water

MDPI

Article

Performance of Conservation Techniques for Semiarid Environments: Field Observations with Caatinga, Mulch, and Cactus Forage Palma

Iug Lopes [1,2,*], Abelardo A. A. Montenegro [2] and João L. M. P. de Lima [3,4]

1 Department of Agricultural Engineering, Federal Institute of Education, Science and Technology of Bahia State, Campus Bom Jesus da Lapa. Rodovia BR349, s/n, Zona Rural, Bom Jesus da Lapa 47600-000, BA, Brazil
2 Department of Agricultural Engineering, Federal Rural University of Pernambuco, Rua Dom Manoel de Medeiros, Dois Irmãos, Recife 50910-130, PE, Brazil; abelardo.montenegro@ufrpe.br
3 MARE—Marine and Environmental Sciences Centre, Department of Life Sciences, Faculty of Sciences and Technology, University of Coimbra, Rua da Matemática, 49, 3004-517 Coimbra, Portugal; plima@dec.uc.pt
4 Department of Civil Engineering, Faculty of Sciences and Technology, University of Coimbra, Rua Luís Reis Santos, Pólo II-Coimbra University, 3030-788 Coimbra, Portugal
* Correspondence: iug.lopes@ifbaiano.edu.br

Received: 4 February 2019; Accepted: 4 April 2019; Published: 16 April 2019

check for updates

Abstract: Understanding small-scale hydrologic processes and the impact of soil conservation techniques are crucial in reducing runoff and sediment losses in semi-arid regions. This study was conducted in the Alto Ipanema River Basin, in Pernambuco State (Brazil). Soil and water dynamics were intensely monitored in twelve experimental plots with different coverage conditions (plot with bare soil—Bare; plot with natural vegetation—Natur; plot with mulch—Mulch; plot with Cactus Palma—Palma). By far, bare soil conditions produced higher runoff and soil losses. Mulch cover was close to natural vegetation cover, but still presented higher runoff and sediment losses. Palma, which is a very popular spineless cactus for animal feed in the Brazilian semi-arid region, presented an intermediate hydrologic impact in controlling runoff, enhancing soil moisture, and also reducing soil losses. Experiments were conducted in one hydrologic year (2016/2017) at three different sites. They were intensely monitored and had the same number of plots. This enabled us to carry out a robust performance assessment of the two soil conservation practices adopted (Mulch and Palma), compared to natural vegetation cover and bare soil conditions. Such low-cost alternatives could be easily adopted by local farms in the region, and, hence, improve soil reclamation and regional resiliency in a water-scarce environment.

Keywords: hillslope; mulch; Caatinga; Cactus Palma; soil; runoff generation

1. Introduction

Erosion is a natural process, leading to serious environmental consequences, reducing agricultural productivity, and increasing the sediment amount for the water bodies downstream. Soil erosion is probably one of the most relevant environmental degradation challenges, especially in hilly shallow soils typical in arid and semi-arid regions [1–4].

Reliable local-scale measurements of runoff and erosion under natural rainfall for different soil cover conditions are still limited, especially in semiarid environments, with sparse vegetation cover [5,6].

Mulch minimizes the impact rain has on soil surfaces [7], which might contribute to improved soil fertility, increase water availability through enhancing infiltration, and reduce evaporation, thus minimizing nutrient losses and also controlling soil temperature variations [4,8,9].

Another potential alternative largely adopted in Brazilian semiarid areas is the cultivation of forage Palma, a cactus crop that presents a modified stem a with thin, flat vertical structure. Although it has limited rainfall interception, it has a high leaf area index [10], and if cropped along contour lines, then it tends to reduce surface runoff [11].

The use of field erosion plots under natural rainfall allows the study of many hydrological processes at on local scale. Well-designed experimental plots provide an opportunity to improve understanding of the local-scale water budget and plant cover effects on runoff. The knowledge to be acquired on these experimental small plots is valuable for some specific issues, such as evaluation of soil and water conservation practices, water retention, infiltration, and soil water dynamics [12].

Small-scale plots both in laboratory and in natural watersheds can also successfully contribute to the understanding of major hydrological processes during extreme rainfall events [13,14]. In semiarid environments it is very challenging to collect runoff and soil loss data of a reasonable quality under natural conditions, as the number of rainfall runoff events is very limited; therefore, each event might have an important role in evaluating the impact of soil and water conservation alternatives [15].

Santos and Montenegro [16] analyzed high intensity rainfall events and their contributions to soil disaggregation, transport, and deposition in the Pernambuco semiarid environment. Based on a time series of 29 years, the authors verified that the first half of the year was characterized by rainfall events with high erosive potential, and complex rainfall patterns were observed with a higher occurrence where the peak level fell at the beginning of each rainfall event. Previously, Santos et al. [11] verified the potential use of mulching and Palma cactus in increasing soil moisture, over a 301-day study period, during a wet year. This was conducted in the same area as in our investigation, although no attempt was made regarding rainfall runoff analysis.

In studies of water and soil conservation in watersheds in Africa, Wenninger et al. [17] highlighted that hydrological processes in semi-arid regions usually presented high spatio-temporal variability. Hence, it is important to obtain local rainfall and runoff measurements, for soil moisture dynamics, in order to properly understand runoff generation.

Northeastern Brazil, particularly the semi-arid region of Pernambuco State, is usually subject to high intensity local rainfall events, known as thunderstorms [18]. Such events cause high runoff rates and sediment losses, requiring conservation alternatives to be adopted in order to prevent irreversible degradation of the topsoil.

The objective of this study was to investigate small-scale hydrologic processes and the impact of soil conservation techniques on reducing runoff and sediment losses. This study used textural characterization of the associated transported sediments, using runoff plots with different soil covers (Bare, Natur, Mulch, and Palma) under natural rainfall, in the Caatinga biome of Brazil.

2. Materials and Methods

2.1. Study Sites

The study area (Figure 1) was located at the Alto Ipanema River Basin (AIRB), a sub-basin of Ipanema River, one of the sub-basins monitored by the Hydrology Network of the Semi-Arid Region (REHISA). It is part of the municipalities of Arcoverde and Pesqueira, in the Pernambuco State (Brazil). The area has a complex landscape, characterized by a high spatial variability of elevation and climate, and deciduous vegetation, which constitutes the Caatinga Biome.

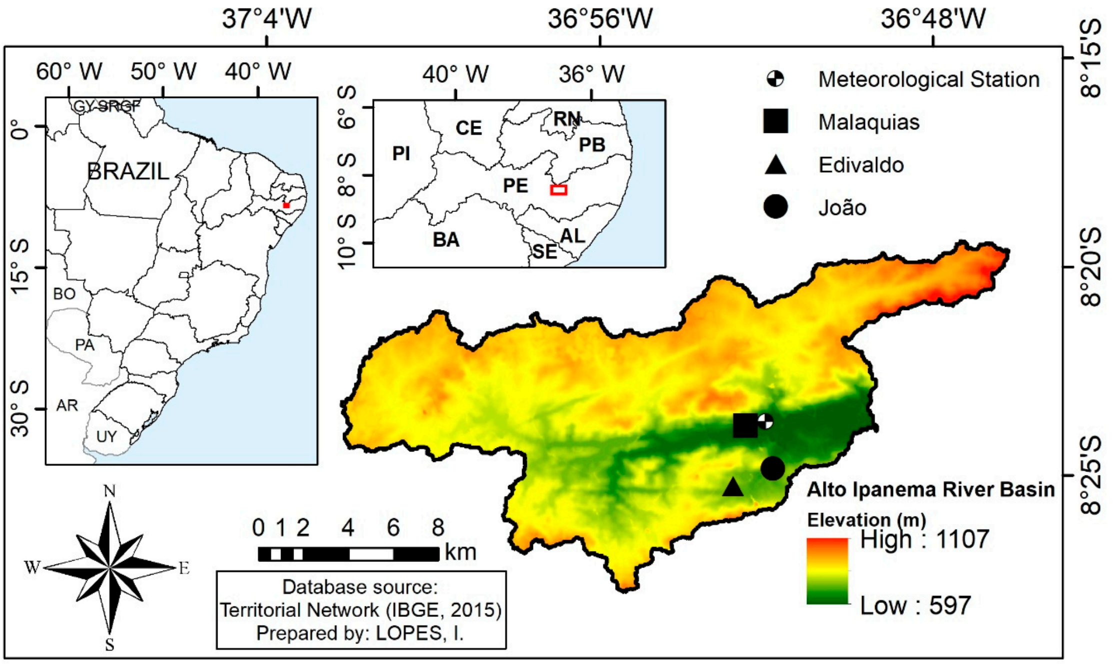

Figure 1. Location of the study sites of Malaquias, Edivaldo, and João in Alto Ipanema River Basin, Pernambuco State, Brazil.

