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Effects of Land Use and Cropping on Soil Erosion in Agricultural Frontier Areas in the Cerrado-Amazon Ecotone, Brazil, Using a Rainfall Simulator Experiment

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Abstract: Agricultural soils provide ecosystem services, but the removal of natural vegetation reduces water infiltration capacity, increasing surface runoff. Thus, monitoring erosion is critical for sustainable agricultural management. Sediment losses and surface runoff were evaluated using a simulated rainfall of 75 mm/h in areas with crops and pastures in both the Caiabi River and Renato River sub-basins of the Teles Pires River watershed in Mato Grosso State, Brazil. In both the Caiabi and Renato sub-basins, data were collected from 156 observations in the upper, middle, and lower regions where (1) soybeans, (2) maize, and (3) pasture were grown alone, with another crop, or with soil that was scarified. Erosion occurred independent of soil texture and was closely related to the management and use of systems involving fewer crops and more soil scarification, regardless of sub-basin location. In uncovered, scarified soil, the soil losses from erosion were greater compared to covered soil, regardless of sub-basin and sub-basin region. In the Renato River sub-basin, soil losses in cultivated areas not planted with crops but with scarification were 66.01, 90.79, and 60.02 g/square meter in the upper, middle, and lower regions, respectively. Agricultural producers need to increase the planting of crops throughout the year and minimize soil disturbance, which will reduce soil erosion and improve sustainability.

Keywords: Cerrado-Amazon; crops; geoprocessing; GIS; land use; mapping; rainfall simulator; satellite images; soil erosion

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1. Introduction

Soil is essential for both macro- and microscopic life and provides ecosystem services, ensuring a stock for carbon, nutrient cycling, water retention and infiltration, and food production [1]. However, most soils in Brazil and around the world are compromised due to contamination, pollution, and erosive processes that have contributed to soil degradation [2,3]. In addition to adversely affecting farming production and ecosystem services, degraded soils contribute to global warming and hydrological extremes since they have lower capacities to store carbon and facilitate the infiltration and storage of water [4–6].

Erosion is one of the main causes of soil loss in Brazil and around the world, specifically water erosion [2,7], which is responsible for detaching soil particles, transporting them, and depositing them in areas at lower altitudes. Therefore, soil carbon stocks are exposed and lost through decomposition, mineralization, and transport, while mineral particles silt up rivers, streams, and lakes [8]. While soil compaction, surface crusting, and soil erosion can be reduced by soil organic matter, which can also provide nutrients to plants, soil erosion can also be reduced by vegetative cover [9]. Uncovered and/or badly managed soils accelerate this process since the absence of vegetative cover (e.g., crops) promotes direct exposure to raindrops [10]. Factors such as the duration of rain and the slope of the area are also responsible for increases in soil losses by erosion, as they influence surface runoff [11,12], while soil turning (scarification) promotes the breakdown of aggregates, making the particles more susceptible to the erosive process [13].

In order for Brazil to reduce its soil and water losses, producers need to adopt management techniques such as the no-tillage system, contour lines, and pasture management with rotational grazing. In contrast, areas covered with native forest, crop straw residues, and pasture tend to have less soil loss than areas with exposed and tilled soils [13–15], minimizing the environmental damage from soil erosion. Undisturbed natural vegetation can also minimize soil erosion. For example, in an area with native forest located in the Amazon biome, the measured surface runoff and soil losses were close to zero due to the greater rainfall infiltration capacity of the soil [16]. The removal of natural vegetation from forest areas and its transformation into crops and pastures cause soil and water losses and the subsequent destruction of biodiversity, due to the reduction of carbon stocks [11]. When this removal is accompanied by farming practices involving continuous soil disturbance, such as scarification, these losses are even more marked since soil disruption favors erosive processes [2,17]. Long-term research studies over decades demonstrate that shifting grasslands to progressively more disturbed or scarified (e.g., tilled) cropping systems can decrease soil microbiome diversity, make soil microbiome processes more variable, and increase the prevalence of pathogenic soil organisms [18].

Located in the Cerrado-Amazon ecotone and holding great socioeconomic and environmental importance, the upper and middle Teles Pires regions in Mato Grosso State, Brazil, are agricultural frontiers that have undergone constant native vegetation removal and are susceptible to severe soil, water, and nutrient losses [17]. These areas represent the dynamics of land occupation and land use in the region; soil erosion monitoring is an important tool for decision-making, especially regarding sustainable agricultural production. Due to difficulties in collecting and quantifying the runoff in the experimental plots and the temporal variability of the intensity of natural rainfall, rainfall simulators have been used in different classes, uses, and occupations [12] and in studies about water infiltration into the soil [19], revealing distinct classifications and operational characteristics [20–22]. Additionally, the simulation equipment allows control of the duration and rainfall intensity, and the size and speed of the droplets impacting the soil [20]. Known as sprinkler infiltrometers, these simulators take less time and have a lower cost when conducting field research, compared to experimental natural rainfall plots, and can accurately control water input, thereby reducing the errors associated with natural rainfall variability [23].

The use of rainfall simulators to measure soil erosion in agricultural production systems in the Cerrado-Amazon transition region is unprecedented. Our research can serve as a guide for agricultural producers, ranchers, the public agencies of agrarian policies, and non-governmental agencies seeking to improve the management of soil and water resources in the tropics. The goal of our study is to quantify soil losses when under different agricultural land uses in the Caiabi and Renato River sub-basins of the Teles Pires River watershed in Mato Grosso State, Brazil.

