reported by Liu et al. (2010), who found $a = 35.66$ and $b = 1.18$, using a fixed rainfall intensity of 120 mm/h and 15% as a fixed slope varying only the vegetation cover. The difference could be related to the high slope steepness 15° used in their study. Martínez-Zavala, López, and Bellinfante (2008) investigating seasonal variability of runoff and soil loss on forest road back slopes under fixed simulated rainfall of 90 mm/h relating sediment concentration to vegetation cover and found an exponential function with $a = 11.445$ and $b = 0.057$ with high coefficient of determination $R^2 = 0.93$. We point out that the value of *b* of Martínez-Zavala et al. (2008) is much closer to *b* value of this study (see Table 4).

In the light of this context, we can conclude that, both the sediment concentration C_s and *ASD* are highly related with the vegetation cover (λ and C_v) following an exponential function, but the coefficients of determination show that $ASD = f(\lambda)$ and $C_s = f(C_v)$ represent better the effect of vegetation cover on soil loss. In addition to this the *a* value could be related to soil surface characteristics and *b* value to rainfall intensity.

Conclusion

The plants density and area covers, which are related to each other, reacted differently with the overland flow parameters and soil erosion under different rainfall intensities. In this study a remolded and saturated agricultural soil is used. From the results and the findings, we can conclude that, the mean flow velocity, U_m, is better related to the density stems λ than area cover C_v following a polynomial function. More than this, the density cover could increase mean flow velocity until one critical point; once this point is overstepped, the velocity starts to decrease with increasing density and the rainfall intensity is gradually intercepted. The critical point could be deduced mathematically from the regression equations.

As regards the Reynolds number (*Re*), on the light of the findings and the findings from the literature review, we can conclude that the Reynolds number (*Re*) vary with the experimental conditions. In this particular study the Reynolds number (*Re*) depends theoretically, on vegetative cover, sediment concentration, rainfall intensity, and length soil plot.

Based on the findings of these experiments and on the literature review, the Froude number (*Fr*) is highly related to the vegetation cover by a polynomial function. Finally, soil and overland flow surface characteristics and rainfall properties has an effect on Froude number (*Fr*).

From the results, the observations during the running experiment, and the findings, we can conclude that both, the sediment concentration C_s and *ASD* are highly related with the vegetation cover (λ and C_V) following an exponential function. But the coefficients of determination show that $ASD = f(\lambda)$ and $C_s = f(C_v)$ represent better the effect of vegetation cover on soil loss. In addition to this the *a* values could be related to soil surface characteristics and *b* values to rainfall intensity.

Finally, in this work the vegetation cover has been studied and roots have been dispensed. This is in order to know the extent of the impact of density on the soil erosion. Therefore, it can be said that the results obtained are exaggerated.

References

Abrahams, A. D., Li, G., Krishnan, C., & Atkinson, J. F. (2001). A sediment transport equation for interrilloverland flow on rough surfaces. *Earth Surface Processes and Landforms*, *26*(13), 1443–1459. https://doi.org/10.1002/esp.286

Achite, M., Touaibia, B., & Ouillon, S. (2006, May 14–19). *Erosion hydrique en Algérie du Nord: Ampleur, Conséquences & Perspectives* [Water Erosion in Northern Algeria: Extent, Consequences & Prospects]. 14th International Soil Conservation Organization Conference "Water Management and Soil Conservation in Semi-Arid Environments". Marrakech, Morocco. Retrieved from https://www.Researchgate.net/publication/269690195_Erosion_hydrique_en_Algerie_du_Nord_Ampleur_Consequences_Perspectives

Arnaez, J., Lasanta, T., Ruiz-Flaño, P., & Ortigosa, L. (2007). Factors affecting runoff and erosion under simulated rainfall in Mediterranean vineyards. *Soil and Tillage Research*, *93*(2), 324–334. https://doi.org/10.1016/j.still.2006.05.013

Bassette, C., & Bussière, F. (2008). Partitioning of splash and storage during raindrop impacts on banana leaves. *Agricultural and Forest Meteorology*, *148*(6–7), 991–1004. https://doi.org/10.1016/j.agrformet.2008.01.016

Bouanani, A. (2004). *Hydrologie transport solide et modélisation: Cas du bassin versant de la Tafna (NW Algerie)* [Hydrology, sediment discharge and modeling, study of some basins of Tafna (NW Algeria)] (Doctoral thesis, University of Abou Bekr Belkaid, Tlemcen, Algeria). Retrieved from http://hydrologie.org/ THE/BOUANANI_A.pdf