The vegetation presents strong seasonality over time, characteristic of the Caatinga Biome. In the dry period, the native forest area presents loss of foliage (deciduous behaviour) and, in areas of sparse vegetation, large areas exhibit exposed soils. However, the cover conditions change considerably during the rainy season, which is characteristic of semi-arid regions, with rapid foliage regeneration [6,19].

Previous field investigations were adopted [10,16] as sources of information for the physical and chemical characteristics of soil in the experimental plots. These studies were located in the same pedological unit, and the soil properties were very similar among the three studied sites. The mean values from the data are presented in Table 1. The soil classification was Ultisol Eutrophic Typical and the infiltration capacity was 0.134 m h^{-1}.

Table 1. Soil physical and chemical characteristics for the experimental plots. Alto Ipanema River Basin, Pernambuco State, Brazil. Source: [10,16].

Depth	Hor.	Sand	Clay	Silt	Dp	Ds	P	pH	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	H+Al	OC
m			%		g cm^{-3}		%			cmol$_c$ kg^{-1}				g kg^{-1}
0.00–0.12	Ap	44.9	23.2	32.0	2.64	1.48	43.9	6.07	2.08	0.65	0.43	0.27	2.39	20.80
0.13–0.27	A1	44.2	26.5	29.3	2.72	1.51	44.5	5.20	1.57	0.41	0.16	0.24	2.15	15.70
0.28–0.46	A2	31.5	32.5	36.0	2.64	1.45	45.1	5.43	0.81	0.29	0.18	0.23	2.12	8.10
0.47–0.69	AB	28.9	33.8	37.3	2.67	1.68	37.1	5.47	0.73	0.36	0.21	0.30	1.71	7.30
0.70–0.86	Bt	15.2	69.2	29.3	2.66	1.88	29.3	6.10	1.44	1.32	0.10	1.58	1.43	14.40

(where: Hor. = soil horizon; Dp = particle density; Ds = soil bulk density; P = porosity; and OC = organic carbon).

Four experimental plots with different cover conditions were considered at each of the three sites (corresponding to 12 plots in total). Soil and water monitoring was performed in experimental plots with different cover conditions (plot with bare soil—Bare; plot with natural cover—Natur; plot with mulch—Mulch; plot with Cactus Palma—Palma). Maintenance was carried out on the experimental plots before the beginning of the experiment, and minimal reworking was performed only to allow proper representativeness of the soil cover conditions (e.g., weed control procedures).

Figure 2 shows a general view of the investigated cover conditions (Bare, Natur, Mulch, and Palma): Bare—soil without any of natural or artificial cover on the plot; Natur—predominantly natural and/or spontaneous vegetation composed of small and medium-sized shallow caatinga, with predominant quince (*Croton sonderianus*) and jurema-preta (*Mimosa hostilis Benth.*); Mulch—dry grass mulch (*Brachiaria decumbens*) with a density of 8 t ha^{-1}; Palm—presence of forage spineless Palma (*Opuntia cochenillifera*) planted in regular spacing of 0.5 × 1.5 m, forming a vegetation contour ridge.

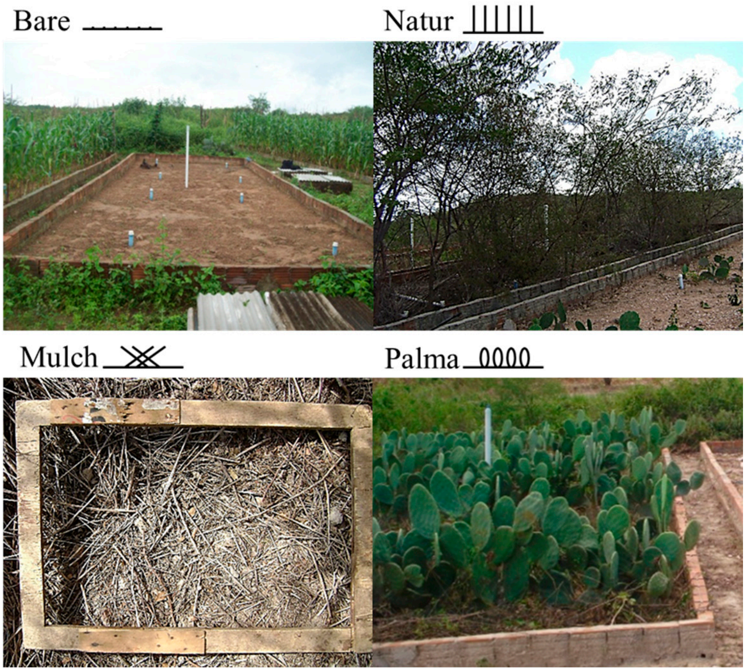

Figure 2. Photographs of the experimental plots for the different cover conditions (plot with bare soil—Bare; plot with natural cover—Natur; plot with mulch—Mulch; and plot with Cactus Palma—Palma).

2.2. Climate Data

According to Köppen's classification, the climate in the region was BSsh (extremely hot, semi-arid). The mean annual precipitation, according to local historical data (1910 to 2012) was 671.90 mm. According to climate classification, total annual evaporation was ~1600 mm, and the mean temperature was 27.40 °C, varying from 18.5 to 29 °C. According to the aridity index, on average more than 60% of the region presented low susceptibility to desertification and exhibited medium susceptibility spots [20]. The predominant vegetation was the hypoxerophilic caatinga and cactus [21].

Climatic data were recorded at an Automatic Weather Station installed near the experimental plots (Pesqueira, Brazil), as observed on the map (Figure 1). The station consisted of a set of sensors and a communication interface for data recording (CR1000 datalogger) and transfer including: an anemometer, a rain gauge, a temperature sensor, a relative humidity sensor, and a pyranometer, recording data hourly.

2.3. Data Processing

From October 2016 to October 2017, runoff and sediment yield were monitored and characterized in the 12 experimental plots. The experimental plots were already established some years ago [11], and they were delimited by brick walls 0.25 m above the soil surface and inserted 0.10 m into the soil. Downstream of the plots, a drain system collected runoff into two consecutive tanks 1 m^3 in volume (Figure 3). During the study period, no runoff events reached the maximum storage capacity of the collection tanks, nor were significant losses of the stored water due to evaporation observed. Snapshots were taken by the end of each rainfall event using a camera.