2. Materials and Methods

2.1. Study Area

The Teles Pires River watershed is located in the states of Mato Grosso and Pará, Brazil (Figure 1). Despite being located, in hydrological terms, in the Amazon region, the Teles Pires watershed has variable vegetative cover, with its upper and lower regions in the Cerrado and Amazon biomes, respectively. The upper and middle Teles Pires regions correspond to 26.2 and 57.71% of the basin area; they have a population density of 45.9

and 27.5% of the total population of the basin and are responsible for 66.3 and 18.7% of the gross domestic product (GDP) obtained in the two Teles Pires River areas, respectively. The two regions together represent more than 17% of the GDP of Mato Grosso. Analyses of the soil and water losses were conducted in two drainage sub-basins, the Caiabi River (upper) and Renato River (middle), with drainage areas of approximately 500 and 1450 km^2, respectively (Figure 1).

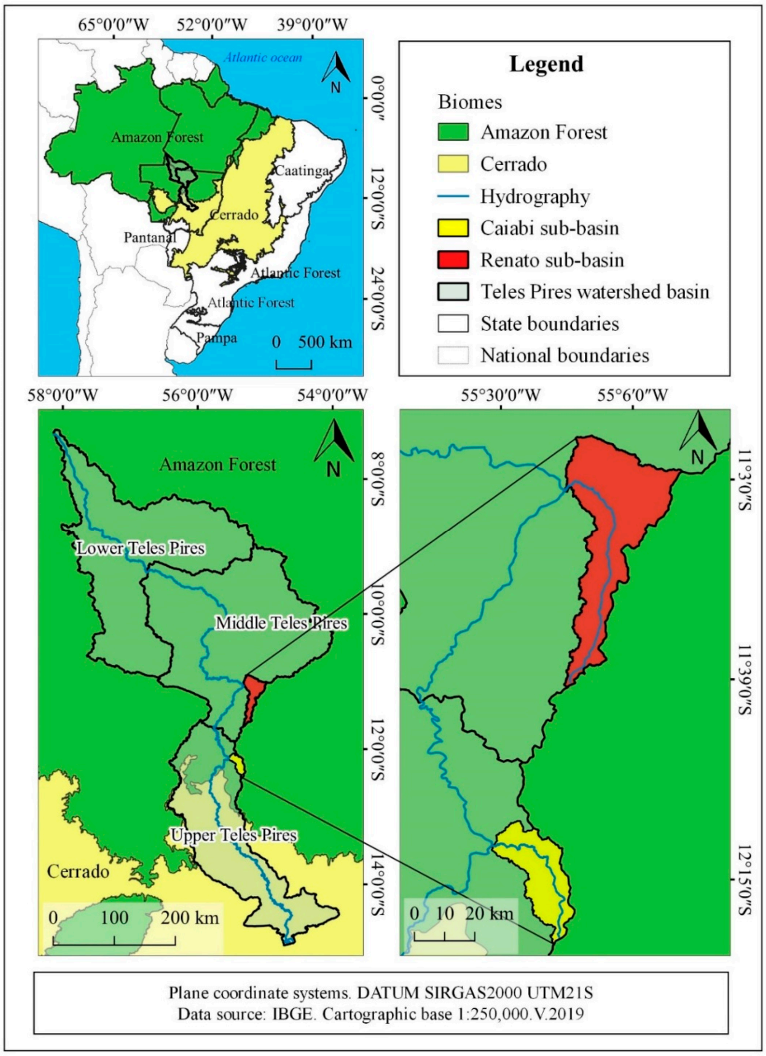

Figure 1. The Teles Pires River watershed and the location of the Caiabi and Renato River basins (data source: Ref. [24]).

Regarding the soils in the Caiabi sub-basin, the most recurrent classes are the inceptisols, oxisols, and entisols [24,25], formed from metasedimentary rocks belonging to the Cuiabá Group and the Raizama and Araras formations (Upper Paraguai Group). Conversely, the Renato sub-basin presents pedological characterization, with ultisols, oxisols, entisols, and Plinthic oxisols [24,25], formed from the granitic and rhyolitic rocks of the Juruena magmatic arc, with several gold occurrences: sandstones from the Dardanelos Formation and the Beneficiente Group, with sandstones, siltstones, and claystones from the Upper Tapajós basin (Capoeiras Formation).

In the Caiabi River sub-basin, located in the Cerrado-Amazon ecotone, monoculture areas of soybean (*Glycine max* L.), immediately followed by maize (*Zea mays* L.) in the same production year succession, are predominant, while in the Renato River sub-basin, there is also a predominance of native Amazon rainforest under forest management. According to the Köppen climate classification model, the climate of the region is the Aw type, considered a tropical wet and dry climate, with a dry period between June and August [26]. The mean annual temperature is 25 °C, with a minimum temperature below 16 °C and a maximum temperature above 34 °C. The mean annual precipitation varies by approximately 1900 mm [27]. In 2019, the percentages (%) of land use and occupation in the Caiabi sub-basin were most for crops (51.96%) followed by water (22%), native forest (31.78%), pastures (3.6%), and burned areas (0.08%), respectively. Likewise, in the Renato River hydrographic sub-basin, these same classes of land use and occupation were highest for native forest (61.32%) followed by water (27%), pastures (9.7%), crops (9.57%), and burned areas (0.18%), respectively (Figure 2).