Brookes, C. J., Hooke, J. M., & Mant, J. (2000). Modelling vegetation interactions with channel flow in river valleys of the Mediterranean region. *CATENA*, *40*(1), 93–118. https://doi.org/10.1016/S0341-8162(99)00065-X

Cantalice, J. R. B., Silveira, F. P. M., Singh, V. P., Silva, Y. J. A. B., Cavalcante, D. M., & Gomes, C. (2016). Interrill erosion and roughness parameters of vegetation in rangelands. *CATENA*, *148*(Part 2), 111–116. https://doi.org/10.1016/j.catena.2016.04.024

Defersha, M. B., & Melesse, A. M. (2012). Effect of rainfall intensity, slope and antecedent moisture content on sediment concentration and sediment enrichment ratio. *CATENA*, *90*, 47–52. https://doi.org/10.1016/j.catena.2011.11.002

Emmett, W. W. (1970). *The Hydraulics of Overland Flow on Hillslopes* (Geological Survey Professional Paper 662–A). https://doi.org/10.3133/pp662A

Espigares, T., Moreno-de las Heras, M., & Nicolau, J. M. (2011). Performance of Vegetation in Reclaimed Slopes Affected by Soil Erosion. *Restoration Ecology*, *19*(1), 35–44. https://doi.org/10.1111/j.1526-100X.2009.00546.x

Fattet, M., Fu, Y., Ghestem, M., Ma, W., Foulonneau, M., Nespoulous, J., Le Bissonnais, Y., & Stokes, A. (2011). Effects of vegetation type on soil resistance to erosion: Relationship between aggregate stability and shear strength. *CATENA*, *87*(1), 60–69. https://doi.org/10.1016/j.catena.2011.05.006

Fullen, M. A., Zhi, W. B., & Brandsma, R. T. (1998). A comparison of the texture of grassland and eroded sandy soils from Shropshire, UK. *Soil and Tillage Research*, *46*(3–4), 301–305. https://doi.org/10.1016/S0167-1987(98)00096-8

Gilley, J. E., & Finkner, S. C. (1991). Hydraulic Roughness Coefficients as Affected by Random Roughness. *Transactions of the ASAE*, *34*(3), 0897–0903. https://doi.org/10.13031/2013.31746

Grierson, I. T., & Oades, J. M. (1977). A rainfall simulator for field studies of run-off and soil erosion. *Journal of Agricultural Engineering Research*, *22*(1), 37–44. https://doi.org/10.1016/0021-8634(77)90091-9

Janeau, J. L., Mauchamp, A., & Tarin, G. (1999). The soil surface characteristics of vegetation stripes in Northern Mexico and their influences on the system hydrodynamics: An experimental approach. *CATENA, 37*(1–2), 165–173. https://doi.org/10.1016/S0341-8162(98)00059-9

Järvelä, J. (2005). Effect of submerged flexible vegetation on flow structure and resistance. *Journal of Hydrology*, *307*(1–4), 233–241. https://doi.org/10.1016/j.jhydrol.2004.10.013

Kilinc, M. Y., & Richardson, E. V. (1973). *Mechanics of Soil Erosion from Overland Flow Generated by Simulated Rainfall* (Hydrology papers No. 63). Retrieved https://mountainscholar.org/bitstream/handle/10217/61574/HydrologyPapers_n63.pdf?sequence=1&isAllowed=y

Li, J., Zhang, F., Wang, S., & Yang, M. (2015). Combined influences of wheat-seedling cover and antecedent soil moisture on sheet erosion in small-flumes. *Soil and Tillage Research*, 151, 1–8. https://doi.org/10.1016/j.still.2015.02.006

Liu, G., Tian, F. X., Warrington, D. N., Zheng, S. Q., & Zhang, Q. (2010). Efficacy of grass for mitigating runoff and erosion from an artificial loessial earthen road. *Transactions of the ASABE*, *53*(1), 119–125. https://doi.org/10.13031/2013.29509

Liu, Y.-J., Hu, J.-M., Wang, T.-W., Cai, C.-F., Li, Z.-X., & Zhang, Y. (2016). Effects of vegetation cover and road-concentrated flow on hillslope erosion in rainfall and scouring simulation tests in the Three Gorges Reservoir Area, China. *CATENA*, *136*, 108–117. https://doi.org/10.1016/j.catena.2015.06.006

Martínez-Zavala, L., López, A. J., & Bellinfante, N. (2008). Seasonal variability of runoff and soil loss on forest road backslopes under simulated rainfall. *CATENA*, *74*(1), 73–79. https://doi.org/10.1016/j.catena.2008.03.006