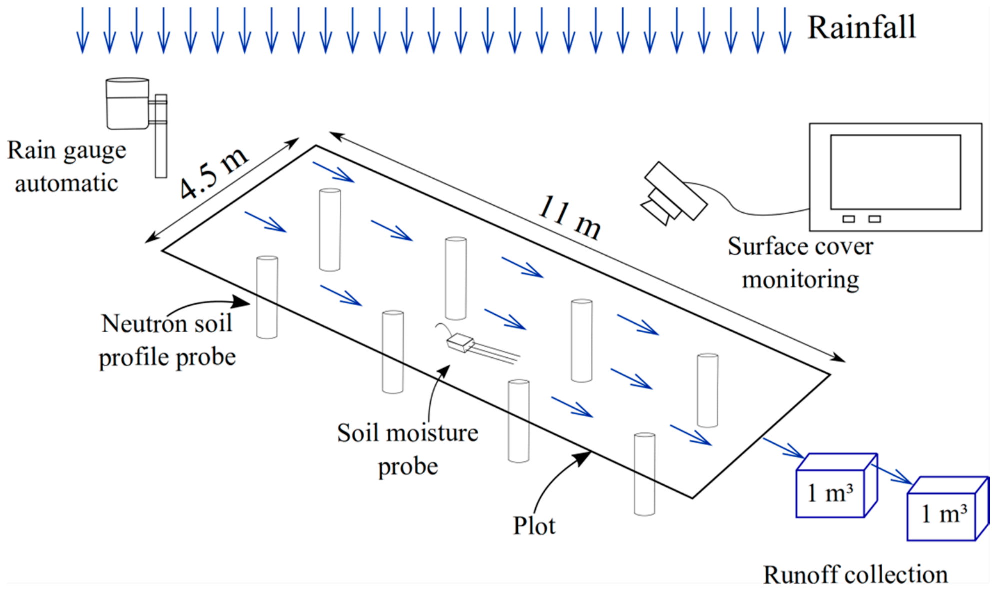

Figure 3. Sketch of the experimental layout.

Each plot had eight polyvinyl chloride (PVC) access tubes installed 2 m apart from each other. Due to the depth of the impervious layer of the soil profile, the access tubes were installed mainly up to 0.60 m in depth, and the depths for the soil water content measurement were 0.20, 0.40, and 0.60 m. The soil water content was monitored every 15 days using a Neutron Probe Device model CPN 503 DR. The neutron probe readings were converted into soil water volumetric content based on pre-established calibration curves that were available for the studied soil.

2.4. Water and Sediment Measurements

For all effective rainfall events, runoff and sediments were manually collected individually in the tanks within one day after each event. In addition, the particle size of eroded soil was monitored during the experiment for different soil covers in order to evaluate the impact of runoff on soil texture.

Collection of the stored water only occurred in the first tank, because there was no runoff volume that exceeded the tank's capacity. The stored water was stirred for uniformity (for 3 min), and 1 L random samples were collected in triplicate. In order to estimate the sediment concentration, samples were dried in an oven (105 °C). Soil sand, clay, and silt fractions were determined by the Boyoucus densimeter method, following the methodology proposed by Embrapa [22].

Total rainfall and rainfall intensity were measured with an automatic rain gauge (TB4-L) located at each experimental site, with an average distance of 2 m from the plots. This equipment was connected to a CR1000 datalogger, programmed to record events every 5 min.

2.5. Statistical Analysis

The experimental plots within the sites (Malaquias, Edivaldo, and João) were randomly located. The experimental data were submitted to variance analysis. For comparison of the mean behavior for the treatments, Tukey's test was applied at a 5% significance level. Correlation analysis was carried out, scored by the R^2 value and significance of the slope coefficient, when appropriate.

3. Results and Discussion

3.1. Rainfall Event Analyses

The studied hydrologic year of 2016/2017 can be classified as water-scarce. During the study period there were 76 daily rainfall events, which totaled 404.20 mm (corresponding to 60% of the mean rainfall depth in the 2017 hydrological year).

Figure 4 presents the observed rainfall, runoff, soil losses, and soil moisture temporal behaviors occurring from October 2016 to October 2017, for rainfall higher than 5 mm.

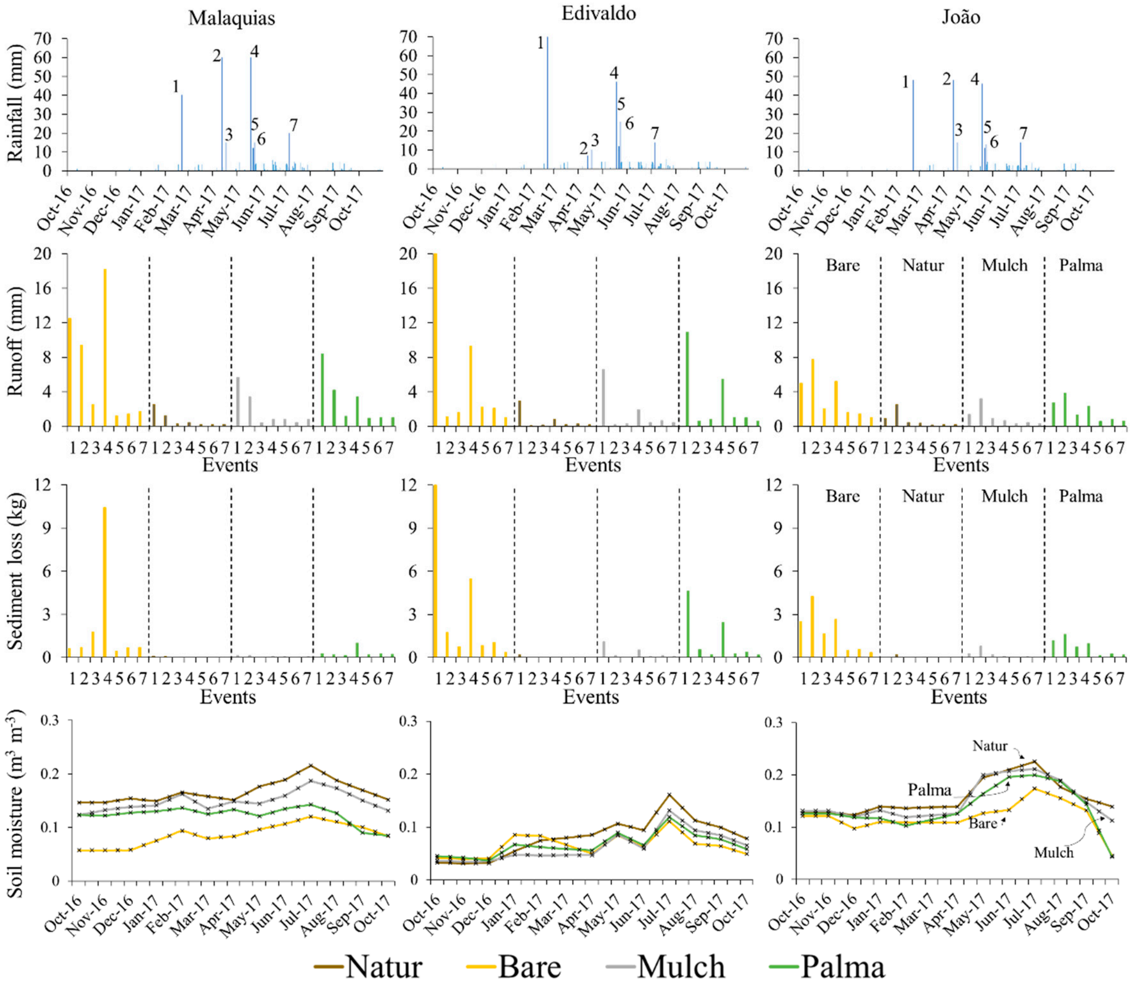

Figure 4. Time series of rainfall, runoff, sediment loss, and soil moisture during the study period. The cover condition identification was inserted in the charts of João, thus representing all the other sites.