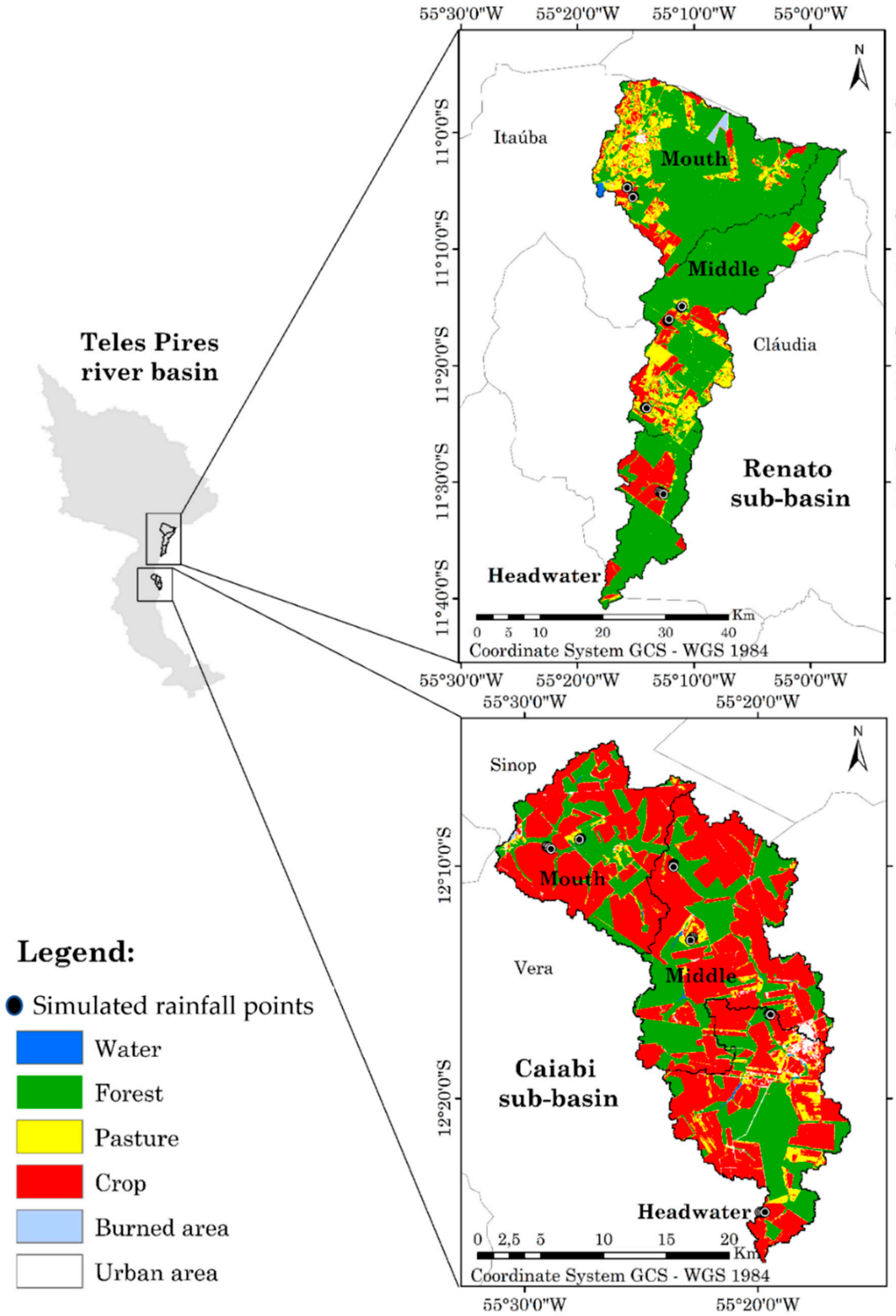

Figure 2. Location of the sampling points of simulated rainfall and land use, along with occupation in the Caiabi and Renato sub-basins, which are tributaries of the Teles Pires river.

Rainfall simulator experimental tests were carried out on 12 farms, two in each region of each sub-basin. In general, in the region each property operates in, only one type of farming activity occurs (either cropping or pasture). In the Caiabi river sub-basin, 84 tests were carried out on six farms, distributed as follows: (1) on the farms occupied by soybeans, only four soil covers were evaluated at each sampling point (soybean + straw, straw only, uncovered soil, and scarified soil), totaling 48 tests; (2) on the farms occupied by pastures, three soil covers were evaluated at each sampling point (pasture, uncovered soil, and scarified soil), totaling 36 tests. In the Renato sub-basin, 72 tests were carried out, since in both of the areas occupied by corn and by pastures, three soil covers were evaluated (with vegetation, uncovered soil, and scarified soil), resulting in 36 tests in areas occupied by corn and 36 tests in areas occupied by pastures. In Figure 2, the four repetitions evaluated in the same farm are not so evident, due to the spatial scale. However, the tests with simulated rainfall were carried out considering a minimum distance of 500 m between repetitions (examples can be seen in Figure 3). The areas selected for carrying out these tests had spent at least 5 years under the same land use.

