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Characteristics of rainfall and erosion under natural conditions of land use in semiarid regions

Cleene A. de Lima[1], Helba A. de Q. Palácio[2], Eunice M. de Andrade[3], Julio C. N. dos Santos[3] & Paulilo P. Brasil[2]

ABSTRACT

The characteristics of rainfall can provide important information for management and land use may also minimize the water erosion problems. This study was carried out to evaluate soil and water loss in erosion plots with different coverage, and the interference of natural rainfall characteristics on these processes. The experiment was carried out during the rainy season in the years of 2009 and 2010, on three erosion plots, each of 20 m^2, and under different land use conditions: native ‘caatinga’, thinned ‘caatinga’ and natural herbaceous cover. The rainfall was classified into three different rainfall patterns, characterized as early, intermediate and late. The predominant rainfall pattern for the two years under study was early rainfall with 47.6%, followed by intermediate and late with 30.5% and 22%, respectively. The smallest soil losses for the entire studied period were recorded for the native ‘caatinga’ plot, demonstrating the protective effect of vegetation on sediment production. Despite the early rainfall pattern being prevalent in the period of study, this was not the main factor responsible for water and soil loss.

Key words: rainfall intensity, erosivity, water erosion

Características das chuvas e da erosão sob condições naturais de usos do solo no semiárido

RESUMO

As características das chuvas podem não apenas fornecer informações importantes no que diz respeito ao uso e manejo do solo, mas também minimizar os problemas causados pela erosão hídrica. Neste sentido, objetivou-se avaliar as perdas de solo e água em parcelas de erosão com diferentes coberturas e a interferência das características das chuvas naturais nesses processos. O experimento foi conduzido durante a estação chuvosa dos anos de 2009 e 2010 em três parcelas de erosão de 20 m², submetidas a diferentes condições de uso do solo: Caatinga nativa, Caatinga raleada e cobertura herbácea natural. As chuvas foram classificadas em três diferentes padrões de precipitação caracterizados como avançado, intermediário e atrasado. O padrão de chuva predominante para os dois anos de estudo foi o avançado, com 47,6% do total de eventos, seguido pelo intermediário e atrasado com 30,5 e 22%, respectivamente. Para todo o período estudado as menores perdas de solo foram registradas na Caatinga nativa caracterizando o efeito protetor da cobertura vegetal quanto à produção de sedimentos. Apesar do padrão de chuva avançada ter sido predominante para o período estudado, este não foi o principal fator responsável pelas perdas de água e solo.

Palavras-chave: intensidade das chuvas, erosividade, erosão hídrica

[1] UFRPE. Rua Dom Manoel de Medeiros s/n, Dois Irmãos. CEP 52171-900, Recife, PE. Fone: (81) 3320-6264. E-mail: cleene2@hotmail.com
[2] IFCE, Campus Iguatu, Rodovia Iguatu/V. Alegre Km 05, S/N, C. P. 38, Vila Cajazeiras, CEP 63500-000, Iguatu, CE. Fone: (88) 3582-1000, Ramal 252. E-mail: helbaraujo23@yahoo.com.br; paulilopalacio@gmail.com
[3] Departamento de Engenharia Agrícola/UFC. Av. Mister Hull, S/N, C. P. 12.168, Campus do Pici, CEP 60455-970, Fortaleza, CE. Fone: (85) 3366-9762. E-mail: eandrade@ufc.br; juliocesarnds@yahoo.com.br

Introduction

That accelerated soil erosion is an important problem in the world and is widely recognized. It is the primary source that pollutes streams and fills reservoirs. Among major variables that affecting soil erosion the rainfall pattern is important and complex. In a study of 19 independent variables of rainfall characteristics, Wischmeier & Smith, (1978) showed that the most important single measure of the erosion-rainfall process is rainfall times maximum 30 min intensity. Since rainfall energy is one of the main active agents in the process of erosion by water, it is extremely important to assess the response of the soil to different characteristic of precipitation (depth, duration and intensity) (Carvalho et al., 2009). Authors such as Desir & Marín (2005) and Thomaz (2009) describe rainfall as being the most important physical parameter that affects soil erosion in tropical regions. Therefore, its characteristics are essential to the understanding of the process of flow and erosion.

Knowledge of the rainfall characteristics allows for the safer planning of structures and agricultural practices aimed for soil conservation (Carvalho et al., 2005; Evangelista et al., 2005). To this effect, it is important to obtain the erosivity index (the potential rainfall has to cause soil erosion), which is exclusively a function of the physical characteristics of the rainfall, including the quantity, intensity, drop diameter, terminal velocity and kinetic energy (Carvalho et al., 2005; Machado et al., 2008).