Only seven events produced runoff. The highest precipitation intensity occurred on 4 March 2017, with a value of 70 mm during 0.5 hours, corresponding to a return period of 300 years, according to Silva et al. [18].

The water and sediment production characteristics for each rainfall event are presented in Figure 4, as well as the mean soil moisture for the 0 to 0.6 m layer, as a function of time.

Runoff generation and soil losses were very limited for the Natur soil cover condition, and the conservation practices of Mulch and Palma efficiently reduced water and soil losses, as expected. More detailed rainfall runoff and rainfall soil loss analyses have been carried out in Section 3.2, exploring the correlations between the variables and also their statistical behaviors.

The main variations observed for the moisture values could be explained by semi-arid characteristics, with precipitation events of high intensity and small duration, followed by high evapotranspiration rates. Lopes et al. [23], studying the rainfall spatial distribution for a region of the Brazilian semi-arid region, observed that there was a high spatio-temporal variation caused by the previously mentioned rainfall characteristics.

The different surface covers influenced soil moisture dynamics. At the beginning of the hydrological year, soil moisture was below the soil water content at the permanent wilting point (0.071 m^3 m^{-3}). Soil moisture for bare soil was the lowest among the studied soil cover conditions.

Table 2 gives an overview of the different sites and plots, namely the relative position of the different cover plots in each site. Although there were differences, plot characteristics were approximately the same, and rainfall had the same magnitude order. In addition, Table 2 also presents the statistical analysis results for runoff, soil losses, and soil moisture for the different sites and soil cover conditions.

Table 2. General characteristics (mean values and Tukey test for all seven events in each site) for the plots with surface covers: n—Natural; b—Bare soil; m—Mulch; and p—Palma.

Site	**Soil**	**Slope**	**Exposition**		**Position of Plots (from Left to Right)**
Malaquias	Red Yellow Argisol	~6%	Northwest		m; p; b; n
Edivaldo			Northwest		b; n; p; m
João			Northeast		m; b; p; n
Site	**Maximum/Mean total rainfall (mm)**	**Maximum/Mean rainfall intensity in 30 min (mm h^{-1})**	**Mean soil losses (kg)**	**Mean Runoff (mm)**	**Soil moisture (m^3 m^{-3})**
Malaquias	60/31	48/24.5	n- 0.03 (c); b- 1.91 (a); m- 0.06 (c); p- 0.28 (b)	0.6 (d); 5.9 (a); 1.5 (c); 2.5 (b)	0.16 (a); 0.11 (d); 0.15 (b); 0.13 (c)
Edivaldo	70/26	90/33.6	n- 0.03 (c); b- 3.31 (a); m- 0.26 (c); p- 1.03 (b)	0.6 (d); 5.4 (a); 1.3 (c); 2.5 (b)	0.08 (a); 0.06 (c); 0.07 (b); 0.06 (c)
João	48/28	60/24.4	n- 0.04 (c); b- 1.56 (a); m- 0.18 (c); p- 0.63 (b)	0.6 (d); 3.0 (a); 0.9 (c); 1.5 (b)	0.16 (a); 0.08 (d); 0.14 (b); 0.12 (c)

Mean values followed by the same letter do not significantly differ in the same column, according to the Tukey test ($p < 0.05$).

Statistical differences occurred between the distinct cover conditions and bare soil for the three studied sites (Malaquias, Edivaldo and João—Table 2). Higher soil loss was observed for the bare soil condition, followed by Palma. Natural Caatinga cover and mulch presented lower soil erosions.

Runoff had different behavior, with natural cover generating the smallest runoff depth and bare soil conditions producing the highest runoff. Mulch reduced soil loss because small barriers of accumulated mulch material formed, approximately following the elevation contours. These barriers (Figure 5) promoted the deposition of soil particles upslope.

Figure 5. Photograph detailing the soil surface after a rainfall event (plot with mulch cover).

Statistical differences were also detected for the mean soil moisture for the whole period, being more evident for the João Site. Araújo et al. [24] studied the spatial distribution of soil moisture for the Ipanema River Basin, where the experimental plots were inserted, and also observed low water availability conditions for the whole area in the same period.

Observing Figure 4, it can be verified that some moisture differences were more evident for periods with rainfall spells as a result of the rainfall pattern, evapotranspiration, and the limited soil water holding capacity at the plots.

According to Table 2, mulch was the most suitable conservation practice for maintaining the highest soil moisture values. The observed soil moisture contents varied over time during the experimental period, and variations were related to the different cover types.

Santos et al. [11], studying the same soil cover conditions for a wet hydrologic year in the same region, observed that soil surface conditions had a high influence on soil moisture variation, both in the dry and the rainy periods. It was verified that natural vegetation cover (Caatinga biome) presented the largest water content in soil compared to the other treatments for the entire rainy period. Bezerra et al. [25] highlighted the importance of monitoring soil water dynamics for different cover conditions in semi-arid Brazil, especially in the Caatinga biome, aiming to improve soil water storage and to provide experimental in situ data for soil losses resulting from rainfall events.

3.2. Runoff and Soil Loss Correlations

Figures 6 and 7 verify the relationships between the runoff coefficient (defined as the ratio between runoff depth and total rainfall) and soil loss as a function of rainfall depth and intensity. Rainfall intensity explains better the observed variations in the runoff coefficient than rainfall depth. It was shown that mulching successfully protected the soil surface for all three sites, which allowed a higher infiltration rate and, thus, greater soil moisture storage. For Palma, a similar behavior was observed both for runoff and soil loss.

These results can be explained by the following mechanisms and surface characteristics, presented by Montenegro et al. [4]: (1) soil cover protection from direct impact of rain drops; (2) higher hydraulic roughness based on mulch cover, retarding surface flow, and enhancing infiltration; and (3) water retention of the mulch cover. In addition, contour barriers provided by the Palma reduced overland flow velocities, favoring sediment deposition.

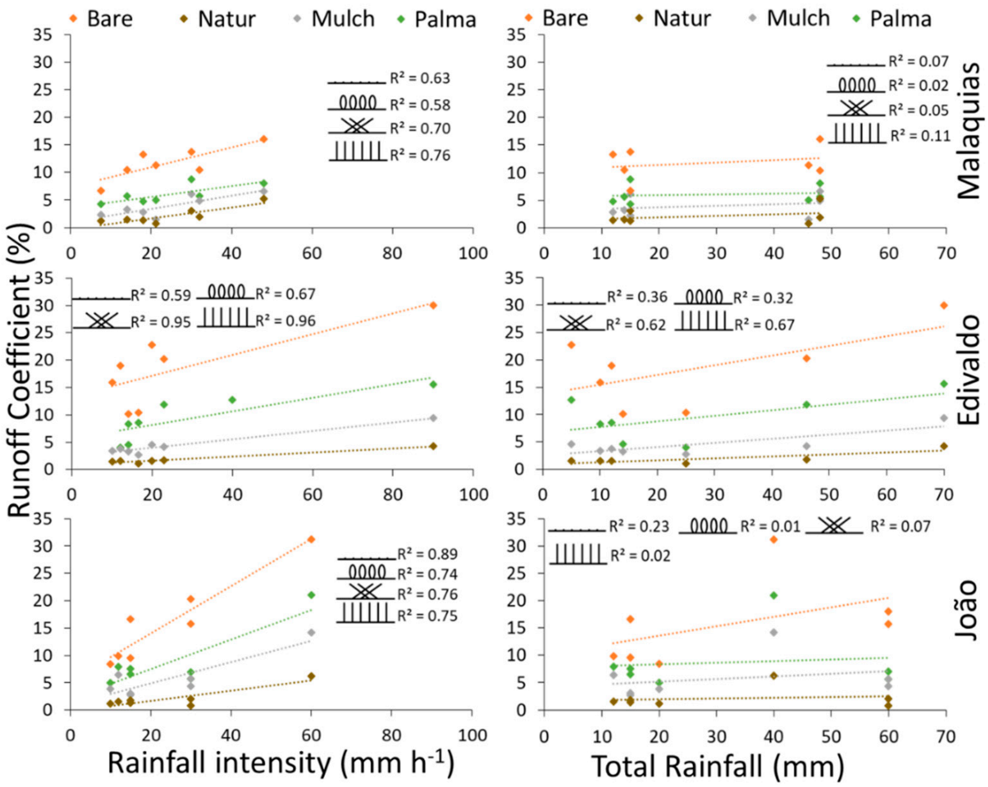

Figure 6. Runoff coefficient as a function of rainfall volume and intensity, for all sites and plots.

