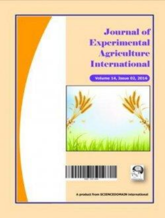

Journal of Experimental Agriculture International

22(4): 1-14, 2018; Article no.JEAI.40090
ISSN: 2457-0591
(Past name: American Journal of Experimental Agriculture, Past ISSN: 2231-0606)

Interrill Erosion in Semi-arid Soils: Impacts and Vegetation as an Attenuating Factor in Erosive Processes

Cristina dos Santos Ribeiro Martins[1], Ana Maria Maciel dos Santos[1], Antonio Elton da Silva Costa[1], Kleyton Danilo da Silva Costa[2], Jackson da Silva[3*] and Rejane Rodrigues da Costa e Carvalho[1]

[1]Rural Federal University of Pernambuco (UFRPE), Recife, PE, Brazil.
[2]Federal Institute of Alagoas (IFAL), Piranhas, AL, Brazil.
[3]São Paulo State University (UNESP), Botucatu, SP, Brazil.

Authors' contributions

This work was carried out in collaboration between all authors. Authors CSRM, AMMS and AESC planned the study and wrote the first draft of the manuscript. Authors KDSC, JS and RRCC managed the literature searches and edited the manuscript. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JEAI/2018/40090
Editor(s):
(1) Mariusz Cycon, Professor, Department and Institute of Microbiology and Virology, School of Pharmacy, Division of Laboratory Medicine, Medical University of Silesia, Poland.
Reviewers:
(1) Ade Onanuga, Canada.
(2) Ahmed Karmaoui, Morocco.
(3) Daniel Jaleta, Ethiopian Environment and Forest Research Institute, Ethiopia.
(4) Mehraj U Din Dar, Punjab Agricultural University, India.
(5) Natalia Borrelli, Universidad Nacional de Mar del Plata, Argentina.
Complete Peer review History: http://www.sciencedomain.org/review-history/24262

Review Article

Received 9th February 2018
Accepted 14th April 2018
Published 21st April 2018

ABSTRACT

Soil erosion is characterized as a serious environmental problem. Erosive processes depend on intrinsic soil characteristics, such as texture, structure, mineralogy, organic matter, as well as surface characteristics related to land use, vegetation cover, biological activity and edaphoclimatic interactions. In semi-arid regions, the problem is further aggravated by environmental conditions. Cultivation conditions in semi-arid environment are generally adversely affected conditions of fragile and poorly developed soils due to the occurrence of rainfall events, which are highly erosive. Besides precipitation, another factor of great relevance for soil erosion understanding is vegetation

---

*Corresponding author: E-mail: jackson.silva.batalha@gmail.com;

cover, because vegetation is an important factor in preventing soil erosion. Generally, vegetation attenuates erosion processes, mainly by reducing rainfall impact forces on soil, reducing runoff speed, increasing hydraulic roughness and water infiltration rates in soil, thus increasing its resistance to erosion.

Keywords: Interrill erosion; vegetation cover; semi-arid environment; food safety; sustainable production; erosion by rain.

1. INTRODUCTION

Soil is a vital component of the planet, fundamental to many aspects of the agrarian sciences [1]. In the last few years, this resource has been abruptly degraded, due to urban development and anthropogenic actions, leading to significant yield losses on agricultural crops [2,3,4]. Representing a threat to food security and limiting the production of renewable biological resources [3,4].

The environmental problems have presented great dimensions, causing, therefore, changes around the globe. The problems related to soil degradation are among the most concerning [5]. Soil erosion is a major environmental problem responsible for large soil losses, imbalances in the environment, as well as a decrease in productivity of cultivated lands [6].

Erosion is seen as one of the most destructive soil processes. It is estimated that man has already degraded 53 billion hectares of the terrestrial globe, by inappropriate use of the soil, leading to deterioration of its physical, chemical and biological properties [7,8]. In tropical and subtropical zones, the annual soil loss varies between 0.28 and 113 t/ha^{-1}, depending on the annual precipitation, landscape, and land use [9].

In semi-arid regions where the absence of vegetation cover is common, the erosive processes are more intense after rainfall events. Under these conditions, the importance of native vegetation is relevant to the regulation of surface hydrological processes. According to [10], vegetation removal is the main cause of soil degradation in semi-arid areas. Changes in soil properties induced by vegetation removal modify runoff and response to soil erosion in a semi-arid area.

Currently, soil erosion has been increasingly recognized as a serious environmental problem in semi-arid regions. Recent studies conducted in southern Italy (semi-arid Mediterranean) have soil erosion rates ranging from 10-85 t/ha/year^{-1}, in areas covered by vegetation [11] and from 100-150 t/ha/year^{-1}, in cultivated lands [12]. These high erosion rates reflect the impact caused by human activity.

The rainfall regime in semi-arid areas is characterized by events of extremely short duration and with very high intensity, besides an irregular spatio-temporal distribution, followed by long periods of drought, making these areas environments particularly prone to erosion [13]. Human activities potentialize the risk of erosion. Among those is the creation of bare surfaces on cultivated land after plowing operations and subsequent abandonment of land [11].

In semi-arid regions, soils are characterized by low levels of organic matter and high levels of expansive clay [14], properties that may decrease the stability of soil structure [15]. This makes them very susceptible to water erosion [16], mainly due to scarce vegetation cover and low resistance to erosion forces. The magnitude of water erosion also depends on its texture, water content, evaporation, percolation and leaching. These characteristics are absent in soils of these regions, and make them more susceptible to water erosion [17].

When these soils are exposed to the impact of raindrops, a structural seal develops on the surface of the soil, called surface sealing [15,18], a thin layer (a few millimeters) characterized by having a higher density, and lower hydraulic conductivity than the underlying soil [19,20]. According to [21], the formation of surface sealing is the result of two complementary mechanisms: (i) the physical disintegration of the aggregates at the soil surface caused mainly by the kinetic energy of the impact of the raindrops, and (ii) the dispersion of clay particles, which clog the pores immediately below the surface of the soil [18].

(i) The disintegration of the soil particles from its surface, (ii) the transportation of the resulting sediments, mainly by the action of surface runoff, and (iii) sediment deposition [22] are involved in the erosive process. Soil erosion reduces water availability on the field scale by affecting its quality and storage. According to [23], the loss of water and soil by surface runoff on eroded slopes is maximized by different mechanisms, namely reduction of roughness, the effective evacuation of water flows from the inclination through the rill networks, which increase the connectivity of the runoff on the slopes and open efficient ways to conduct water out of the system, and the reduction of water infiltration by formation of surface crusts, which are thin layers of organic and mineral particles on the soil surface, affect soil disaggregation [24], altering, infiltration of water in the soil and surface runoff [25].