As the raindrops hit the soil, their kinetic energy can detach and move soil particles a short distance. Surface runoff allows the transportation of these broken-up soil particles to downstream areas (deposition zones) or to water bodies, such as rivers, lakes and dams, causing sedimentation and eutrophication of the bodies of water. Water erosion is identified as the main cause of reduction in the productive capacity of the soil, as it results in the depletion and degradation of the soil, and pollute water resources (Santos et al., 2011).

Measurements of soil erosion made in the field are few, especially in semiarid regions. Also, when they exist, they are reduced to small sets of data. The low availability of data obtained "in situ" is due to the high costs, the difficulties in affecting these measurements and also the long time required to obtain reliable results. Several researchers in various parts of Brazil point out to the scarcity of data and research in the field to evaluate soil losses (Albuquerque et al., 2002; Santos et al., 2007; 2011). One way to reduce this limitation is to install experimental watersheds.

Due to the scarcity of the data and the necessities for long-term hydrological studies, some experimental watersheds were installed in northeastern Brazil. However, they were deactivated after a short period of data acquisition, due to the high costs of continuing with the monitoring activities and the lack of resources (Santos et al., 2007).

In trying to understand the erosive processes on different vegetation coverages, researches like Cardoso et al. (2012) remain to evaluate the influences cover plants and the spacing of field plots on the control of water and soil loss in Lavras, southeast Brazil. Caten et al. (2012), studying land use in the district of Vêneto Valley, São João do Polêsine municipality, in the center of the State of Rio Grande do Sul, showed that with a 16.2% increase in Forest area, the brute specific erosion was reduced by 44%. Santos (2012), studying soil loss through water erosion, in different spatial scales and with different soil uses in the Brazillian semiarid, observed less soil loss for a vegetation cover composed of thinned 'caatinga', in any spatial scale.

In this respect, the objective of the present study was to evaluate soil and water losses in erosion plots with different cover, under field conditions, as well as the effect of the characteristics of natural rainfall on these processes.

Material and Methods

The experimental area belongs to the Federal Institute for Education, Science and Technology of Ceará (IFCE), Campus Iguatu, located in the South Central region of the state of Ceará in the watershed of the Upper Jaguaribe river, between the coordinates 6° 23' 38" to 6° 23' 58" S and 39° 15' 21" to 39° 15' 38" W (Figure 1).

The climate is classified as a BSw'h' (Semiarid hot), according to the Köppen climate classification, with mean temperatures consistently above 18 ºC in the coldest month. The mean potential evapotranspiration is 1988 mm yr^{-1} and the average annual rainfall is 867 ± 304 mm. Precipitation is concentrated in the January-May period (85% of total annual precipitation) with an average of 30% recorded in the month of march (Agritempo, 2011), expressing the maximum concentration of rainfall in those five months. The soil of the study areas is classified as a typical deep-black, carbonate vertisol (EMBRAPA, 2006).

Monitoring was carried out from 2009 to 2010 during the rainfall season (January to June of each year). During this time 79 natural rainfall events were recorded. Rainfall data were monitored by an automated weather station installed in the study area, containing a bascule-type pluviograph, with data acquisition every 5 min.

To determine rainfall patterns, the methodology developed by Mehl et al. (2001) was used. This methodology works using three rainfall patterns: early (EA) intermediate (IN) and late (LA), according to the position of the peak of greatest intensity (maximum intensity over 5 min - I_5 max) in relation to the total time of the event. With early-pattern rainfall, the greatest intensity occurs within a period of time of less than 30% of the total duration. With intermediate-pattern rainfall, the greatest intensity is between 30 and 60% of the total rainfall time, whereas for late-pattern rainfall, the greatest intensity should occur after 60% of the total duration of the event. Also rainfalls of two patterns were seen, being the presence of more than one individual rainfall for a day, with the appearance of different patterns.

In order to obtain the erosivity index, the intensities (I) for each rainfall event as well as for the maximum intensity over thirty minutes (I_{30}max), were calculated in mm h^{-1}. The kinetic energy (KE) associated with the rain, in MJ ha^{-1} mm^{-1}, was obtained by the equation proposed by Wischmeier & Smith (1978) and modified by Foster et al. (1981), which was used to calculate the Erosivity Index EI_{30}:

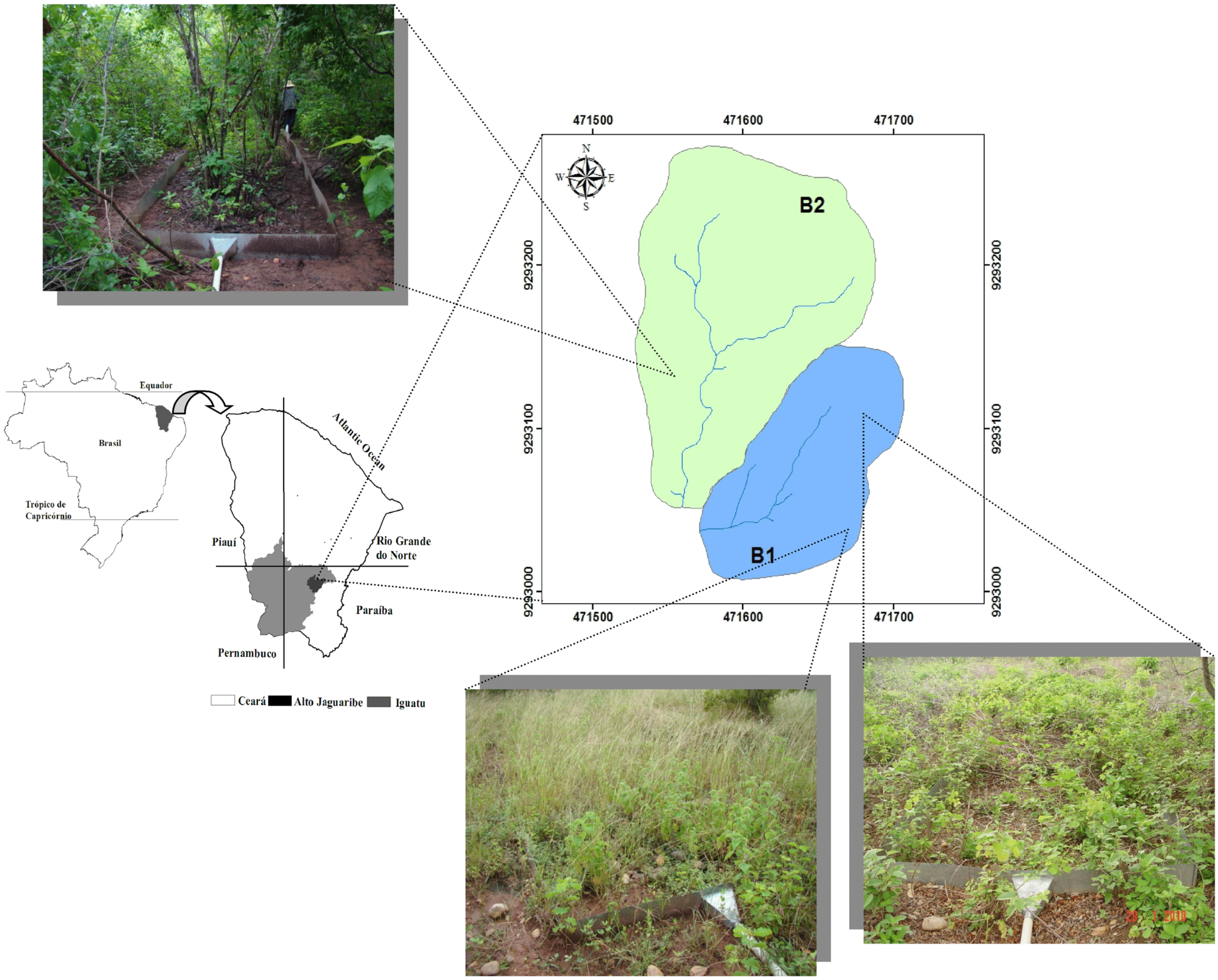

Figure 1. Location of the experimental area in the state of Ceará, Brazil

$$KE = 0.119 + 0.0873 \text{ Log } I \quad (1)$$

$$EI_{30} = KE \times I_{30\,max} \times R \quad (2)$$

where:

KE - Kinetic energy of the storm, MJ ha^{-1} mm^{-1}
I - Rainfall intensity, mm h^{-1}
EI_{30} - Erosivity index, MJ mm ha^{-1} h^{-1}
$I_{30\,max}$ - Maximum intensity of rainfall in 30 min, mm h^{-1}
R - Total rainfall event depth, mm

Three erosion plots (20 m^2) with three different soil cover were installed: native caatinga, thinned caatinga and an area with natural herbaceous cover. The plots were bounded by galvanized steel sheets, 0.30 m high, buried 0.15 m into the soil.

Although the Wischmeier parcels are 4.55 x 22.5 m in their original pattern, an erosion plot with a 10 m ramp and 20 m^2 area was used instead, since, even in this smaller scale, the process has representatively similar to that of the Wischmeier plot (Mutchler et al., 1994). With this studied ramp length, aside the effects of soil particle disaggregation by the impact of the raindrop, disaggregation due to surface flow and rill and interrill erosion also occur.

The lower part of each plot was connected to a collection system consisting of three tanks with a capacity of 30, 100 and 200 L respectively. The first tank consisted of a system of seven windows which, after the first tank was full, allowed 1/7th of the surface runoff to be piped to the second tank, which once filled, directed the surplus runoff to the third tank.