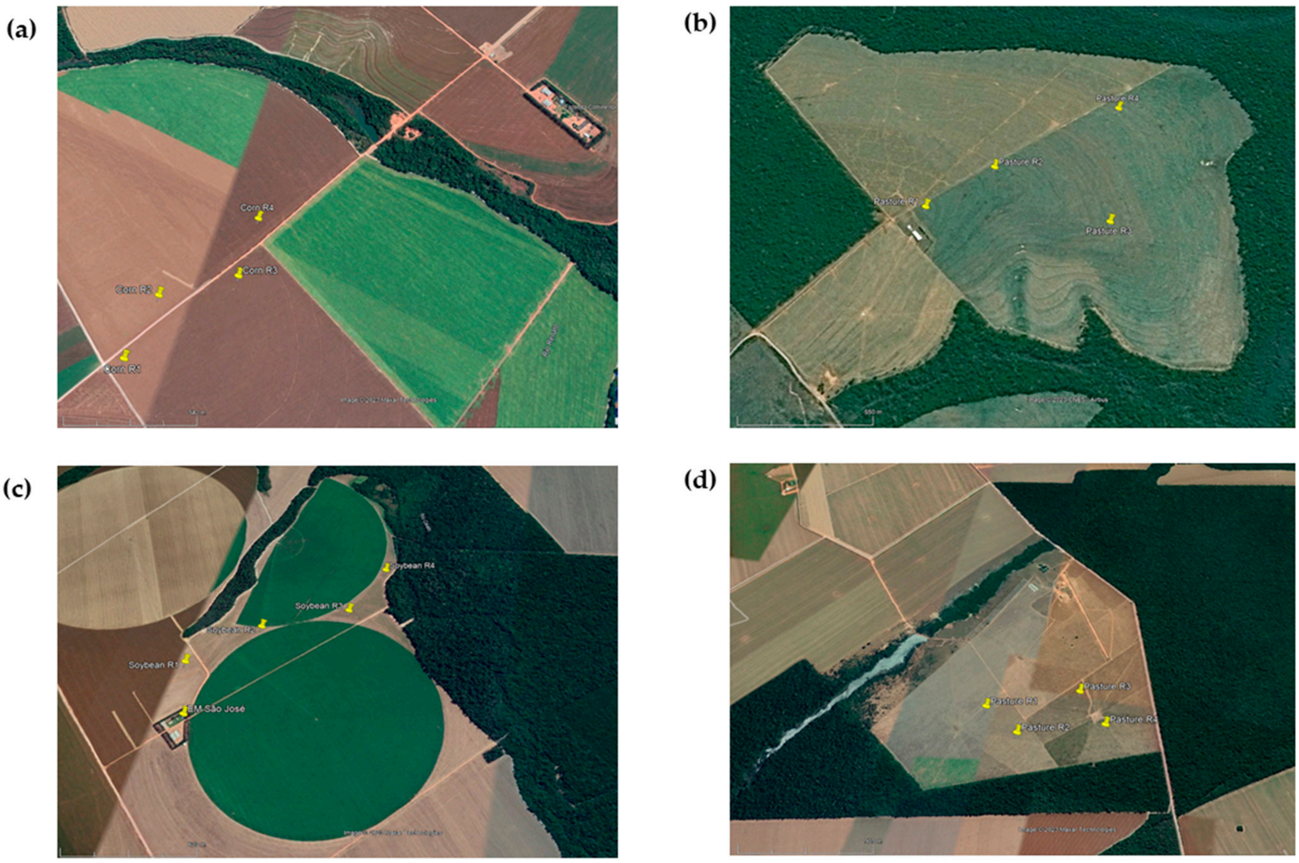

Figure 3. Locations of the simulated rainfall points in (**a**) Continental Farm (headwater sub-basin region), (**b**) Aremisa III Farm (middle sub-basin region), with land use of maize crops and pasture, in the Renato sub-basin, (**c**) São José Farm, and (**d**) Taguá Farm, both in the middle region of the Caiabi sub-basin. The scales in (**a**–**d**) are 1:54,200, 1:361,000, 1:55,000, 1:62,300, and 1:90,500 cm, respectively.

The evaluations of soil and water losses occurred for different agricultural crops, depending on the specific cultivation calendar for soybeans and maize in the state of Mato Grosso. Figure 4 summarizes the rainfall in the two hydrographic sub-basins being evaluated, along with the arrangement of crops in the region, regulated by the federal ordinances of the Secretaria de Política Agrícola (SPA) of the Ministério de Agricultura, Pecuária e Abastecimento (MAPA) of Brazil. For soybean cultivation, the Portaria SPA/MAPA 249/2022 legislation [28] recommends sowing soybeans between 1 October and 31 December in the municipalities located in the Caiabi and Renato hydrographic basins. This legislation also establishes a "sanitary void" for soybean cultivation, which is a recommended break in the planting of soybeans after 1 January and before 15 September each year. Therefore, in the region studied, maize is planted as the second crop (*safrinha*), and its planting depends on the sowing time and the growth cycle of the soybean cultivar that is planted. This is regulated by the Agricultural Zoning of Climatic Risk (ZARC), established by Ordinance SPA/MAPA 332/2022 [29], which recommends planting maize between 1 February and 10 March each year.