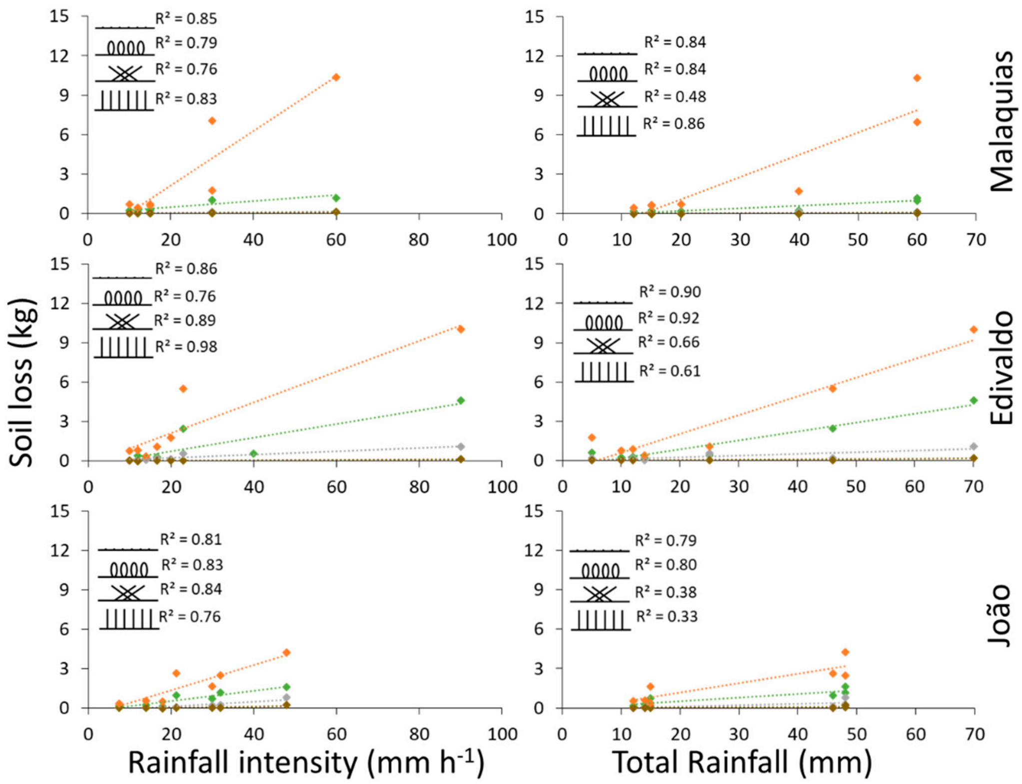

Figure 7. Soil loss as a function of rainfall volume and intensity, for all sites and plots.

Runoff generation was strongly related to antecedent moisture conditions of a specific event, as observed in Figure 8a. Soil loss, however, was more correlated to rainfall intensity (Figure 8b). Characteristic rainfall temporal regimes in the Brazilian semi-arid region, where higher intensities were verified at the beginning of the event, were also observed.

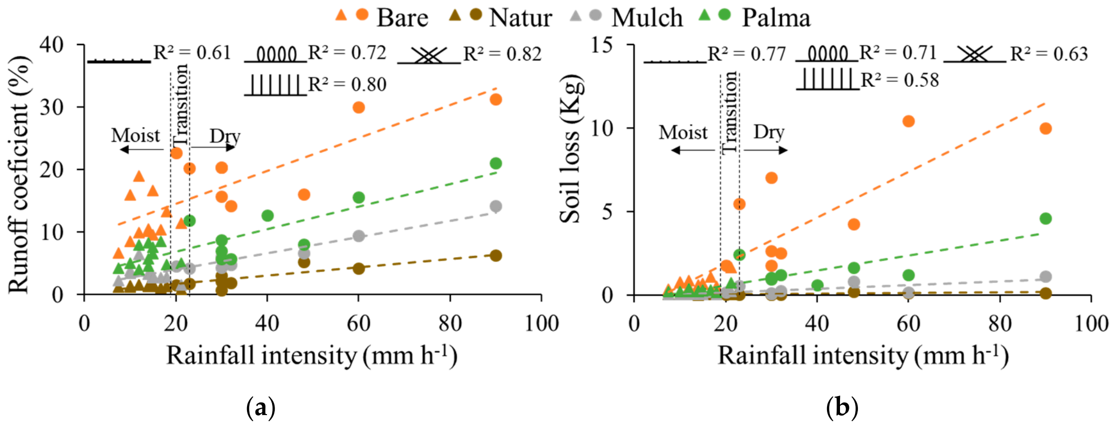

Figure 8. Runoff coefficient (**a**) and soil loss (**b**) for all sites and all rainfall events. Antecedent soil moisture conditions are indicated by triangles, representing high antecedent soil moisture (moist conditions), and circles, representing low antecedent soil moisture (dry conditions).

Figure 9 describes the basic statistics for runoff and soil loss by comparing the different surface covers. By far, the bare soil plots produced more total runoff and sediments. Mulch cover was close to natural vegetation cover, but still had a higher runoff and sediment loss. Palma presented an intermediate hydrologic response (see also Figures 6 and 7).

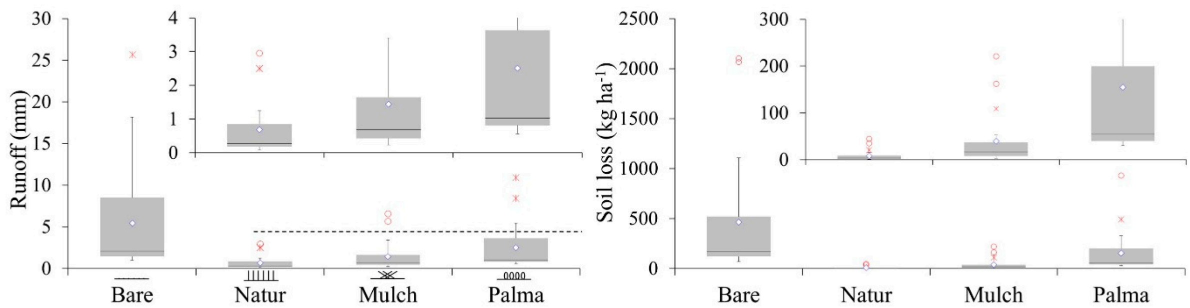

Figure 9. Box plot runoff and soil loss for all plot covers. The superimposed graphs are enlarged in order to visualize details for Caatinga, Mulch, and Palma plots. Key: '◊' average; '-' median; '□' 25% to 75% probability; '⊤' maximum; '⊥' minimum; '*' outlier; and '°' extreme.