Collections to quantify the volume of surface runoff, and samples to determine soil loss, were taken for each erosive rainfall event (where surface runoff was generated), in an accumulated period of 24 h.

Analyses for determining soil loss were carried out at the Water and Soil Analysis Laboratory - LABAS at the IFCE - Iguatu Campus, and total solids were measured according to Standard Methods methodology (APHA, 1998).

Results and Discussion

For the hydrological year 2009, the total rainfall was 22.3% higher than the regional mean, with a value of 1060.6 mm (Table 1). The rainfall presented a high kinetic energy and

Table 1. Rainfall patterns, mean rainfall duration and total erosivity for 2009 and 2010 in Iguatu, Ceará

Rainfall characteristics		Rainfall Patterns							
		2009				2010			
		EA	IN	LA	Total	EA	IN	LA	Total
		Non-erosive rainfall							
Events	N	3.0	2.0	2.0	7.0	5.0	1.0	5.0	11.0
	%	42.8	28.6	28.6	100.0	45.5	9.0	45.5	100.0
Mean duration (min)		128.3	27.5	87.5	-	103.6	60.0	160.0	-
Mean I_5 max. (mm h^{-1})		30.5	27.4	44.2	-	43.9	24.4	25.6	-
		Erosive rainfall							
Events	N	24.0	12.0	12.0	48.0	5.0	7.0	1.0	13.0
	%	50.0	25.0	25.0	100.0	38.4	54.0	7.6	100.0
Mean duration (min)		152.7	71.3	107.5	-	247.0	349.0	355.0	-
Mean I_5 max. (mm h^{-1})		46.2	56.1	39.9	-	59.7	68.4	54.9	-
Anual erosivity (MJ mm ha^{-1} h^{-1})		2815.4	2137.6	762.9	5716.4	1760.1	3013.5	644.5	5418.1
Total anual PPT (mm)		550.8	245.7	264.1	1060.6	292.3	364.0	143.7	800.0

PPT - Precipitation; EA - Early; IN - Intermediate; LA - Late

erosivity (EI_{30} of 5716.4 MJ mm ha^{-1} h^{-1}). Rainfall events of high intensity and erosivity (characteristic of semiarid regions) are often responsible for most of the volume of eroded soil in a season (Santos et al., 2007).

The knowledge of maximum-intensity rainfall on hydrological and soil conservation studies is important since these are essential for the development of hydraulic structures (Carvalho et al., 2005). In 2009, 55 rainfall events were registered, spread into three patterns: early, intermediate and late, of which 48 generated runoff (Table 1). Of the erosive rainfall, 50% had maximum-intensity at the beginning of the rainfall, matching early rainfall pattern. The remaining erosive rainfall matched the intermediate and late patterns, with 25% for each. Researchers in other parts of Brazil, such as Lavras in Minas Gerais and Santa Maria in Rio Grande do Sul, obtained similar results (under natural rainfall) with the highest incidence of rainfall being of the early-pattern type (Mehl et al., 2001; Evangelista et al., 2005).

Analysing the occurrence of intensity rainfall and the I_5 max mean for each rainfall pattern of erosive rainfall events for 2009, three high-intensity rains can be observed (maximum-intensity greater than 100 mm h^{-1}). One of them was classified as early rainfall pattern and the other two as intermediate, with a mean duration of 147.5 min. For 2009, the highest mean for I_5 max of the rainfall patterns was 56.1 mm h^{-1}, and occurred for intermediate rainfall pattern (Table 1). Mehl et al. (2001) studying the rainfall pattern characterization obtained different results from those obtained in this study, where the maximum-intensity mean was greatest for early rainfall pattern.

The total erosivity rainfall index in 2009 was 5,716.4 MJ mm ha^{-1} h^{-1} of 49.3% of them corresponded to early rainfall pattern, 37.4% to intermediate and 13.3% to late rainfall pattern (Table 1). Thus, it was found that the early rainfall pattern was not only that with the highest incidence in 2009, but also that which showed higher erosivity index. According to Oliveira et al. (2013) the annual erosivity in Brazil goes from 1,672 to 22,452 MJ mm ha^{-1} h^{-1} year^{-1}. The lowest values occurred in the Northeast region while the highest were registered in the north of Brazil. In 2010, rainfall in the region showed high temporal variability, with the occurrence of 34 continuous dry days. The total precipitation that year during the period of January to June was 800 mm (Table 1).