There are a number of factors that control erosion. Among them, we can mention the angle of land slope, the nature and type of vegetation cover, the erodibility and the type of soil management [26]. The vegetation-soil system has mechanisms that regulate soil formation, vegetation development and erosion and sedimentation processes [27]. [28], studying the erosion in China semi-arid region, observed that runoff and soil loss varied according to the types of land use. They also observed that the higher the index of vegetation coverage the lower the erosion soil losses. [29] reported that when the vegetation cover rate increased by 10%, 28%, 56% and 60%, soil erosion decreased from 1523 t km2 to 527 t km2, 218 t km2 and 107 t km2, respectively. [30], also found that soil erosion was negatively linear correlated with the vegetation cover ($r = 0.99$) for a mountainous area.

In semi-arid environments, it is conventional to use dry land agriculture, where the farmer removes all the vegetation from riverbanks to cultivate agricultural species [31]. For the occurrence of sustainable production, farmers must have a selection of integrated management options [32], which will provide sufficient benefits with reasonable costs and, at the same time, reduce the degradation of dry lands and maintain sustainable incomes, such as the application of conservation strategies [33,34].

The implemented strategies should include agronomic measures of soil surface manipulation, such as mulching and changes to prevent and control land degradation and improve field-scale productivity. Despite government efforts to reverse soil erosion processes at the river basin scale, the pluviometric regime of semi-arid regions is very problematic, causing degradation and inefficiency in land use [35]. Moreover, even in years of sufficient annual precipitation yields remain low [36].

For [37], in a semi-arid environment, the preservation and/or restoration of vegetation can effectively reduce surface runoff and sediment transport. Native forests are more effective in soil erosion control [38]. Some researchers, but not all of them, state that a mixed pattern of trees and shrubs would be ideal for inhibiting soil erosion. In view of the above, the objective of the present study was to evaluate the importance of the relationships between soil water erosion and vegetation cover forms of the caatinga biome in a semi-arid environment.

2. INTERRILL EROSION: FACTORS THAT AFFECT DEVELOPMENT OF EROSIVE PROCESS

Soil erosion comprises two main components, interrill and rill erosion [39]. Interrill erosion happens when there are no incisions in the surface of the ground performed by the surface runoff. The most important factor at that moment is the breakdown of the soil by the impact of raindrops on its surface, and the existence of a blade of runoff that seems to carry more than disaggregate the soil [40]. The surface runoff that occurs in interrill erosion is frequently called shallow laminar flow [41].

Several are the negative effects on interrill erosion, highlighting the reduction of soil fertility, off-site effects triggered by sediment transport, nutrients, and pollutants, causing great efforts to mitigate damages, with high costs [42,43], affecting nutrient cycling and the functioning of the ecosystem [44,45].

Interrill erosion can also lead to the emergence of poor, hard soils, with low water storage capacity [46]. In the Revised Universal Soil Loss Equation (RUSLE), which is used to predict soil loss rates, the proportion of interrill erosion is a very important parameter [47], the same importance is equivalent to other models based on recent processes, for example, LISEM [48], WEPP [49], EUROSEM [26], and PSEM-2D. However, it is difficult to measure interrill erosion rates directly, because of the difficulty of observing the rill erosion processes associated with costs and the intensive work in the field [50].

The parameter of interrill erodibility, which expresses soil resistance to interrill erosion, is used along with other parameters, including rainfall erosivity, slope characteristics, hydraulic factors and vegetation cover. Where the last is one of the most important parameters for the study of interrill erosion [51,52], besides soil type and land use.

The vegetation cover has an important effect on soil erosion, the vegetable residues on the surface particles, and on the formation of surface sealing. In addition, plant residues on the soil surface reduce the interrill flow because the cover generally increases the hydraulic roughness of the surface flow, which in turn increases the height of the flow sheet [53]. [54] found an exponential reduction of interrill erosion with the increase in soil cover attributed to residues of maize and wheat. For [55], the interrill erosion and the reduction of the flow speed caused by the presence of plant residues on the surface occur generally because of the increase in hydraulic roughness of surface flow, resulting in increased flow height [54,56]. The relationship between the rates of disaggregation and the presence of plant residues in interrill erosion is expressed, according to [56], below:

$$D_i = K_i I^2 S_f C_i \tag{1}$$

Where Di is the rate of soil disaggregation (kg/m^{-2}/s^{-1}); Ki is factor of interrill erodibility (kg s/m^{-4}); I is the intensity of the rain (m/s^{-1}); Sf is the slope factor; Ci is the coefficient of soil cover. This coefficient Ci combines several subfactors, according to the expression:

$$C_i = C_iI\ C_iII\ C_iIII \tag{2}$$

Where C_iI is the factor that expresses the effect of cover of canopy; C_iII is the factor that expresses the effect of the cover by residues in direct contact with the surface of the soil; C_iIII is the factor that expresses the effect of the residue incorporated to the soil.

For the total hydraulic roughness estimate in agricultural areas, size, number, and volume of resistance elements should be considered [57]. It is also important to highlight the factors that determine differences in soil cover between cultural residues, namely type, shape, quantity, decomposition stage, distribution of surface, and soil preparation methods [58]. Residues effect on direct contact with soil surface in interrill erosion was evaluated by some authors, who proposed relations capable of quantifying the effect of this roughness in a way that translates in resistance to the flow and, therefore, in disaggregation rates of soil. [59] proposed the following expression to evaluate flow resistance:

$$C_iII = \xi exp\left\{ - 0.21\left[\left(\frac{yc}{yd}\right) - 1\right]^{1.18}\right\} \tag{3}$$

Where C_iII is the factor that expresses the effect of the cover by residues in direct contact with the soil surface; ξ is the fraction of surface exposed to the impact of rain; yc/yd is the ratio of laminar flow height with coverage (yc) and without coverage (d).

[60] developed a simpler expression:

$$C_iII = e^{2.5CS} \tag{4}$$

Where C_iII is the factor that expresses the effect of the cover by residues in direct contact with the soil surface; e is the basis of the neperian logarithm; CS is the soil cover (m^{-2}/m^{-2}).

[61], studying different types of vegetation cover on a dystrophic Red-Yellow Argisol, obtained an adjustment for the following power model:

$$C_iII = ab^{CS} \tag{5}$$

Where a = 1.014; b = 0.08203 for a r^2 of 0.992.

3. INTERACTION OF SOIL PROPERTIES AND ENVIRONMENTAL FACTORS THAT AFFECT SOIL DISINTEGRATION AND SOIL LOSSES

The disaggregation of soil in interrill erosion is defined as the displacement of soil particles from a soil mass at a specific location on the surface, by the kinetic energy of the raindrops, being the surface runoff the main transport agent, which may lead to the formation of rill and gullies [62,63,64,65,66]. The mechanisms of soil disaggregation by interrill and rill erosion are different and, therefore, they are considered separate processes [67].

Effects of capacity of soil disaggregation in interrill erosion have been studied extensively under different environmental conditions, both in laboratory and in field experiments, using hydraulic parameters such as flow regime, liquid discharge, slope, speed, and sediment concentration [67,68,69,70]. Erosive processes are also controlled by soil erodibility [71].