According to the box plot in Figure 9, the natural Caatinga cover was efficient at increasing soil water storage; this result was also reported by Caloiero et al. [26]. Although the presence of native forest increased water consumption as a result of transpiration, it was also verified that soil moisture of nearby soil surfaces increased in comparison to areas where vegetation was removed.

Brasil et al. [6] studied the importance of the Caatinga canopy in reducing rainfall kinetic energy and increasing soil water storage. In addition to the aforementioned contributions, natural cover enhances infiltration [27] and reduces evapotranspiration [2].

The study by Kiani-Harchegani et al. [28] might explain the presence of outliers and extremes for runoff and soil loss data, which also occurred in their study when rain intensity and surface slope were varied. Such values were associated with rainfall intensities that were outside of the 99% probability of occurrence for the studied dataset [18].

3.3. Aspects Related to Granulometry

Erosion in the bare soil plot provided the highest sand percentage (Figure 10), and the highest percentages of silt and clay were observed for the natural vegetation cover plot. Palma cover crop presented similar behavior to bare soil, since the soil was largely unprotected from direct drop impact, with sand percentage clearly above the silt and clay percentages for the transported sediments.

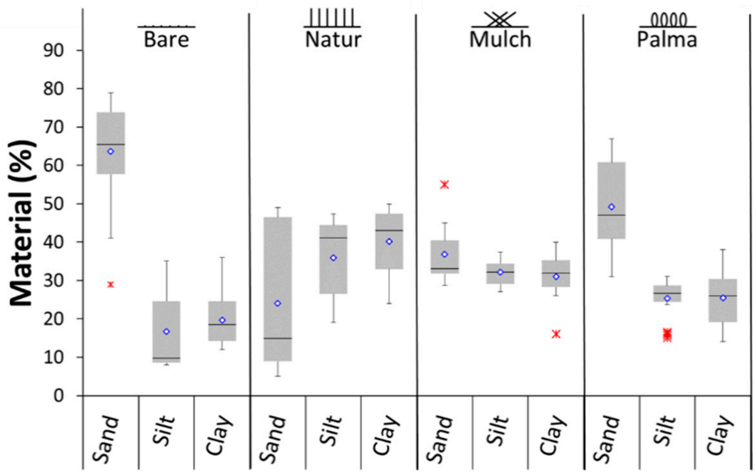

Figure 10. Boxplot of the percentages of sand, silt, and clay for sediments transported in runoff, for all plot covers. Key: '◊' average; '-' median; '□' 25% to 75% probability; '⊤' maximum; '⊥' minimum; '*' outlier; and '°' extreme.

In general, runoff carried more sand fraction for the earlier events of the year, as noted by the maximum discharges that were observed. Later, more intermediate and finer materials were observed. Sand components in the eroded sediment resulted from both raindrop impact and the higher surface runoff, which resulted in higher velocity and, hence, in higher transportation capacity, observed mainly for bare soil cover conditions.

An experiment to help understand sediment loss was performed by Silveira et al. [29]. In spite of the fact that the study was conducted in urban environment, the authors observed that the nature of sediment accumulation was complex, and it depended on the type of soil cover, such as green cover, compacted soil, construction, and slope activities. In addition, combinations of bare soil and steeper slopes have greater contributions to sediment loss.

Sediments for the natural cover (Caatinga) treatment consisted mainly of fine particles, because interception prevented the direct impact of raindrops reaching the soil surface. Observations by Kiani-Harchegani et al. [28] under laboratory conditions highlighted the relevance in considering all the key variables involved in sediment transport processes for a better understanding of grain size dynamics.

Bashari et al. [30], studying the effects of soil textures on soil losses, verified that erosion in soils is complex, and more research is still needed to fully understand the erosion mechanism.

Sediment evolution, in terms of percent of clay, silt, and sand in our study, can be observed for the sequence of rainfall events in Figure 11. Lines show the behavior of the textural displacement in the United States Department of Agriculture (USDA) textural chart. According to Figure 11, there were common textural displacement patterns for each soil cover (Bare, Natur, Mulch, and Palma).

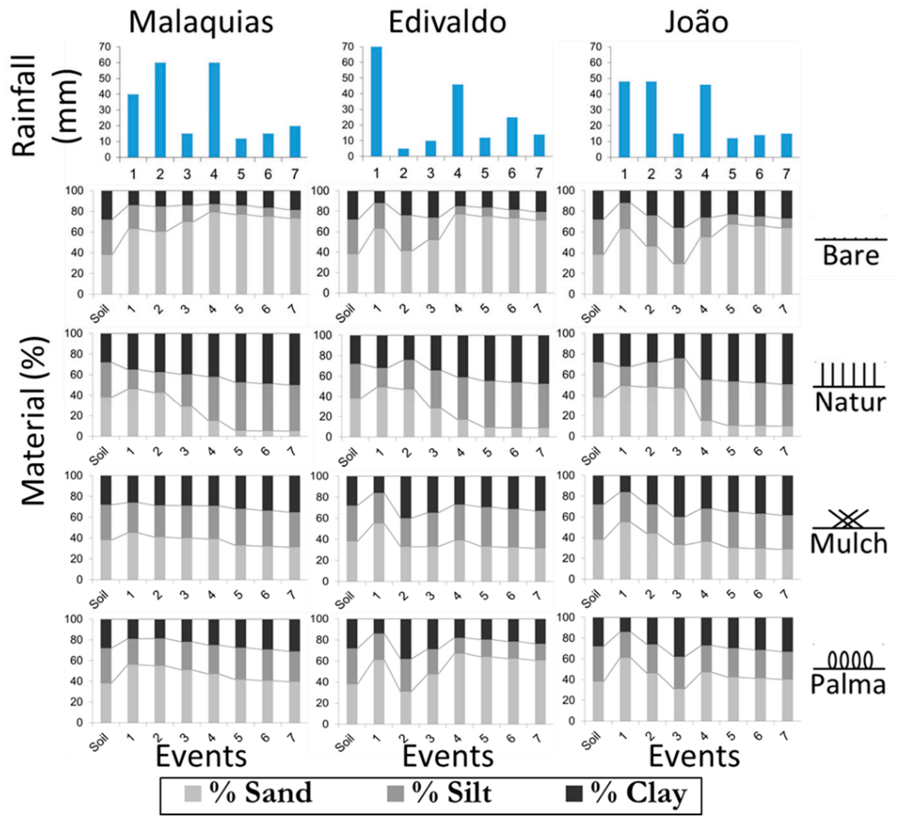

Figure 11. Tracking percentages of sand, silt, and clay for the three sites in all soil covers, together with the seven rainfall events that produced erosion in the plots.

The flow takes thick material first, and when the soil loses the loose particles, as well as increasing wetness, the finer particles begin to be carried off. The more unprotected soil, the greater the amount of coarse material in the transported material. Bare soil plots, because of their unprotected soil surfaces and higher observed runoffs, are subjected to more energy and sediment transport capacity, especially for heavier sand particles. Such behavior was observed for all events and sites in our study.

The USDA textural charts (Figure 12) highlight the variation of the granulometric composition of the original soil and for runoff composition. For the uncovered soil, it was possible to observe that initially there was a loss of finer sediment, and later a predominance of sand fraction loss occurred.

The paths (position sequence, illustrating the evolution in time) in the USDA textural classification chart (triangle) associated with the rainfall events for the bare soil plots have different paths associated with the other coverages. Natural cover presented an unmodified pattern, with coarser grain sizes at the beginning of the runoff evolving to a finer size when soils had a higher water content.

For natural cover conditions, the transported sediment texture was always thinner than for the original soil. For Mulch cover, however, rainfall events produced dynamic soil texture losses around the original soil composition.