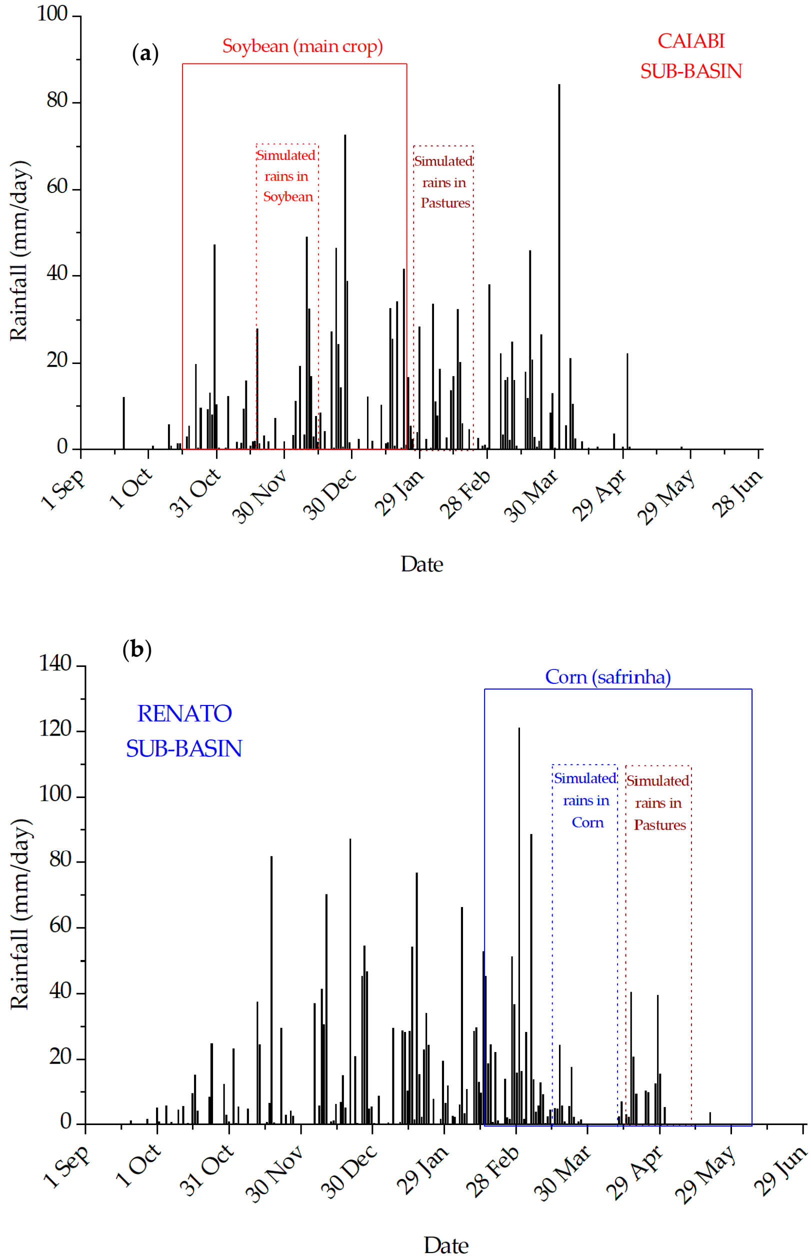

Figure 4. Daily rainfall in (**a**) the Caiabi sub-basin and (**b**) the Renato sub-basin, between 15 September 2020 and 30 June 2021.

2.2. Simulated Rainfall Treatments

Field trials with the InfiAsper rainfall simulator [20] were carried out in pastures and in areas under crop cultivation in the upper, middle, and lower regions of the two watersheds (Figure 5). The simulator operates with two Veejet 80.150 nozzles parallel to each other, positioned 2.3 m from the ground surface, with an average service pressure of 35.6 kPa. The diameter of drops applied by the simulator, considering the different pressure settings and rotation of the obturator disk, was exhaustively measured by Macedo et al. (2021) [22] using the flour method. Alves Sobrinho et al. 2008 [20] also made this assessment, confirming a mean drop diameter of 2.0 mm. Calibration tests were carried out in the laboratory, using a grid with 25 collectors over an area of 50 square centimeters, and uniformity coefficients above 80% were obtained.