Twenty-four rainfall events were recorded in 2010, of which only 13 were erosive (Table 1). On these, the intermediate pattern was responsible for 54%, followed by the early and late patterns with 38.4 and 7.6% of the total respectively. On the 13 records of erosive rainfall, the intermediate pattern was the only one with heavy rainfalls (maximum-intensity greater than 100 mm h^{-1}) with a total duration of 135 min. It was possible to identify that high-intensity rainfalls were not frequent during the studied period, and that when they occurred they showed a short time as presented by Rodrigues et al. (2008).

Total erosivity for the hydrological year 2010 was 5,418.1 MJ mm ha^{-1} h^{-1}, where 32.5% of the erosivity was represented by early rainfall pattern, 55.6% by intermediate and 11.9% by late rainfall pattern (Table 1). Regarding the distribution of EI_{30} in the rainfall patterns for 2009 and 2010, a predominance of the highest index for early rainfall pattern was found in 2009 and intermediate rainfall pattern in 2010. These results are mainly attributed to the greater predominance of these patterns in that year, and that it is directly related to erosivity. Several authors have obtained similar results of erosivity in their studies in various regions of Brazil (Machado et al., 2008; Carvalho et al., 2009; Oliveira et al., 2010). Another important point to be analyzed is that while in 2010 erosive intermediate rainfall pattern predominated, differing from 2009, the total erosivity was very similar to that recorded in 2009. This indicates that erosivity does not depend on rainfall patterns, and that other important factors such as antecedent soil moisture, should be considered in studies of the erosion process.

When the events were evaluated together for the two years, the pattern of early rainfall accounted for 47.6% of the total erosive rainfall, followed by 31.1% for intermediate rainfall pattern and 21.3% for late-pattern (Table 1). Several authors, studying rainfall patterns in the south and southeast of Brazil, also found a predominance of early rainfall pattern (Mehl et al., 2001; Carvalho et al., 2005, 2009; Machado et al., 2008).

The total soil loss in 2009 were 2,166.56, 1,165.25 and 227.38 kg ha^{-1} (Table 2) for the plots of natural herbaceous cover, thinned caatinga and native caatinga, respectively. Water loss followed the same trend as soil loss.

In the native caatinga condition, soil losses for the year 2009 ranged from 74.2, 63.02 and 90.16 kg ha^{-1} for rainfall

Table 2. Soil and water loss for rainfall patterns in erosion plots with different soil cover for the year 2009 in the semiarid region of Ceará

Rainfall patterns	Treatments					
	NP	TP	HP	NP	TP	HP
	Water loss (mm)			Soil loss (kg ha^{-1})		
Early	13.98	113.18	146.37	74.20	718.38	1133.17
Intermediate	10.87	48.99	67.20	63.02	163.79	429.08
Late	16.49	76.16	30.03	90.16	221.21	405.72
Two patterns*	0.00	19.42	36.78	0.00	61.87	198.59
Total	41.34	257.75	280.38	227.38	1165.25	2166.56

NP - Native Plot; TP - Thinned Plot; HP - Plot with natural herbaceous cover; *Events with more than one individual rainfall during one day and having different patterns

patterns EA, IN and LA respectively (Table 2). The soil loss for the LA was superior to those of the EA and IN by 22 and 43% respectively. The trend of greater losses, seen for LA, probably occurred because the maximum intensity is reached when the soil already has high humidity, which allows more detachment and higher sediment-carrying capacity of the soil particles. Of the 41.34 mm total amount of rainfall, 16.49 mm occurred for the late rainfall pattern, showing it to be superior to the EA and IN rainfall patterns by about 15 and 34% respectively (Table 2). Greater soil loss for the late pattern (LA) have already been found by Mehl et al. (2001), and were explained by the modified surface condition and by soil humidity during rainfall.

For the thinned-out plots (Table 2), soil losses ranged from 163.79 to 718.38 kg ha^{-1} for intermediate and early-pattern precipitation respectively. This can be explained by the combination of high kinetic energy which occurs in the early pattern rainfall, and the condition of the bare soil creating greater detachment of particles by the direct impact of raindrops onto the soil (Albuquerque et al., 2002; Carvalho et al., 2009). Water loss followed the same trend as that of soil, with losses for the early pattern being greater than for the IN and LA patterns and for the events with two rainfall patterns, by around 131, 49 and 483% respectively.

The natural herbaceous cover provided the greatest total soil and water losses (2166.56 kg ha^{-1} and 280.38 mm), with the greatest losses being recorded for the early rainfall pattern (Table 2). This is due to the vegetation cover being insufficient to protect the soil, as already suggested by other researchers (Santos et al., 2007; Carvalho et al., 2009; Santos et al., 2011).