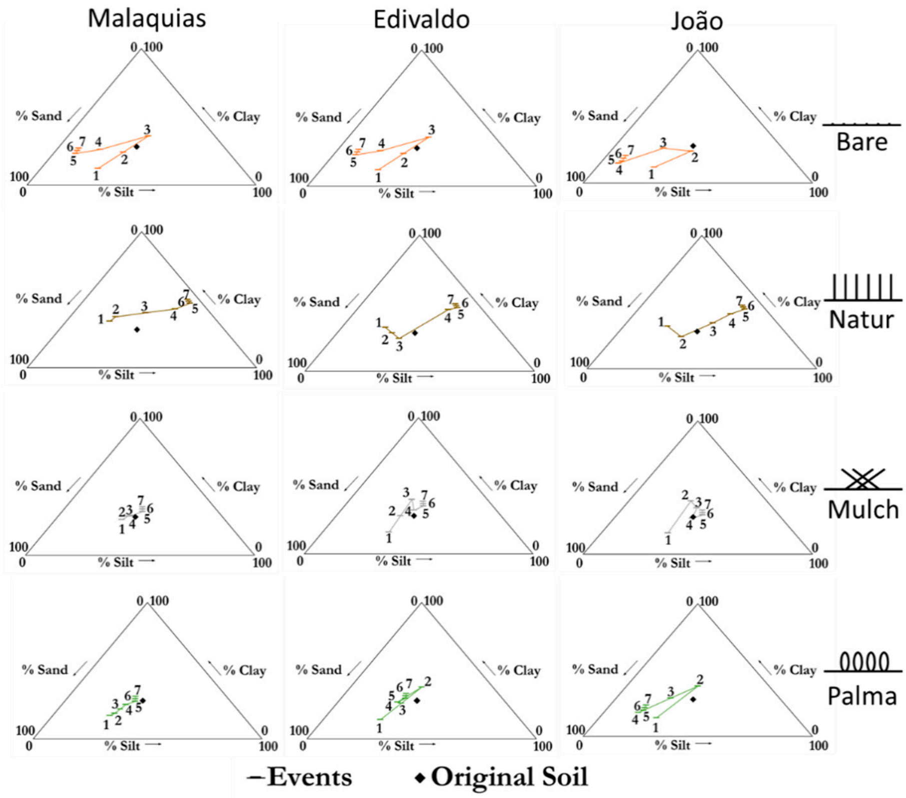

Figure 12. Evolution of sand, silt, and clay percentages during the hydrology year 2016/2017, for all runoff events and studied plot covers.

Few studies were found focusing on the granulometric variation of the transported sediments. De Lima et al. [31] studied soil texture variation under laboratory conditions in various plot sizes and slopes, and observed that an increase in the plot length, and, hence, in the peak discharge, had a greater erosive capacity. Thus, surface water was mainly composed of thicker material, independent of the slope.

Experimental data for flow and sediment losses can contribute to improving the performance of hydrological models in predicting runoff and sediment transport for varied soil cover conditions. Such experimental observations are required, not only for model calibration/validation, but mainly for better parameterization. For instance, when applied to hydrosedimentological models such as Water Erosion Prediction Project (WEPP) (described by Brooks et al. [32]) and Soil & Water Assessment Tool (SWAT)for simulating extreme processes on a basin scale [33], including drastic coverage withdrawal, texture dynamics might aid the model's ability to predict the impact of land use changes in runoff and soil conservation conditions

4. Conclusions

Based on field experiments conducted during the 2016/2017 hydrologic year, after a five-year drought in the studied region, the experimental data from three sites with 12 plots and four surface covers successfully enabled us to assess the performance of two low-cost soil conservation practices (Mulch and Palma), compared to natural cover conditions and to bare soil conditions.

By using experimental plots to compare natural cover conditions (Caatinga) with the applied soil conservation practices, the following conclusions can be drawn:

- Mulch was more efficient as a soil conservation technique than Cactus Palma, although Palma significantly increased soil moisture compared to bare soil.
- Natural Cover (Caatinga) yielded less mulch runoff and sediment loss when compared to bare soil and to soil conservation practices (Mulch and Palma).

- Rainfall intensity was the single most important factor in runoff generation and soil losses.

When mulch is not available, Cactus Palma appears to be an attractive solution for reducing sediment losses and increasing infiltration. Moreover, being rooted, they are not easily transported away by wind, and they can be used as relevant livestock food alternatives during severe drought situations.

Author Contributions: A.A.A.M. conceptualisation; I.L. Field investigation and data acquisition; I.L., A.A.A.M., and J.L.M.P.d.L. Data analysis and interpretation; I.L. Writing original draft; J.L.M.P.d.L. Review.

Acknowledgments: To the National Council for Scientific and Technological Development (CNPq), the Funding Agency for Studies and Projects (FINEP), the Foundation for Science and Technology Support of the Pernambuco State (FACEPE), and to the Agronomic Institute of Pernambuco (IPA) for supporting the development of the research. To the financial support of Project HIRT—Modelling surface hydrologic processes based on infrared thermography at local and field scales (PTDC/ECM-HID/4259/2014–POCI-01-0145-FEDER-016668), from FCT, Portugal.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Brocca, L.; Tullo, T.; Melone, F.; Moramarco, T.; Morbidelli, R. Catchment scale soil moisture spatial–temporal variability. *J. Hydrol.* **2012**, *39*, 422–423. [CrossRef]
2. Serengil, Y.; Gökbulak, F.; Özhan, S.; Hızal, A.; Şengönül, K.; Nihat, B.A.; Özyuvac, N. Hydrological impacts of a slight thinning treatment in a deciduous forest ecosystem in Turkey. *J. Hydrol.* **2007**, *333*, 569–577. [CrossRef]
3. Alkharabsheh, M.M.; Alexandridis, T.K.; Bilasb, G.; Misopolinos, N. Impact of land cover change on soil erosion hazard in northern Jordan using remote sensing and GIS. Four decades of progress in monitoring and modeling of processes in the soil-plant-atmosphere system: Applications and challenges. *Procedia Environ. Sci.* **2013**, *19*, 912–921. [CrossRef]
4. Montenegro, A.A.A.; Abrantes, J.R.C.B.; de Lima, J.L.M.P.; Singh, V.P.; Santos, T.E.M. Impact of mulching on soil and water dynamics under intermittent simulated rainfall. *Catena* **2013**, *109*, 139–149. [CrossRef]
5. Ostovari, Y.; Ghorbani-Dashtaki, S.; Bahrami, H.; Naderi, M.; Dematte, J.A.M. Soil loss prediction by an integrated system using RUSLE, GIS and remote sensing in semi-arid region. *Geoderma Reg.* **2017**, *11*, 28–36. [CrossRef]
6. Brasil, J.B.; Palácio, H.A.D.Q.; Araújo Neto, J.R.D.; Ribeiro Filho, J.C.; Andrade, E.M.D. Características das chuvas e interceptação vegetal no Bioma Caatinga. *Irriga* **2017**, *22*, 560–574. (In Portuguese) [CrossRef]
7. Abrantes, J.R.C.B.; Prats, A.S.; Keizer, J.J.; de Lima, J.L.M.P. Effectiveness of the application of rice straw mulching strips in reducing runoff and soil loss: Laboratory soil flume experiments under simulated rainfall. *Soil Till. Res.* **2018**, *180*, 238–249. [CrossRef]
8. Ribeiro Filho, C.J.; Palácio, H.A.D.Q.; Andrade, E.M.D.; Santos, J.C.N.D.; Brasil, J.B. Rainfall characterization and sedimentological responses of watersheds with different land uses to precipitation in the Semiarid Region of Brazil. *Rev. Caatinga* **2017**, *30*, 468–478. [CrossRef]
9. Qin, W.; Hu, C.; Oenema, O. Soil mulching significantly enhances yields and waterand nitrogen use efficiencies of maize and wheat: A meta-analysis. *Sci. Rep.* **2015**, *5*, 162–170. [CrossRef]
10. Pinheiro, K.M.; Silva, T.G.F.; Diniz, W.J.S.; Carvalho, H.F.S.; Moura, S.B. Indirect methods for determining the area index of forage cactus cladodes. *Pes. Agrop. Tropical* **2015**, *45*, 163–171. [CrossRef]
11. Santos, T.E.M.; Silva, D.D.; Montenegro, A.A.A. Temporal variability of soil water content under different surface conditions in the semiarid region of the Pernambuco state. *Rev. Bras. Ciên. do Solo* **2010**, *34*, 1733–1741. [CrossRef]
12. Holko, L.; Holzmann, H.; de Lima, M.I.P.; de Lima, J.L.M.P. Hydrological research in small catchments—An approach to improve knowledge on hydrological processes and global change impacts. *J. Hydrol. Hydromech.* **2015**, *63*, 181–182. [CrossRef]
13. Prats, S.A.; Abrantes, J.R.C.B.; Coelho, C.O.A.; Keizer, J.J.; de Lima, J.L.M.P. Comparing topsoil charcoal, ash, and stone cover effects on the postfire hydrologic and erosive response under laboratory conditions. *Land Degrad. Dev.* **2018**, *18*, 1–10. [CrossRef]
14. Zhou, Q.; Zhou, X.; Luo, Y.; Cai, M. The Effects of Litter Layer and Topsoil on Surface Runoff during Simulated Rainfall in Guizhou Province, China: A Plot Scale Case Study. *Water* **2018**, *10*, 915. [CrossRef]