Soil erodibility is mainly related to soil properties and vegetation characteristics. Soil type, texture and physical-chemical properties of soil like porosity, density, cohesion, clay content, aggregate stability, organic matter content, soil moisture and infiltration rate are indicated in the literature as having a close relationship with the soil disaggregation capacity [26,72,73,74,75]. [76], studying erosive processes in semi-arid basins, found that there are complex interactions between spatio-temporal distributions of precipitation and hydrological responses of river basins. Still, according to these authors, local tempests are important patterns to determine the shape of the hydrographic flow.

[77] found that soil disintegration capacity can be determined by means of aggregate diameter, clay content, soil density and soil resistance. [78] showed the soil disintegration capacity decreased with the increase of soil organic matter, increase in moisture content and with an increase of soil density. Any changes in soil properties will surely alter erodibility of this soil [79,80,81,82,83]. In the study to determine soil erodibility in Cerrado in the Brazilian state of Goias, [84] analyzed the following factors: texture, specific soil and particle density, porosity and moisture retention curve. These authors observed that Quartzarenic Neosol presented greater susceptibility to water erosion when compared to other studied soils, eutrophic Red Argisol, anionic Acrustox, and eutrophic Red Nitosol. With this study, it was still possible to state that Quartzarenic Neosol has a lower cohesion rate between the particles and high concentration of sand fraction, and this may be related to a greater erodibility.

4. THE DIFFERENT FORMS VEGETATION INFLUENCE ON SOIL PROTECTION AND EROSION PROCESS RETARDATION

Vegetation cover has been recognized as a key factor in protection against erosion, increasing the infiltration and surface roughness of the soil, besides reducing the impact of raindrops [85]. The vegetal cover protects the soil, mainly by intercepting the precipitations and reducing the flow speed of water [86,87]. In addition, the root system increases the stability of soil aggregates and soil water infiltration rates [86,88,89].

However, although the positive influence of the vegetation increasing the rates of infiltration and decreasing soil erosion, little attention has been paid to the ecological effects of soil erosion [90,91]. In this way, several papers indicate a critical role of the knowledge of the erosion-vegetation interactions for the understanding of the processes of degradation in limited water environments, especially in the current context of land use and climate change [92,93,84].

In theory, both the morphological characteristics of plants, such as the diameter of the root, and biomechanical characteristics, the resistance to root traction, have significant effects on soil erosion [51,89].

The diversity of species is one of the main factors for the success of vegetation in controlling soil erosion; the functional diversity of tree communities plays a key role in improving ecosystem services, such as water filtration, climate regulation or erosion control [94,95,96]. As forests are generally considered to be beneficial for erosion control, reforestation is a common measure of soil protection [97,98].

Different forms of soil-vegetation relationship can probably be explained by different types of vegetation that present specific characteristics above the soil (leaves and stems), below ground (roots) and spatial distributions [86,99,100, 101,102]. Little is known about the effects of plant diversity on soil protection [103]. There are some indications about which type of plant cover would be more effective in controlling the processes of interrill erosion. As determined by [104], plant cover with a high number of species and different growth forms, functional groups, and root characteristics are more effective in controlling of interrill erosive processes. A study conducted by [89] in the Swiss Alps showed a significant positive correlation between soil aggregates stability and plant species richness. These authors assume that with the increase of plant species, the richness of the number of root types increased, resulting in beneficial effects on the stability of soil aggregates.

[105] studying Brazilian Cerrado, compared soil losses in areas cultivated with sugar cane, corn, eucalyptus and pasture, with native forest. In this study, the native forest had a lower erosion value, being 0.39 Mg $ha^{-1}/year^{-1}$; On the other hand, the highest value was found in cane and corn crops, from 32.50 Mg $ha^{-1}/year^{-1}$ and 42 Mg

ha^{-1}/year^{-1} respectively. These results are satisfactory when analyzed in view of the fact that maize and sugarcane crops have lower vegetation cover, besides the influence of soil types and declivity of the study area.

In the study of land use in the mid-State of Rio Grande do Sul, [106] show that, with a 16.2% increase in forest area, gross erosion was reduced by 44%. [107] carried out a study on erosion in Formoso river basin, state of Tocantins, using the Universal Soil Loss Equation. Soil losses were estimated by erosion. Results showed that, in areas of uncovered soil, natural erosion potential presented an average of 1,200 Mg ha^{-1}/year^{-1}, considered quite high.

[108] applied the RUSLE modeling associated with multitemporal soil use/cover analyzes aiming to verify the effect of the changes in soil use in the erosive process. The period from 1986 to 2011 was evaluated. Results showed changes in soil use have relevant implications in the erosive process. Areas were found with soil loss above TPS (Soil Loss Tolerance) increased from 7.9% in 1986 to 8.4% in 2011. In this sense, authors state that such increase is due to the decrease in pasture and native lands on one hand, and on the other hand, the increase of areas of exposed soil and coffee, maize and sugarcane crops. The average soil loss rate was around 2.4 to 2.6 Mg ha^{-1}/year^{-1} and areas that presented soil loss above Soil Loss Tolerance limit were approximately 8.0%.

[109] carried out a study in a sub-basin located in Eldorado do Sul - RS, during years 2001 to 2004, aiming to evaluate soil losses due to water erosion in eucalyptus plantations, native forest and uncovered soil. The average annual soil losses were 0.81 Mg ha^{-1}/year^{-1} in the year 2004 and 0.12 Mg ha^{-1}/year^{-1} in 2001, values well beyond tolerance limit, which, for this case is, 12.9 Mg ha^{-1}/year^{-1}. Another conclusion of this experiment was that, eucalyptus plantations, from the fifth year of implementation, behave similarly to native forests in relation to water erosion.

The São José basin, located in Cariri, Ceará was studied by [110]. They estimated soil erosion distributed along the basin. Results indicated that the highest erosivity was observed in a slope plateau under the uncovered soil, around 1,800 Mg ha^{-1}/year^{-1}. This is due to a higher level of precipitation registered in this place. In addition, it was evidenced that unprotected vegetation areas and high slope areas are more likely to develop the erosive process.

In studies carried out in semi-arid environments, varied soil losses were found in hydraulic roughness values in vegetation conditions in relation to uncovered soil. The highest values of hydraulic roughness were observed in soil covered by vegetation and the lowest values were observed in conditions of uncovered soil [111,112,113,114].

Positive effects of aerial biomass on erosion control are generally attributed to reductions in the kinetic energy of raindrops and reduced surface runoff speeds [27]. Besides that, plant cover changes intrinsic soil properties, such as erodibility [51], act in the creation of a microclimate and in the supply of organic matter, that affect the activity of microorganisms, and hence the availability of nutrients, resulting in positive feedback on plant productivity.

Both organic matter and microfauna as well as fungal secretions improved the formation of stable aggregates [27,115], affecting the hydraulic conductivity and, therefore, the capacity of water storage [27] being able to increase the resistance of soil to shear [116,117].

Removal of vegetation causes increases of surface runoff, soil erosion, downstream flooding [118,119], and export of sediments, organic matter, nutrients and pollutants which may endanger aquatic habitats and downstream from the flood zone, in addition to associated human infrastructures [120,121].