In 2009, the soil and water losses were higher in the native caatinga plot for the late pattern of rainfall, while in the thinned and natural herbaceous plots the losses were higher for the early pattern rainfall (Table 2). These results point out the importance of studying not only the characteristics of the rainfall, but also how they relate to the vegetation cover and result in soil and water loss (Carvalho et al., 2005). The greatest soil losses occurred in the native caatinga plot under a early rainfall pattern condition can be explained by the intensity of rainfall being higher than the infiltration rate. Another point to be considered is the greater flow depth to overcome the natural barriers formed by this type of vegetation. This happens more often with late-pattern rains.

For the native 'caatinga' plot, soil and water losses were reduced by 89.5 and 85.25% respectively, relative to the area of herbaceous cover (Table 2). This is due to the protective effect provided by trees, which contributed to a greater dissipation of the kinetic energy of the raindrops, reducing the detach process of the soil particles and consequently reducing soil loss by erosion. A reduction of up to 99% in soil loss in native 'caatinga' plots can be found when compared with bare plots (Albuquerque et al., 2002).

Soil loss and runoff depth associated with the rainfall patterns in 2010 differed from those in 2009. In 2010, 13 erosive events were recorded (Table 3), where the rainfalls presented high variability and long periods between them, resulting in the reduction of antecedent soil moisture condition to the events.

Table 3. Total soil and water loss for precipitation patterns in erosion plots with different soil cover for the year 2010 in the semiarid region of Ceará

Precipitation patterns	Treatments					
	NP	TP	HP	NP	TP	HP
	Water loss (mm)			Soil loss (kg ha^{-1})		
Early	0.50	0.15	1.72	1.25	0.46	3.25
Intermediate	1.77	51.40	18.93	36.46	116.17	30.16
Late	8.28	31.23	19.90	25.40	37.79	30.84
Total	24.54	82.78	40.54	63.11	154.42	64.24

NP - Native Plot; TP - Thinned Plot; HP - Plot with natural herbaceous cover

When the total runoff from the native plot was compared to the other plots, a reduction of 73.5 and 58.4% was observed in relation to thinned and natural herbaceous plots, respectively.

With regards to the total runoff generated from the erosion plots, it was identified that the thinned-out area showed a runoff depth 2.37 times greater than that observed in the native 'caatinga' (Table 3). This larger runoff in the thinned-out area is explained by the greater exposure of the soil due to the land used. Vegetation plays an important role in the control of water loss by surface runoff, especially when considering the spatial and temporal irregularity of the rains in the semiarid region of northeastern Brazil (Santos et al., 2007).

According to the soil loss for 2010, the thinned-out plot presented the greatest losses, being 1.5 times those of the plot of native caatinga, and 1.4 times those of the plot of natural herbaceous cover (Table 3). This difference is associated with the removal of the vegetation from the area keeping a bare soil. Albuquerque et al. (2002), studying the management of ground cover and conservation practices for soil losses in Sumé, Paraíba, obtained higher values of soil loss for the bare soil plot, being 231 times greater in relation to the plot with native caatinga.

For the studied land cover during the two years, it can be seen that in 2009 the greatest soil and water losses occurred in the plot of natural herbaceous cover, while in 2010 the thinning-out was responsible for greater soil and water losses (Tables 2 and 3). This fact can be explained by the following conditions: in 2009 there was higher rainfall and the natural herbaceous plot had very sparse cover, consisting mainly of grass, which had not yet completely developed. However, in 2010 the ground was completely covered with denser grass and rains with more temporal spacing occurred, reducing the antecedent moisture. Therefore, the little rainfall, although some of high intensity, was not able to detach the soil, resulting in less loss, closer to the values found for the plot of native 'caatinga'.

The rainfall event of February 18, 2009, with depth equal to 61 mm, presented the maximum-intensity with the highest erosivity (106.68 mm h^{-1}; 936.44 MJ mm ha^{-1} h^{-1}) and accounted for 16% of the total annual erosivity (Figure 2). These results characterize the pattern of rainfall in the region very well, which has a short duration and a high intensity. The soil erosion has a high relation to extreme rainfall events (Boix-Fayos et al., 2005).

Although the depth precipitated in 2010 was 260.6 mm less than in 2009, the erosivity index (EI_{30}) was only 5% lower. This result is due to a higher number of extreme events in 2010 (Figure 2) with rainfall depth higher than 50 mm and erosivity higher than 550 MJ mm ha^{-1} h^{-1}.

Evaluating individual events (Figure 2), it can be seen that rainfalls occurred on January 22 and 23, 2009 were not sufficient to cause runoff on the native 'caatinga' and thinned-out plots, being however erosive for the plot of natural herbaceous cover. This result can be attributed to the vegetation, since in the native 'caatinga' plot, the arboreal vegetation intercepts a part of the rain water, with another part flowing down the stem, favoring the infiltration process. In the thinned-out area, as well as the remaining arboreal vegetation, there were twigs and tree branches left on the ground after treatment, minimizing the impact of raindrops on the ground and forming barriers against the runoff. There are several studies that show the efficiency of vegetation and debris from cultivation in erosion control (Albuquerque et al., 2002, Santos et al., 2007).