15. Phan-Ha, H.A.; Huon, S.; Tureaux, T.H.; Orange, D.; Jouquet, P.; Valentin, C.; de Rouw, A.; Duc, T. Impact of fodder cover on runoff and soil erosion at plot scale in a cultivated catchment of North Vietnam. *Geoderma* **2012**, *8*, 177–178. [CrossRef]
16. Santos, T.E.M.; Montenegro, A.A.A. Erosivity and rainfall hydrological patterns in the Pernambuco Central "Agreste". *Rev. Bras. de Eng. Agrí. e Amb.* **2012**, *16*, 871–880. (In Portuguese) [CrossRef]
17. Wenninger, J.; Uhlenbrook, S.; Lorentz, S.; Leibundgut, C. Identification of runoff generation processes using combined hydrometric, tracer and geophysical methods in a headwater catchment in South Africa. *Hydrol. Sci. J.* **2008**, *53*, 65–80. [CrossRef]
18. Silva, B.M.; Montenegro, S.M.G.L.; Silva, F.B.D.; Araújo Filho, P.F.D.A. Chuvas Intensas em Localidades do Estado de Pernambuco. *Braz. J. Water Res.* **2012**, *17*, 135–147. (In Portuguese) [CrossRef]
19. Santos, J.C.N.; Andrade, E.M.; Guerreiro, M.J.S.; Medeiros, P.H.A.; Palácio, H.A.Q.; Araújo Neto, J.R. Effect of dry spells and soil cracking on runoff generation in a semiarid micro watershed under land use change. *J. Hydrol.* **2016**, *541*, 1–10. [CrossRef]
20. Silva, J.R.L.; Montenegro, A.A.A.; Monteiro, A.L.N.; Silva Júnior, V.P. Modelagem da dinâmica de umidade do solo em diferentes condições de cobertura no semiárido pernambucano. *Rev. Bras. de Ciên. Agrárias* **2015**, *10*, 293–303. (In Portuguese) [CrossRef]
21. Montenegro, A.A.A.; Montenegro, S.M.G.L. Variabilidade espacial de classes de textura, salinidade e condutividade hidráulica de solos em planície aluvial. *Rev. Bras. de Eng. Agrí. e Amb.* **2006**, *10*, 30–37. (In Portuguese) [CrossRef]
22. EMBRAPA—Empresa Brasileira de Pesquisa Agropecuária. *Manual de Métodos de Análises de Solos*; EMBRAPA: Rio de Janeiro, Brazil, 2011; 230p. (In Portuguese)
23. Lopes, I.; Leal, B.G.; Ramos, C.M.C.; Melo, J.M.M. Espacialização da precipitação para a região do Submédio São Francisco. *Rev. Bras. de Agri. Irr.* **2016**, *10*, 893–903. (In Portuguese) [CrossRef]
24. Araújo, D.C.S.; Montenegro, S.M.G.L.; Montenegro, A.A.A.; Silva Júnior, V.P.; Santos, S.M. Spatial variability of soil attributes in an experimental basin in the semi-arid region of Pernambuco, Brazil. *Rev. Bras. de Eng. Agrí. e Amb.* **2018**, *22*, 38–44. [CrossRef]
25. Bezerra, J.M.; Moura, G.B.A.; Silva, B.B.; Lopes, P.M.O.; Silva, Ê.F.F. Biophysical parameters from remote sensing in semiarid region of Rio Grande do Norte state, Brazil. *Rev. Bras. de Eng. Agrí. e Amb.* **2014**, *18*, 73–84. [CrossRef]
26. Caloiero, T.; Biondo, C.; Callegari, G.; Collalti, A.; Froio, R.; Maesano, M.; Matteucci, G.; Pellicone, G.; Veltri, A. Results of a long-term study on an experimental watershed in southern Italy. *Forum Geografic* **2016**, *15*, 55–65. [CrossRef]
27. McLaughlin, D.L.; Kaplan, D.A.; Cohen, M.J. Managing Forests for Increased Regional Water Yield in the Southeastern U.S. Coastal Plain. *J. Am. Water Resour. Assoc.* **2013**, *49*, 953–965. [CrossRef]
28. Kiani-Harchegani, M.; Sadeghi, S.H.; Asadi, H. Comparing grain size distribution of sediment and original soil under raindrop detachment and raindrop-induced and flow transport mechanism. *Hydrol. Sci. J.* **2017**, *63*, 312–323. [CrossRef]
29. Silveira, A.; Júnior, J.A.P.; Poleto, C.; de Lima, J.L.M.P.; Gonçalves, F.A.; Alvarenga, L.A.; Isidoro, J.M.P.G. Assessment of loose and adhered urban street sediments and trace metals: A study in the city of Poços de Caldas, Brazil. *J. Soils Sed.* **2016**, *16*, 2640–2650. [CrossRef]
30. Bashari, M.; Moradi, H.R.; Kheirkhah, M.M.; Jafari-Khaledi, M. Temporal variations of runoff and sediment in different soil clay contents using simulated conditions. *Soil Water Res.* **2013**, *8*, 124–132. [CrossRef]
31. De Lima, J.L.M.P.; Souza, C.S.; Singh, V.P. Granulometric characterization of sediments transported by surface runoff generated by moving storms. *Nonlinear Proc. Geoph.* **2008**, *15*, 999–1011. [CrossRef]
32. Brooks, E.S.; Dobre, M.; Elliot, W.J.; Wu, J.Q.; Boll, J. Watershed-scale evaluation of the Water Erosion Prediction Project (WEPP) model in the Lake Tahoe basin. *J. Hydrol.* **2016**, *533*, 389–402. [CrossRef]
33. Arnold, J.G.; Srinivasan, R.; Muttiah, R.S.; Williams, J.R. Large Area Hydrologic Modeling and Assessment Part I: Model Development. *J. Am. Water. Resour. Assoc.* **1998**, *34*, 73–89. [CrossRef]