4.1 Interaction of Soil Properties and Environmental Factors that Affect Soil Disintegration and Soil Losses

Erodibility is the result of various mechanical processes, adhesives and bonding forces acting within the soil matrix [71] and should be considered as a "sum of a highly complex response pattern, strongly influenced by the intrinsic and extrinsic characteristics of the soil" [122]. The erosion response may be influenced by any soil property, but will be dominated by shear force, stability of the aggregates and hydraulic function of the soil [122]. Roots can alter soil erodibility through its effect on these soil properties.

Firstly, the roots have a high tensile strength [51,117] allowing up to 100% of the cohesive strength of a root permeating the soil [123], thus increasing shear strength. The additional tensile force associated with roots is responsible for the transfer of shear stresses through elastic resistance, or friction interface within the soil-root matrix [117,124].

Secondly, the roots prevent sediment transport, retaining disaggregated soil particles [88] and increasing the number of stable aggregates, due to their shear effect [125]. The same also happens to fungal hyphae [125,126,127] which act through the release of various agents of organic and inorganic binding [128].

Root exudates, such as mucilages, are considered the main mechanism of plant roots that improve the stability of aggregates [127,129]. The mucilage exuded by the roots expand a wet floor covering soil particles. During subsequent drying, the contraction of the mucilage occurs, pulling the soil particles tightly inset to form a rhizosheath, thus reorienting the particles to the parallel axis of the root [128,130,131,132].

In addition, root exudates are associated with the release of polyvalent cations, which form strong bonds between organic molecules and clays [1128,130,133]. Increasing the amount of ions in the soil solution significantly increases the stability of aggregates [133]. The decomposition of roots and fungal hyphae also represent a source of organic matter [125,128,130], which contribute to greater stability to soil aggregates. Thus, the stability of aggregates is enhanced by biological activity (both vegetable as fungal) within the soil.

Root exudates represent 5 to 21% of the carbon (C) fixation of a plant [134] serving as a source of essential energy for microorganisms [125,128]. Fungi and soil bacteria produce polymeric substances that contribute to the cementation of aggregates and, thus, increase its resistance [122,125,129,130,131].

However, the effect of roots on the stability of aggregates is specific of plant species present in this soil [125,128] due to differences in root morphology [89], the growth rates [135], the chemical composition, the amount of root exudates, and the influence of differences of root exudates on microbial activity [125,136]. [125] showed that barley roots (*Hordeum vulgare*) increased the stability of the aggregates, but there is conflicting evidence about the effects of corn roots (*Zea mays*). Corn root mucilage would have an increase in soil aggregation [129], but the corn itself releases chelating agents, such as organic acids (which destroy iron and aluminum bonds with organic matter) decreasing the stability of the aggregates [130]. These contrasting results can be attributed to genotypic variation in the chemistry of root exudates.

Roots can also provide an increase in infiltration rates, since they increase the roughness of the soil [88], while the absorption of water through roots [137] and the creation of continuous pore spaces increase the infiltration capacity, reducing the surface runoff [122,137,138]. [139] found a positive correlation between infiltration rates and root density of the needle grass (*Stipa tenacissima*) and, to a lesser degree, for downy banana (*Plantago albicans*).

Several authors [140,141,142,143] suggest that live roots form flow pathways, and increase infiltration rates over time, because of channels created by the decomposition of these roots. [140] observed that infiltration rates in a sandy soil tripled within 3 years of alfalfa cultivation. [142] observed a significant increase in infiltration rates for the last half of the maize growing season, and after harvest.

A frequently used parameter that sufficiently describes the effectiveness of a species to control erosion rates is the root length density (RLD). RLD is the total root length divided by the volume of soil sample permeated by the root [79], thus providing information on land use by the roots [88,144,127]. Under cereal and grass plants in Belgium, erosion rates declined exponentially with a linear increase in RLD [146]. However, the ability of roots to strengthen soil is determined not only by root characteristics such as RLD, but also by their distribution in the soil.

In short, [145] reported that the ability of roots to reduce soil erosion was greater than that suggested in previous studies [147,148]. To simulate the effects of roots on soil disaggregation, different root parameters, that is, dry weight, mass density, density of length, diameter, surface area density, and an area of reason, should be taken into account [145]. The effects of erosion reduction as a function of the roots are also affected by the root architecture. In general, pivotal roots reduce erosion rates to a lesser extent, compared to fasciculate roots [145,147,148].

5. FINAL CONSIDERATIONS

Soil erosion is one of main environmental problems causing negative impacts both for ecosystem conservation and for agricultural production. One of most severe forms of erosive process is interrill erosion, the main derading agent of shallow, sandy and unstructured soils. These are characteristics common to soils of semi-arid regions. The present study emphasizes the importance of studying impacts of this erosion type, where one of the main attenuating factors, vegetation cover, is noted. This factor acts in protection against water erosion in several ways, protecting the soil from direct raindrops impact, increasing hydraulic roughness of terrain, reducing speed of surface runoff. Another modification provided in the soil is in the subsurface, through the root system, with increased porosity, improved physical characteristics, and source of organic matter to deeper horizons

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Brevik EC, Cerdà A, Mataix-Solera J, Pereg L, Quinton JN, Six J, Van Oost K. The interdisciplinary nature of soil. Soil. 2015;1(1):117-129.
2. Lal R. Soil degradation by erosion, Land Degrad. Dev. 2001;12(1):519- 539.
3. Pimentel D. Soil erosion: A food and environmental threat. Envir. Develop. Sustain. 2006;8(1):119-137.
4. Jankauskas B, Jankauskiene G, Fullen MA. Soil erosion changes in the physical properties of Lithuanian Eutric Albeluvisols under different land use systems. Acta Agric. Scand. Sect. 2008;58(1):66-76.
5. Cunha SB, Guerra AJT. Environmental degradation. In: Guerra AJT, Cunha SB. Geomorphology and the Environment. 3rd ed. Rio de Janeiro: Bertrand Brazil; 2000.
6. Davision P, Hutchins MG, Anthony SG, Betson M, Johnson C, Lord EI. The relationship between potentially erosive storm energy and daily rainfall quantity in England and Wales. Sci. of the Tot. Envir. 2005;344(2):15-25.
7. Brady NC, Weil RR. Elements of nature and soil properties. 3rd. Porto Alegre: Bookman; 2013.
8. Ibáñez J. A model-based integrated assessment of land degradation by water erosion in a valuable Spanish rangeland. Envir. Model. and Soft. 2014;55(1):201-213.
9. Guo Q, Hao Y, Liu B. Rates of soil erosion in China: A study based on runoff plot data. Catena. 2015;124(1):68-76.
10. Castillo VM, Martínez-Mena M, Albaladejo J. Runoff and soil loss response to vegetation removal in a semiarid environment. Soil Sci. Soc. of Amer. Jour. 1997;61(4):1116-1121.
11. Porto P, Walling DE. Validating the use of 137Cs and 210Pbex measurements to estimate rates of soil loss from cultivated land in southern Italy. Jour. of Envir. Radioac. 2012;106(1):47-57.
12. Porto P, Walling DE, Callegari G. Using 137Cs measurements to establish catchment sediment budgets and explore scale effects. Hydrol. Proc. 2011;25(1): 886-900.
13. Hötzl H. Climatic changes and water resources in the Middle East and North Africa. Environmental Science and Engineering. Berlin: Springer; 2008.
14. Singer A. The soils of Israel. Berlin-New York: Springer-Verlag; 2007.
15. Ben-Hur M. Seal formation effects on soil infiltration and runoff in arid and semiarid regions under rainfall and sprinkler irrigation conditions. In: Zereini F, Hötzl H, editors. Climatic Changes and Water Resources in the Middle East and North Africa. Berlin: Springer; 2008.
16. Cornelis WM. Hydroclimatology of wind erosion in arid and semiarid environments. In: D´Odorico P, Porporato A, editors. Dryland Ecohydrology. Netherlands: Springer; 2006.
17. D´Odorico P, Porporato A. Ecohydrology of arid and semiarid ecosystems: An introduction. In: D´Odorico P, Porporato A, editors. Dryland Ecohydrology. Netherlands: Springer; 2006.
18. Morin J, Benyamini Y, Michaeli A. The effect of raindrop impact on the dynamics of soil surface crusting and water movement in the profile. J. Hydrol. 1981; 52(1):321-335.
19. McIntyre DS. Permeability measurements of soil crusts formed by raindrop impact. Soil Sci. 1958;85(1):185-189.
20. Chen Y, Tarchitzky J, Brouwer J, Morin J, Banin A. Scanning electron microscope