The event of February 12, 2009 (Figure 2), which presented a rainfall of 53 mm, was responsible for most of the soil loss (375.8 kg ha^{-1}) in the natural herbaceous cover plot in that year. For that event the maximum intensity occurred 50 min after the onset of the rain, reaching an intensity of 94.48 mm h^{-1}, corresponding to the third-highest intensity recorded. The high kinetic energy favored the soil detachment and transport, since earlier events had contributed to an increase in soil moisture resulting in an earlier runoff. The impact of raindrops on saturated soil increases turbulence in surface flow, providing a greater sediment-carrying capacity; also if there was little vegetation cover at that time (Santos et al., 2011).

The effect of the vegetation cover on soil protection can be clearly seen in the events of February 12, 2009 and April 13, 2009, with similar (Figure 2). The event which occurred

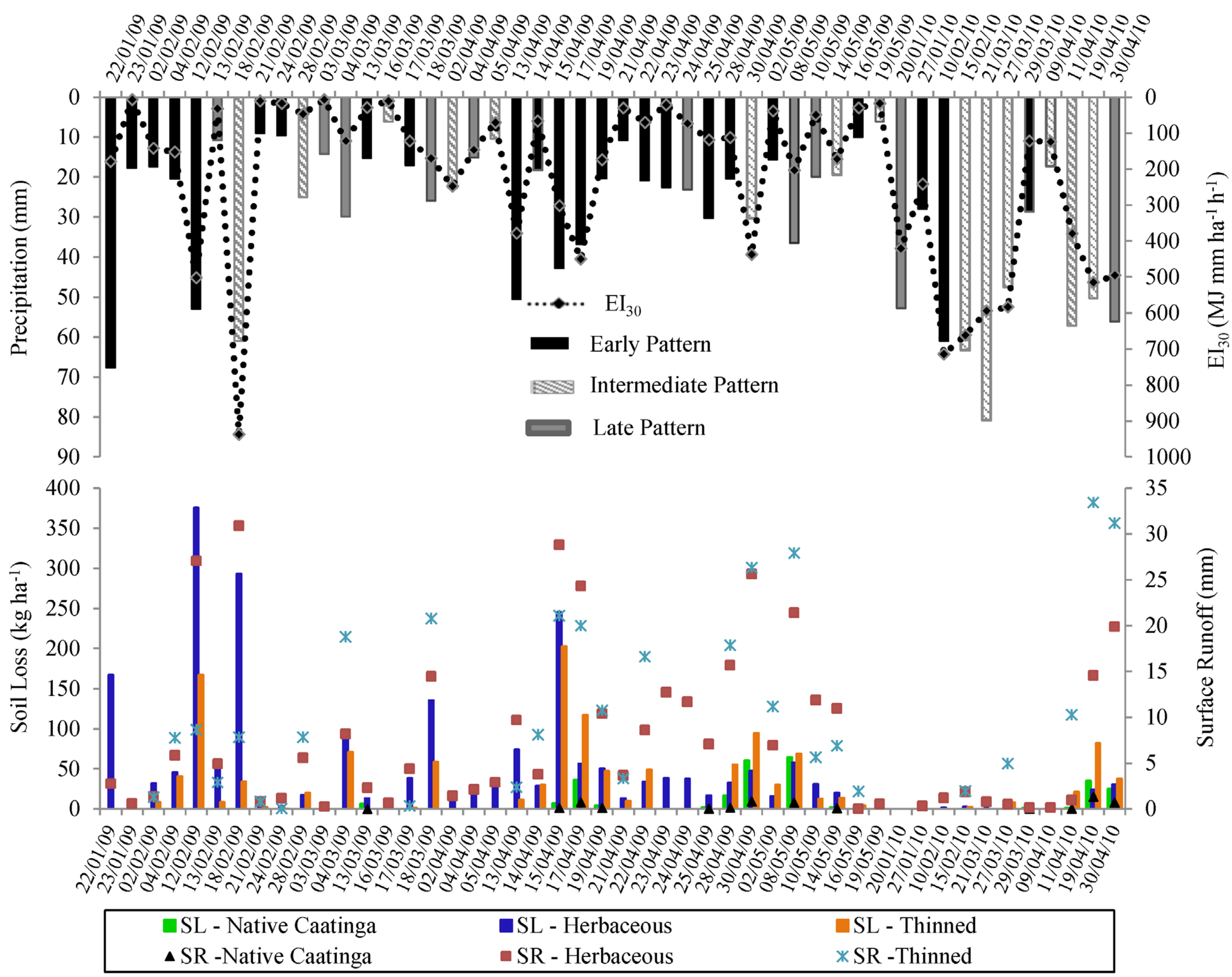

Figure 2. Precipitation, precipitation patterns, erosivity index (EI_{30}), surface runoff (SR) and soil loss (SL) by events in erosion plots with different soil cover for the years 2009 and 2010 in the semiarid region of Ceará