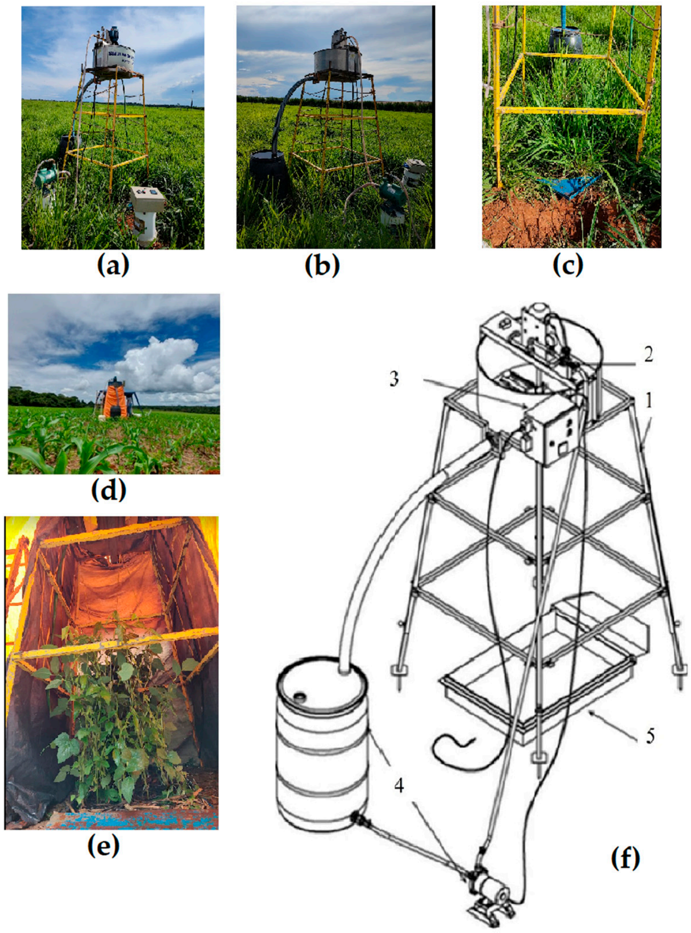

Figure 5. Installation of the *InfiAsper* rainfall simulator (**a**–**d**) and its operation (**e**), with plastic inside the support structure of the *InfAsper* to reduce the effects of wind; scheme of the components of the *InfiAsper* rainfall simulator (**f**) showing: (1) metallic structure, (2) water application unit, (3) control panel, (4) reservoir and water pump, and (5) runoff collector [22].

Due to the regional agricultural calendar, the evaluations in cultivation areas in the Caiabi River basin occurred in soybean plantations at the V7 vegetative stage, with the plants cultivated in maize straw (no-tillage system), whereas in cultivation areas in the Renato River basin, the crops were maize at the V4 vegetative stage after soybean succession. In the two basins, the pasture areas were occupied by *Brachiaria* spp., with an average height of 50 cm. The simulated rainfall was carried out in different areas in the two sub-basins, namely, for soybean (the Caiabi sub-basin) and for maize (the Renato sub-basin). Due to the cultural practices adopted in the region, the amount of remaining soybean straw in the maize crop was very small, when compared with the remaining maize straw, which can influence the timing of soybean planting. For this reason, no simulated rainfall was carried out in those plots with only straw in the Renato sub-basin.

In the cultivation areas of the Caiabi River basin, simulated rainfall was performed considering the following treatments (Figure 6): covered with soybean (plant + straw), only straw, and without crops and scarified at 0.1 m soil depth (4). In the Renato sub-basin, the treatments evaluated were covered with maize, without crops, and scarified. In the pasture areas for both basins, rainfall was assessed with the conditions of soils covered with pasture, uncovered soils, and soils scarified at 10 cm in depth. Simulated rainfall was replicated 4 times per basin region and treatment, totaling 156 tests. The useful area of the simulator plot was 0.7 square meters (m^2) and the average slope of the surface in the field was 3 degrees (Figure 6h). To standardize soil moisture, the plots were dampened before the beginning of the simulated rainfall, according to the methodology described in [12].

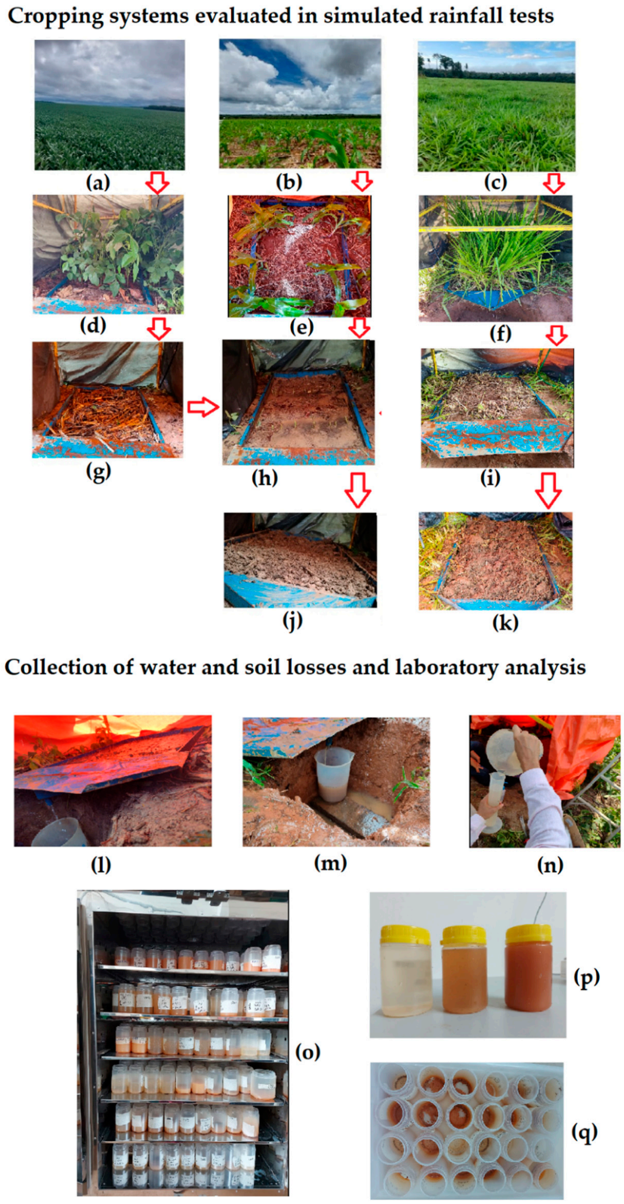

Figure 6. Soil cover treatments with (**a**) soybean, (**b**,**e**) pasture, and (**c**,**f**) maize, soybean + straw (**d**), and straw only (**g**), without crops (**h**,**i**), and scarified (**j**,**k**). The red arrows represent the flowchart of simulated events, as follows: (i) soybean + straw, straw only, without crops and with scarified soil; (ii) maize, without crops and with scarified soil; (iii) pasture, without crops and with scarified soil. In simulated rainfall tests in the different cropping systems, surface runoff was collected every minute (**l**,**m**), measuring the volume of water loss (**n**). Subsequently, the samples were dried in an oven (**o**,**q**); the differences between soil losses in pasture conditions, uncovered soil, and scarified soil for the same sampling point and time after the start of runoff (6 min) can be observed in (**p**).