observations on soil crusts and their formation. Soil Sci. 1980;130(1):49-55.

21. Assouline S. Modeling the dynamics of seal formation: Analysis of the effect of soil and rainfall properties. Wat. Res. Manag. 2004;36(1):2341-2349.
22. Watson DA, Laflen JM. Soil strength, slope, and rainfall intensity effects on interrill erosion. Trans. Am. Soc. Agric. Eng. 1986;29(1):98-102.
23. Croke BFW, Ticehurst JL, Letcher RA, Norton JP, Newham LTH, Jakeman AJ. Integrated assessment of water resources: Australian experiences. Wat. Res. Manag. 2007;21(1):351-373.
24. Issa OM, Trichet J, Defarge C, Coute A, Valentin C. Morphology and microstructure of microbiotic soil crusts on a tiger bush sequence (Niger, Sahel). Catena. 1999; 37(2):175-196.
25. Issa OM, Valentin C, Rajot JL, Cerdan O, Desprats JF, Bouchet T. Runoff generation fostered by physical and biological crusts in semi-arid sandy soils. Geoderma. 2011;167-168:22-29.
26. Morgan RPC, Quinton JN, Smith RE, Govers G, Poesen JWA, Auerswald K, Chisci G, Torri D, Styczen ME. The European Soil Erosion Model (EUROSEM): A dynamic approach for predicting sediment transport from fields and small catchments. Eart. Surf. Process. Landf. 1998;23(1)527-544.
27. Puigdefábregas J. The role of vegetation patterns in structuring runoff and sediment fluxes in drylands. Eart. Surf. Process. Landf. 2005;30(1):133-147.
28. Wei ZY, Hu ZQ, Bai ZK. The loose-heaped-ground method of soil reconstruction on the stackpiles of open-pit coal mine. J. China Coal Soc. 2006;26(1): 18–21.
29. Hou X, Bai G, Cao Q. Study on benefits of soil and water conservation of forest and its mechanism in loess hilly region. Research of Soil and Water Conservation. 1996;3(2):98–103.
30. Zhou Z, Shangguan Z, Zhao D. Modeling vegetation coverage and soil erosion in the Loess Plateau Area of China. Ecological Modeling. 2006;198:263–268.
31. Tavares J, Ferreira AJD, Reis EA, Baptista I, Amoros R, Costa L, Furtado AM, Coelho C. Appraising and selecting strategies to combat and mitigate desertification based on stakeholder knowledge and global best practices in Cape Verde Archipelago. Land. Degrad. Dev. 2013;25(1):45-57.
32. Stroosnijder L, Moore D, Alharbi A, Argaman E, Biazin B, Van Den Elsen E. Improving water use efficiency in drylands. Curr. Opin. Envir. Sustain. 2003;4(1):1-10.
33. Huenchuleo C, Barkmann J, Villalobos P. Social psychology predictors for the adoption of soil conservation measures in Central Chile. Land Degrad. Dev. 2012; 23(1):483-495.
34. Thapa GB, Yila OM. Farmers' land management practices and status of agricultural land in the Jos Plateau, Nigeria. Land Degrad. Dev. 2012;23(1): 263-277.
35. Tavares Filho J, Barbosa GMC, Ribon AA. Physical properties of Dystrophic Red Latosol (Oxisol) under different agricultural uses. Mag. Braz. of Sci. of Soil. 2010; 34(1):925-933.
36. Fao. Food and Agricultura Organization of the United Nations. Evolution of Crop Production, FAOSTAT. Rome: Fao; 2014.
37. García-Ruiz JM. The effects of land uses on soil erosion in Spain: A review. Catena. 2010;81(1):1-11.
38. El Kateb H, Zhang H, Zhang P, Mosandl R. Soil erosion and surface runoff on different vegetation covers and slope gradients: a field experiment in Southern Shaanxi Province. Catena. 2013;105(1):1-10.
39. Foster GR, Meyer LD, Onstad CA. An erosion equation derived from basic erosion principles. Trans. Am. Soc. Agric. Eng. 1976;19(1):678-682.
40. Govers G. Soil erosion process research: A state of the art. Brussel: Paleis der Academien; 1996.
41. Gerits JJP, Lima JLPD, Broek TMWVD. Overland flow and erosion. In: Anderson MG, Burt TP, editors. Process studies in hillslope hydrology. Chichester: Journal Willey; 1990.
42. Pimentel D, Harvey C, Resosudarmo P, Sinclair K, Kurz D, Mcnair M, Crist S, Shpritz L, Fitton L, Sa_Ouri R, Blair R. Environmental and Economic Costs of Soil Erosion and Conservation Benefits. Science. 1995;267(1):1117-1123.
43. Richter G. Bodenerosion: Analyse und Bilanz eines Umweltproblems. Darmstadt: Wissenschaftliche Buchgesellschaft; 1998.
44. Baumann F, He JS, Schmidt K, Kühn P, Scholten T. Pedogenesis, permafrost, and soil moisture as controlling factors for soil nitrogen and carbon contents across the

Tibetan Plateau, Glob. Chang. Biol. 2009; 15(1):3001-3017.