on February 12, 2009, with 53 mm of rainfall and an EI_{30} of 502 MJ mm ha^{-1} h^{-1}, resulted in a soil loss of 376 kg ha^{-1} for the natural-herbaceous plot, and 167 kg ha^{-1}for the thinned 'caatinga' plot. As for the event of April 13, 2009, two months later, when the vegetation was well-developed, a rainfall of 50.5 mm depth and an EI_{30} of 378 MJ mm ha^{-1} h^{-1} resulted in soil losses of 74.5 and 11.4 kg ha^{-1} for the natural herbaceous and thinned-out plots respectively. These losses were 404 and 1366%, lower than those of February 12, 2009 for natural herbaceous and thinned-out plots. This reduction in soil loss is related to the development of vegetation, which decrease the direct impact of the raindrops on the soil and sediment production.

For the natural herbaceous plot, the rainfall event that caused the greatest surface runoff occurred on February 18, 2009 (Figure 2), which had the highest intensity (106.7 mm h^{-1}), corresponding to an EI_{30} of 936.5 MJ mm ha^{-1} h^{-1}. The maximum-intensity was registered between 30 and 60% of the total rainfall time, fitting into the intermediate pattern. This pattern favors a reduction in the infiltration capacity of the water in the soil, which results in an increase in the depth of surface runoff, thus providing the second highest soil loss of the year, with a value of 293.6 kg ha^{-1}. However, the depths of the runoff from the other plots were not the largest, showing that the runoff is not only a function of rain type, but also of a combination of factors. In fact, the antecedent soil moisture condition is a determinant factor of rainfall and sediment transport, also. Assessing the events of January 20 and 27, 2010, with rainfall of 53 and 28 mm respectively (Figure 2), it can be seen that the events, were only able to generate runoff in the natural herbaceous plot, with soil and water losses of 1.13 kg ha^{-1} and 0.35 mm respectively. This result can be attributed to the low antecedent soil moisture, the previous six months without rainfall, the low depth of precipitation and the low rainfall intensity for that month, all of which were not enough to generate surface runoff. Similar behavior for the interference of earlier rainfall on the generation of runoff has been observed by other researchers in semiarid regions (Lobato et al., 2009; Medeiros et al., 2010).

Although the event of March 21, 2010 (Figure 2) presented a depth of 81 mm and an intensity of 103.6 mm h^{-1} (the highest intensity), the depth of runoff was only 0.8 mm for the herbaceous plot, and no runoff for the other plots. This is explained by low antecedent soil moisture (36 days without precipitation). For subsequent events, on March 27, 2010 and April 11, 2010, even with rains of less erosive potential, there was an increase in soil loss, influenced by the erosivity, high rainfall and humidity prior to the events, as reported by Medeiros et al. (2010) and Santos et al. (2011).

In relation to losses of soil and water for the thinned-out plot in 2010, it was observed a large concentration in a single event (April 19, 2010), with soil losses of 82.34 kg ha^{-1} (Figure 2), which represents 53% of the total soil loss. This behavior may have been influenced by depth of the antecedent rainfall events and by the process of detachment, transportation and sediment of soil particles in the lower parts of the plot. Since the soil is detached, it can be easily transported by later rainfall even of a lower erosive potential. The process of connectivity in sediment production has already been detected in a study of sediment production in the semiarid region of Ceará (Medeiros et al., 2010).

The effects of antecedent soil moisture on soil detachment and sediment-carrying capacity can be confirmed by evaluating the events of April 19 and 30, 2010, both with similar precipitation, 50 and 53 mm respectively. These two events were responsible for the largest soil and water losses for all types of vegetation cover (Figure 2). This is a result of previous events that increase the soil moisture content, promoting surface runoff and erosion process.

Conclusions

1. The smallest soil losses for the entire studied period (2009 and 2010) were recorded for the native 'caatinga' plot, demonstrating the protective effect of vegetation on sediment production.

2. The rainfall classified as early, for the year of 2009, resulted in greater soil losses for the plot of natural herbaceous cover (1,133.17 kg ha^{-1}), whereas in the following year the greatest soil losses were for the thinned-out plot, 116.17 kg ha^{-1}, and for the rainfall classified as intermediate.

3. Despite the early rainfall pattern having been prevalent in the studied period, this was not the main factor responsible for the water and soil losses, since temporal variation, total precipitation and coverage type also contributed to the erosion processes on the plots.

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