The rainfall intensity (RI) of the simulated rainfall was defined, based on the intensity–duration–frequency (IDF) relationship created for the study region, according to the authors of [30]. The RI value was approximately 75 mm per hour, considering a return period of 10 years and an average duration of 42 min. After the beginning of the runoff, the material collection was performed at intervals of 1 min using plastic containers, and the runoff volume was measured with a graduated cylinder and then transferred to 0.5-liter (L) jars. The volume of runoff water was sent to the laboratory for the quantification of the water and soils lost through erosion [12]. To identify the amount of sediment in the water, the decantation and subsequent evaporation process of the water was conducted. To achieve this, the jars with the collected material were subjected to a temperature of 55 °C, in a forced circulation ion oven, until reaching a constant dry mass (up to 96 h). After drying, the samples were weighed on an analytical balance for the quantification of sediment.

2.3. Analyses of the Soil Characteristics and Vegetative Cover Dry Matter

For the physical-hydric characterization of the soil, near each point where the simulated rainfall was applied, mini-trenches of 0.4 × 0.4 m were dug for the collection of disturbed and undisturbed soil samples in the 0- to 0.1- and 0.1- to 0.2-m layers in the three regions of each sub-basin. The attributes analyzed in the physical-hydric characterization were granulometry (sand, silt, and clay), bulk density, particle density, total porosity, macro- and microporosity, and hydraulic conductivity. Granulometry was determined by the pipette method, using a sodium hydroxide (NaOH) solution with mechanical agitation for 16 h, based on the principle of Stokes' law. Bulk density was obtained by the graduated cylinder method, using undisturbed samples. In the laboratory, the samples were dried in an oven at 105 °C and then weighed 48 h later [31]. Particle density was determined by the volumetric flask method. Total porosity was obtained via the relationship between the bulk density and particle density in Equation 1 [32]. Macroporosity was obtained by the tension table, with a tension of 10 kilopascals (kPa), and microporosity was obtained by taking the difference between total porosity and macroporosity [31]:

$$TPo = 1 - Bd/Pd \tag{1}$$

where TPo equals total porosity, Bd is bulk density, and Pd equals particle density. The soil class of all studied areas is latosol [25]. Soil textural distribution particles in the two watersheds are shown in Table 1.

Table 1. Soil textural distribution in the hydrographic sub-basins of the Renato and Caiabi Rivers.

Cropland Use	Caiabi River Sub-Basin Region *								
	Upper			Middle			Lower		
	Sand	Clay	Silt	Sand	Clay	Silt	Sand	Clay	Silt
	(%)								
	0 to 0.1 m in depth								
Cultivated	42.49Ab	27.90Aa	29.61Aa	76.56Aa	17.80Bb	5.64Ab	78.50Aa	15.60Ab	5.90Ab
Pasture	49.24Ab	36.10Aa	14.66Ba	49.21Bb	34.60Aa	16.19Aa	84.37Aa	11.00Ab	4.63Ab
	0.1 to 0.2 m in depth								
Cultivated	52.40Ab	35.80Ba	11.80Aa	75.75Aa	20.20Bb	4.05Aa	79.29Aa	16.90Ab	3.81Aa
Pasture	36.12Bb	49.00Aa	14.88Aa	45.40Bb	43.70Aa	10.90Aa	83.32Aa	11.80Ab	4.88Aa
	Renato River Sub-Basin Region *								
	0 to 0.1 m in depth								
Cultivated	75.18Ab	16.20Aab	8.62Aa	82.87Aa	12.90Ab	4.23Aa	73.90Bb	19.40Aa	6.70Aa
Pasture	80.43Aa	15.90Aa	3.67Aa	83.16Aa	12.90Aa	3.94Aa	81.94Aa	14.70Ba	3.36Aa
	0.1 to 0.2 m in depth								
Cultivated	75.88Aab	19.00Aab	5.12Aa	80.52Aa	16.20Ab	3.28Aa	71.98Bb	23.20Aa	4.82Aa
Pasture	75.30Aa	18.30Aa	6.40Aa	81.58Aa	13.40Aa	5.02Aa	79.93Aa	17.70Ba	2.37Aa

* Means that are followed by equal uppercase letters in the same column and equal lowercase letters in the same row do not differ significantly from each other, as established by the Kruskal-Wallis test at a 5% confidence level.

Vegetation cover was removed after rainfall on the covered ground and before rainfall on the bare ground from each plot. To measure the dry matter content of the vegetation cover, plant materials were collected, identified, and taken to the Hydraulics and Hydrology Laboratory at the Federal University of Mato Grosso. Subsequently, they were dried in an oven with forced air circulation at a temperature of 65 °C for 72 h, until reaching a constant dry mass of around less than 5% moisture. The dry mass was quantified using a thousandth of an analytical scale, while for the straw dry mass, the separation of the remaining soil particles was carried out.