45. Zhao HL, He YH, Zhou RL, Su YZ, Li YQ, Drake S. Efects of desertification on soil organic C and N content in sandy farmland and grassland of Inner Mongolia. Catena. 2009;77(1):187-191.
46. Krautzer B, Wittmann H, Peratoner G, Graiss W, Partl C, Parente G. Site-specific high zone restoration in the Alpine Region: The current technological development. Irdning: Federal Research and Education Centre (HBLFA) Raumberg- Gumpenstein; 2006.
47. Renard KG, Foster GR, Weesies GA, Porter JP. Rusle: Revised Universal Soil Loss Equation. J. Soil and Water Cons. 1991;46(1):30-33.
48. De Roo APJ, Wesseling CG, Ritsema CJ. Lisem: A single-event physically based hydrological and soil erosion model for drainage basins I: Theory, input and output. Hydrol. Process. 1996:10(1):1107-1117.
49. Ascough JC, Baffaut CM, Nearing AJC, Liu B. The WEPP watershed model: II. Sensitivity analysis and discretization on small watersheds. St. Joseph: American Society of Agricultural and Biological Engineers; 1997.
50. Zhang GH. Using 7Be measurements to estimate the relative contributions of interrill and rill erosion. Geomorphology. 2014;206(1):392-402.
51. Gyssels G, Poesen J, Bochet E, Li Y. Impact of plant roots on the resistance of soils to erosion by water: A review. Prog. in Phys. Geog. 2005;29(1):189-217.
52. Stolte J, Liu B, Ritsema CJ, Van Den Elsen HGM. Hessel, R Modelling water flow and sediment processes in a small gully system on the Loess Plateau in China. Catena. 2003;54(2):117-130.
53. Mannering JV, Meyer LD. The effects of various rates of surface mulch on infiltration and erosion. Soil Sci. Soc. of Amer. Proc. 1963;27(1):84-86.
54. Braida JA, Cassol EA. Erosion relationships between grooves with the type and the amount of vegetal residue on the soil surface. Braz. Jour. of Soil Sci. 1999;23(3):699-709.
55. Cantalice JRB. Flow and erosion in interrill and rill in different soil surface conditions. Porto Alegre, Federal Rural University of Rio Grande do Sul; 2002.
56. Thapa GB, YILA OM. Farmers' land management practices and status of agricultural land in the Jos Plateau, Nigeria. Land Degrad. Dev. 2012;23:263–277.
57. Gilley JE, Kottwitz ER. Darcy-Weisbach roughness coefficients for surfaces with residue and gravel cover. Transactions of the ASAE. 1995;38(2):539-544.
58. Wang JG, Li ZX, Cai CF, Yang W, Ma RM, Zhang GB. Predicting physical equations of soil detachment by simulated concentrated flow in Ultisols (subtropical China). Earth Surf Process Landf 2012; 37(6):633–41.
59. Foster GR. Modeling the erosion process. In: Haan CT, Johnson HP, Brakensiek DL, editors. Hydrologic modeling of small watersheds. St. Joseph: American Society of Agricultural Engineering; 1982.
60. Laflen JM, Foster GR, Onstad C. Simulation of individual storms soil losses for modeling the impact of soil erosion on cropland productivity. In: El-Swafy SA, Moldenhauer WC, editors. Soil erosion and conservation. Ankeny: Soil Conservation Society of America; 1985.
61. Cardoso DP, Silva MLN, Carvalho GJ, Freitas DAF, Avanzi JC. Covering plants in the control of soil, water and nutrient losses due to water erosion. Braz. Jour. of Agric. and Envir. Eng. 2012;16(1):632-638.
62. Young RA, Wiersma J. The role of rainfall impact in soil detachment and transport. Wat. Res. Manag. 1973;9(6):1629-1636.
63. Gilley JE, Woolheiser D, Mcwhorter D. Interril soil erosion, Part I. Development of model equations. Biol. Syst. Eng. Pap. Publ. 1985;28(1):147-153.
64. Bradford J, Ferris J, Remly P. Interrill soil erosion processes: I. Effect of surface sealing on infiltration, runoff, and soil splash detachment. Soil Sci. Soc. Am. J. 1987;51(6):1566-1571.
65. Govers G, Everaert W, Poesen J, Rauws G, De Ploey J, Lautridou JP. A long flume study of the dynamic factors affecting the resistance of a loamy soil to concentrated flow erosion. Earth Surf. Proc. Land. 1990; 15(4):313-328.
66. Beuselinck L, Govers G, Hairsine P, Sander G, Breynaert M. The influence of rainfall on sediment transport by overland flow over areas of net deposition. Jour. Hydrol. 2002;257(1):145-163.
67. Zhang GH, Liu BY, Liu GB, He XW, Nearing MA. Detachment of undisturbed

soil by shallow flow. Soil Sci. Soc. Am. J. 2003;67(3):713-719.

68. Cochrane TA, Flanagan DC. Detachment in a simulated rill. Trans. Asae. 1997;40(1): 111-119.
69. Zhang GH, Liu BY, Nearing MA, Huang CH, Zhang KL. Soil detachment by shallow flow. Trans. Asae. 2002;45(2):351-357.
70. Poesen J, Nachtergaele J, Verstraeten G, Valentin C. Gully erosion and environmental change: importance and research needs. Catena. 2003;50(2-4):91-133.
71. Knapen A, Poesen J, Govers G, Gyssels G, Nachtergaele J. Resistance of soils to concentrated flow erosion: A review. Eart. Sci. Rev. 2007;80(1):75-109..
72. Nearing MA, West LT, Brown LC. A consolidation model for estimating changes in rill erodibility. Trans. Asae. 1988;31(3):696-700.
73. Ghebreiyessus YT, Gantzer CJ, Alberts EE. Soil-erosion by concentrated flow-shear-stress and Bulk-density. Trans. Asae. 1994;37(6):1791-1797.
74. Khanbilvardi RM, Rogowski AS. Modeling soil-erosion, transport and deposition. Ecol. Model. 1986;33(2-4):255-268.
75. Zheng FL, Huang CH, Norton LD. Vertical hydraulic gradient and run-on water and sediment effects on erosion processes and sediment regimes. Soil Sci. Soc. Am. J. 2000;64(1):4-11.
76. Morin E, Goodrich DC, Maddox RA. Spatial patterns in thunderstorm rainfall events and their coupling with watershed hydrological response. Advances in Water Resources. 2006;29(6):843–860.
77. Torri D, Ciampalini R, Gil PA. The role of soil aggregates in soil erosion processes. Modelling Soil Erosion by Water. 1998;19: 247–257.
78. Knapen A, Poesen J, Govers G, De Baets S. The effect of conservation tillage on runoff erosivity and soil erodibility during concentrated flow. Hydrol. Process. 2008; 22(10):1497–1508.
79. Abrahams AD, Parsons AJ, Wainwright J. Resistance to overland flow on semiarid grassland and shrubland hillslopes, Walnut Gulch, southern Arizona. Jour. Hydrol. 1994;156(1):431-446.
80. Parsons AJ, Abrahams AD, Wainwright J. Responses of interrill runoff and erosion rates to vegetation change in southern Arizona. Geomorphology. 1996;14(4):311-317.
81. Wainwright J, Parsons AJ, Abrahams AD. Plot-scale studies of vegetation, Overland flow and erosion interactions: Case studies from Arizona and New Mexico. Hydrol. Process. 2000;14(16-17):2921-2943.
82. Zhang GH, Liu GB, Tang KM, Zhang XC. Flow detachment of soils under different land uses in the Loess Plateau of China. Trans. Asabe. 2008;51(3):883-890.
83. Zhang GH, Tang MK, Zhang XC. Temporal variation in soil detachment under different land uses in the Loess Plateau of China. Eart. Surf. Proc. Land. 2009;34(9):1302-1309.
84. Castro WJ, Castro MLL, Lima JO, Oliveira LFC, Rodrigues C, Figueiredo CC. Erodibilidade de solos do cerrado goiano. Revista em Agronegócios e Meio Ambiente. 2011;4(2):305-320.
85. Morgan RPC, Quinton JN, Edwards J. Vegetation strategies for combating desertification. MEDALUS II Project 3 Managing Desertification. Contract EV5V-CT92-0165; 1995.
86. Bochet E, Poesen J, Rubio JL. Runoff and soil loss under individual plants of a semi-arid Mediterranean shrubland: Influence of plant morphology and rainfall intensity. Eart. Sur. Proc. and Landf. 2006;31(1): 536-549.
87. Morgan RPC. Vegetative-based technologies for erosion control. In Stokes A, Spanos JE, Norris, Cammeraat E, editors. Eco- and ground bio-engineering: The use of vegetation to improve slope stability. Dordrecht: Springer; 2007.
88. De Baets S, Poesen J, Gyssels G, Knapen A. Effects of grass roots on the erodibility of topsoil during concentrated flow. Geomorphology. 2006;76(1):54-67.
89. Pohl M, Alig D, Körner C, Rixen C. Higher plant diversity enhances soil stability in disturbed alpine ecosystems. Plant Soil. 2009;324(1):91-102.
90. Jiao J, Zou H, Jia Y, Wang N. Research progress on the effects of soil erosion on vegetation. Acta Ecol. Sin. 2009;29(1): 85-91.
91. Wainwright J, Parsons AJ. Classics in physical geography revisited. In: Thornes JB, editors. The ecology of erosion. Progress in Physical Geography; 2010.
92. Thornes JB. Stability and instability in the management of Mediterranean desertification. In: Wainwright J, Mulligan M, editors. Environmental Modelling:

Finding Simplicity in Complexity. Chichester: John Willey; 2004.

93. Zehe E, Sivapalan M. Threshold behaviour in hydrological systems as (human) geo-ecosystems: Manifestations, controls, implications. Hydrol. and Eart. Syst. Sci. 2009;13(1):1273-1297.
94. Quijas S, Jackson LE, Maass M, Schmid B, Raffaelli D, Balvanera P. Plant diversity and generation of ecosystem services at the landscape scale: expert knowledge assess- 10 ment. Jour. Appl. Ecol. 2012; 49(1):929-940.
95. Chisholm RA. Scale-dependent relationships between tree species richness and ecosystem function in forests, Jour. Ecol. 2013;101(1):1214-1224.
96. Scherer-Lorenzen M. The functional role of biodiversity in the context of global change. In: Coomes DA, Burslem DFRP, Simonson WD Forests and global change. Cambridge: Cambridge University Press; 2014.
97. Romero-Diaz A, Belmonte-Serrato F, Ruiz-Sinoga JD. The geomorphic impact of afforestations on soil erosion in Southeast Spain, Land Degrad. Dev. 2010;21(1):188-195.
98. Jiao J, Zhang Z, Bai W, Jia Y, Wang N. Assessing the Ecological Success of Restoration by Afforestation on the Chinese Loess Plateau. Rest. Ecol. 2012; 20(1):240-249.
99. Boer M, Puigdefabregas J. Effects of spatially structured vegetation patterns on hillslope erosion in a semiarid Mediterranean environment: A simulation study. Eart. Surf. Proc. and Landf. 2005; 30(1):149-167.
100. Bautista S, Mayor AG, Bourakhouadar J, Bellot J. Plant spatial pattern predicts hillslope semiarid runoff and erosion in a Mediterranean landscape. Ecosystems. 2007;10(1):987-998.
101. Durán ZVHD, Pleguezuelo CRR. Soil-erosion and runoff prevention by plant covers: A review. Agron. for Sust. Devel. 2008;28(1):65-86.
102. Li Y, Shao M. Change of soil physical properties under long-term natural vegetation restoration in the Loess Plateau of China. Jour. Arid Environ. 2006;64(1): 77-96.
103. Körner C. Mountain biodiversity, its causes and function. Ambio. 2004;4(4):11-17.
104. Körner C, Spehn EM. Mountain biodiversity: A globa assessment. London: Parthenon Publishing Group; 2002.
105. Silva FGB, Minotti RT, Neto FL, Primavesi O, Crestana S. Previsão da perda de solo na Fazenda Canchim – SP (EMBRAPA) utilizando geoprocessamento e o USLE 2D. Engenharia Sanitária e Ambiental, abr/jun. 2010;15(2):141-148.
106. Carvalho DF, Cruz ES, Pinto MF, Silva LDB, Guerra JGM. Características da chuva e perdas por erosão sob diferentes práticas de manejo do solo. Revista Brasileira de Engenharia Agrícola e Ambiental. 2009;13:3-9.
107. Marinho Filho GM. Avaliação do potencial natural de erosão na bacia hidrográfica do rio formoso através da aplicação da equação universal de perda de solo. Dissertação (Mestrado em Engenharia Ambiental), Universidade Federal do Tocantins; 2014.
108. Oliveira VA, Mello CR, Durães MF, Silva AM. Soil erosion vulnerability in the Verde River Basin, Southern Minas Gerais. Ciência & Agrotecnologia. 2014;38(3): 262–269.
109. Silva BPC, Silva MLN, Batista PVG, Pontes LM, Araújo EF, Curi N. Soil and water losses in eucalyptus plantation and natural forest and determination of the USLE factors at a pilot sub-basin in Rio Grande do Sul, Brazil. Ciência e Agrotecnologia. 2016;40(4):432-442.
110. Costa KVM, Barreto AC, Mendonça LAR, Fontenele SB. Estimativa de perda de solo distribuída em uma bacia hidrográfica de pequeno porte através de técnicas de geoprocessamento. Anais... XVI Simpósio Brasileiro de Sensoriamento Remoto - SBSR, Foz do Iguaçu, PR, Brasil, 13 a 18 de abril de 2013, INPE.
111. Inácio E dos SB, Cantalice JRB, Nacif PGS, Araujo QR de, Barreto A C. Quantificação da erosão em pastagem com diferentes declives na microbacia do Ribeirão Salomea. rev. bras. eng. agric. Ambiental. 2007;11(4):355-360.
112. Martins Filho MV, Liccioti TT, Pereira GT, Marques Júnior J, Sanchez RB. Perdas de solo e nutrientes por erosão num Argissolo com resíduos vegetais de cana-de-açúcar. Eng. Agríc.,Jaboticabal 2009;29(1):8-18.
113. Veena UJ, Tambe DT. Estimation of infiltration rate, run-off and sediment yield under simulated rainfall experiments in upper Pravara Basin, India: Effect of slope

angle and grass-cover. Journal of Earth System, Bangalore. 2010;119(6):763– 773.