Molina, A., Govers, G., Vanacker, V., Poesen, J., Zeelmaekers, E., & Cisneros, F. (2007). Runoff generation in a degraded Andean ecosystem: Interaction of vegetation cover and land use. *CATENA, 71*(2), 357–370. https://doi.org/10.1016/j.catena.2007.04.002

Nunes, A. N., de Almeida, A. C., & Coelho, C. O. A. (2011). Impacts of land use and cover type on runoff and soil erosion in a marginal area of Portugal. *Applied Geography*, *31*(2), 687–699. https://doi.org/10.1016/j.apgeog.2010.12.006

Pan, C., & Shangguan, Z. (2006). Runoff hydraulic characteristics and sediment generation in sloped grassplots under simulated rainfall conditions. *Journal of Hydrology*, *331*(1–2), 178–185. https://doi.org/10.1016/j.jhydrol.2006.05.011

Parsons, A. J., & Stone, P. M. (2006). Effects of intra-storm variations in rainfall intensity on interrill runoff and erosion. *CATENA*, *67*(1), 68–78. https://doi.org/10.1016/j.catena.2006.03.002

Rey, F., Vallauri, D., & Chauvin, C. (2001). Génie écologique contre l'érosion des marnes dans les Alpes du Sud [Ecological engineering against the erosion of marls in the Southern Alps]. *Ingenieries, 25*, 41–55. Retreived from https://hal.archives-ouvertes.fr/hal-00464527

Rogers, R. D., & Schumm, S. A. (1991). The effect of sparse vegetative cover on erosion and sediment yield. *Journal of Hydrology, 123*(1–2), 19–24. https://doi.org/10.1016/0022-1694(91)90065-P

Romero, C. C., Stroosnijder, L., & Baigorria, G. A. (2007). Interrill and rill erodibility in the northern Andean Highlands. *CATENA*, *70*(2), 105–113. https://doi.org/10.1016/j.catena.2006.07.005

Shen, H., Zheng, F., Wen, L., Han, Y., & Hu, W. (2016). Impacts of rainfall intensity and slope gradient on rill erosion processes at loessial hillslope. *Soil and Tillage Research*, *155*, 429–436. https://doi.org/10.1016/j.still.2015.09.011

Smets, T., Poesen, J., Langhans, C., Knapen, A., & Fullen, M. A. (2009). Concentrated flow erosion rates reduced through biological geotextiles. *Earth Surface Processes and Landforms*, *34*(4), 493–502. https://doi.org/10.1002/esp.1729

Snelder, D. J., & Bryan, R. B. (1995). The use of rainfall simulation tests to assess the influence of vegetation density on soil loss on degraded rangelands in the Baringo District, Kenya. *CATENA*, *25*(1–4), 105–116. https://doi.org/10.1016/0341-8162(95)00003-B

Sun, J., Yu, X., Li, H., Chang, Y., Wang, H., Tu, Z., & Liang, H. (2016). Simulated erosion using soils from vegetated slopes in the Jiufeng Mountains, China. *CATENA*, *136*, 128–134. https://doi.org/10.1016/j.catena.2015.02.019

Vogel, E., Deumlich, D., & Kaupenjohann, M. (2015). Bioenergy maize and soil erosion—Risk assessment and erosion control concepts. *Geoderma*, *261*, 80–92. https://doi.org/10.1016/j.geoderma.2015.06.020

Zhao, C., Gao, J. E., Huang, Y., Wang, G., & Zhang, M. (2016). Effects of vegetation stems on hydraulics of overland flow under varying water discharges. *Land Degradation and Development*, *27*(3), 748–757. https://doi.org/10.1002/ldr.2423

Zhou, J., Fu, B., Gao, G., Lü, Y., Liu, Y., Lü, N., & Wang, S. (2016). Effects of precipitation and restoration vegetation on soil erosion in a semi-arid environment in the Loess Plateau, China. *CATENA*, *137*, 1–11. https://doi.org/10.1016/j.catena.2015.08.015

Zhou, Z. C., Shangguan Z. P., & Zhao, D. (2006). Modelling vegetation coverage and soil erosion in the Loess Plateau Area of China. *Ecological Modelling*, *198*(1–2), 263–268. https://doi.org/10.1016/j.ecolmodel.2006.04.019

Zhou, G., Wei, X., & Yan, J. (2002). Impacts of eucalyptus (*Eucalyptus exserta*) plantation on sediment yield in Guangdong Province, Southern China—a kinetic energy approach. *CATENA*, *49*(3), 231–251. https://doi.org/10.1016/S0341-8162(02)00030-9