114. Chartier MP, Rostagno CM, Pazos GE. Effects of soil degradation on infiltration rates in grazed semiarid rangelands of northeastern Patagonia, Argentina.Journal of Arid Environments, London. 2011;75(7): 656-661.
115. Vásquez-Méndez R, Ventura-Ramos E, Oleschko K, Hernández-Sandoval L, Parrot JF, Nearing MA. Soil erosion and runoff in different vegetation patches from semiarid Central Mexico. Catena. 2010; 80(1):162-169.
116. Tengbeh GT. The effect of grass roots on shear strength variations with moisture content, Soil Tech. 1993;6(1):287-295.
117. De Baets S, Poesen J, Reubens B, Wemans K, De Baerdemaeker J, Muys B. Tensile strength and root distribution of typical mediterranean plant species and their contribution to soil shear strength. Plant Soil. 2008;305(1):207-226.
118. Carvalho DF, Cruz ES, Pinto MF, Silva LDB, Guerra JGM. Rainfall characteristics and erosion losses under different soil management practices. Braz. Jour. of Agric. and Envir. Eng. 2009;13(1):3-9.
119. Ben-Hur M, Fernandez C, Sarkkola S, Cerezal JCS. Overland flow, soil erosion and stream water quality in forest under different perturbations and climate conditions. In: Bredemeier M, Cohen S, Godbold DL, Lode E, Pichler V, Schleppi P, editors. Forest Management and the Water Cycle. Netherlands: Springer; 2011.
120. Wagenbrenner JW, Macdonald LH, Rough D. Effectiveness of three post-fire rehabilitation treatments in Colorado Front Range. Hydrol. Proces. 2006;20(1):2989-3006.
121. Ferreira ADJ, Coelho COA, Ritsema CJ, Boulet AK, Keizer JJ. Soil and water degredation processes in burnt areas: lessons learned froma nested approach. Catena. 2008;74(1):273-285.
122. Shakesby RA, Doerr SH. Wildfire as a hydrological and geomorphological agent. Eart. Sci. Rev. 2006;74(1):269-307.
123. Bryan RB. Soil erodibility and processes of water erosion on hillslope. Geomorphology. 2000;32(1):385-415.
124. Hales TC, Ford CR, Hwang T, Vose JM, Band LE. Topographic and ecological controls on root reinforcement. Jour. Geoph. Res. 2009;114(1):1-17.
125. Prosser IP, Dietrich WE, Stevenson J. Flow resistance and sediment transport by concentrated overland flow in a grassland valley. Geomorphology. 1995;13(1):71-86.
126. Haynes RJ, Beare MH. Influence of six crop species on aggregate stability and some labile organic matter fractions, Soil Biol. Bioch. 1997;29(1):1647-1653.
127. Degens BP. Macro-aggregation of soils by biological bonding and binding mechanisms and the factors affecting these: A review. Austr. Jour. Soil Res. 1997;35(1):431-459.
128. Moreno-Espíndola IP, Rivera-Becerril F, De Jésus FGM, De Léon-González, F. Role of root-hairs and hyphae in adhesion of sand particles, Soil Biol. Bioch. 2007; 39(1):2520-2526.
129. Amezketa E. Soil aggregate stability: A review. Jour. Sust. Agron. 1999;14(1):83-151.
130. Morel JL, Habib L, Plantureux S, Guckert A. Influence of maize root mucilage on soil aggregate stability. Plant Soil. 1991;136(1): 111-119.
131. Oades JM. Soil organic matter and structural stability: Mechanisms and implications for management. Plant Soil. 1984;76(1):319-337.
132. Watt M, Mccully ME, Canny MJ. Formation and stabilization of rhizosheats of *Z. mays* L. Plant Physiol. 1994;106(1):179-186.
133. Mccully ME. Roots in soil: Unearthing the complexities of roots and their rhizospheres, Ann. Rev. Plant Phys. 1999;50(1):695-718.
134. Pojasok T, Kay BD. Effect of root exudates from corn and bromegrass on soil structural stability. Can. Jour. Soil Sci. 1990;70(1):351-362.
135. Walker TS, Harsh PB, Grotewold E, Vivanco JM. Root exudates and rhizosphere biology. Plant Physiol. 2003; 132(1):44-51.
136. Stokes A, Atger C, Bengough AG, Fourcaud T, Sidle RC. Desirable plant root traits for protecting natural and engineered slopes against landslides. Plant Soil. 2009; 324(1):1-30.
137. Bertin C, Yang X, Weston L. The role of root exudates and allelochemicals in the rhizosphere. Plant Soil. 2003;256(1):67-83.
138. Macleod CJA, Binley A, Hawkins SL, Humphreys MW, Turner LB, Whalley WR, Haygarth PM. Genetically modified hydrographs: what can grass genetics do

for temperate catchment hydrology?, Hydrol. Process. 2007;21(1):2217-2221.

139. Bronick CJ, Lal R. Soil structure and management: A review. Geoderma. 2005; 124(1):3-22.
140. Quinton JN, Edwards GM, Morgan RPC. The influence of vegetation species and plant properties on runoff and soil erosion: results from a rainfall simulation study in south east Spain. Soil Use Man. 2002; 13(1):143-148.
141. Meek BD, Rechel EA, Carter LM, De Tar WR. Changes in infiltration under alfalfa as influenced by time and wheel traffic. Soil Sci. Soc. Am. Jour. 1989; 53(1):238-241.
142. Mitchell AR, Ellsworth TR, Meek BD. Effects of root systems on preferential flow in swelling soils. Comm. in Soil Sci. and Plant Anal. 1995;26(1):2655-2666.
143. Archer NAL, Quinton JN, Hess TM. Below-ground relationships of soil texture, roots and hydraulic conductivity in two-phase mosaic vegetation in South-east Spain. Jour. Arid Envir. 2002;52(1):535-553.
144. Devitt DA, Smith SD. Root channel macropores enhance downward movement of water in a Mojave Desert ecosystem. Jour. Arid Envir. 2002;50(1): 99-108.
145. Bauhus J, Messier C. Soil exploitation strategies of fine roots in different tree species of the southern boreal forest of eastern Canada. Can. Jour. Fores. Res. 1999;29(1):260-273.
146. De Baets S, Poesen J, Knapen A, Galindo P. Impact of root architecture on the 23 erosion-reducing potential of roots during concentrated flow. Eart. Surf. Proc. Land. 2007;32(9):1323-1345.
147. Poesen J, Nachtergaele J, Verstraeten G, Valentin C. Gully erosion and environmental change: Importance and research needs. Catena. 2003;50(2-4):91-133.
148. Wischmeier WH. Estimating the soil loss equation's cover andmanagement factor for undisturbed areas. Pres. and Prosp. Tech. for Pred. Sed. Yiel. and Sour. 1975:118-124.

Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sciencedomain.org/review-history/24262