2.4. Experimental and Statistical Design

In cultivated areas in the Caiabi River, the experimental design was conducted in randomized blocks (RBD), in a 3 × 4 factorial scheme, with 3 regions in the basin (upper, middle, and lower) and 4 soil cover/management treatments (soybean + straw, straw, without crops, without crops and scarified). In the Renato River basin, a similar experimental design was used (RDB), but in a 3 × 3 factorial scheme, with 3 regions in the basin and 3 soil cover/management treatments (maize, without crops, without crops and scarified). In pasture areas, regardless of the basin, a 3 × 3 factorial scheme was used, with 3 regions in the basin and 3 soil cover/management treatments (*Brachiaria* spp., without crops, and without crops and scarified). In all the conditions mentioned above, simulated rainfall was replicated 4 times. The repetitions were spaced 50 m apart, ensuring the same level in the toposequence and land use. The slope of the field area in our experiments ranged from 3 to 4 degrees. All variables were subjected to the Kruskal-Wallis test at a 5% probability (test for nonparametric data) using the Statistica program, version 10.0.

3. Results

3.1. Vegetative Cover Dry Matter

The sampled dry-matter contents of soybean and maize (crops), pasture, and straw are contrasted in Table 2. The dry mass of vegetative cover in plots that were subjected to simulated rainfall ranged from 7.26 to 11.91 metric tons/hectare in the Caiabi sub-basin and did not show significant differences in the Kruskal–Wallis test between the hydro-graphic sub-basin regions. The straw represents at least 70% of the dry mass of the vegetative cover (soybean + straw). This vegetative cover condition makes it possible to understand the soil and water losses in the absence of these covers and their relationships with the physical and water characteristics of the soil. No comparisons were made between the two sub-basins because the crops (soybean and maize) and the phenological stages were different.

Table 2. Dry matter (metric tons/hectare) measured for soil-cover treatments of vegetation, straw, and pasture in the experimental plots of simulated rainfall in the hydrographic basins of the Caiabi and Renato rivers.

		Dry Matter (Metric Tons/Hectare)		
Sub-basin	**Region**	**With Crops ***	**Straw**	**Pasture**
Caiabi	Upper	11.91 Aa	8.34 Aa	8.24 Aa
	Middle	10.20 Aa	7.96 Aa	8.90 Aa
	Lower	10.99 Aa	8.95 Aa	7.26 Aa
Renato	Upper	5.21 Ba	-	8.07 Aa
	Middle	6.48 Ba	-	8.29 Aa
	Lower	12.07 Aa	-	8.65 Aa

* "With crops" indicates the presence of soybean and straw in the experimental plots of the Caiabi sub-basin (with only maize for the Renato sub-basin). Differences between means were compared using the Kruskal–Wallis test at 5% probability, where (i) capital letters represent the analysis of the sub-basin regions for the same soil cover, while (ii) lowercase letters represent the analysis of land cover for the same region of the sub-basin.

The Renato River sub-basin has phytophysiological, geological, and pedological characteristics that are different from those found in the Caiabi River basin. Those areas occupied by cultivation had maize at the V4 vegetative stage, while the plants in pasture areas (*Brachiaria* spp.) had an average height of 45 cm. The dry weight obtained for maize varied along the sub-basin, due to the planting density; in both regions, the spacing adopted was 0.5 m between rows. However, the plant populations were 55,000 and 80,000 plants per hectare in the upper/middle and lower regions, respectively. In this sub-basin, there were also no significant differences that were verified by the Kruskal-Wallis test for the dry weight of plants in cultivation, with vegetation (e.g., maize) and pasture areas.

3.2. Caiabi River Sub-Basin

3.2.1. Soil Characteristics in the Caiabi River Sub-Basin

The physical attributes of the soil in the Caiabi river basin varied according to the different regions (Table 3). There was a greater presence of clay in the upper region, while the lower region was characterized by a higher sand content. Although the soil classes are the same, with a predominance of oxisol [25], the lower part of the Caiabi River has a lower altitude, favoring the deposition of sand. The same occurred with bulk density and particle density, with higher values in the lower Caiabi River, since minerals present in the sand fraction have higher densities than clay minerals.

Table 3. Physical and hydric characterization of the Caiabi River sub-basin soils in the pasture and cultivation areas.

Cropland Use	**Caiabi River Sub-Basin Region ***								
	Upper			**Middle**			**Lower**		
	Micro	Macro	**TPo**	**Micro**	**Macro**	**TPo**	**Micro**	**Macro**	**TPo**
	(m^3/m^3)								
	0 to 0.1 m depth								
Cultivated	0.28Aa	0.08Aa	0.36Aa	0.27Aa	0.11Aa	0.38Aa	0.35Aa	0.08Aa	0.43Aa
Pasture	0.27Aa	0.10Aa	0.38Aa	0.35Aa	0.02Aa	0.37Aa	0.29Aa	0.11Aa	0.39Aa
	0.1 to 0.2 m depth								
Cultivated	0.25Aa	0.07Aa	0.32Aa	0.27Aa	0.07Aa	0.34Aa	0.34Aa	0.04Aa	0.38Aa
Pasture	0.26Aa	0.13Aa	0.39Aa	0.32Aa	0.06Aa	0.38Aa	0.29Aa	0.12Aa	0.41Aa
	Pd	**Bd**	**K_0**	**Pd**	**Bd**	**K_0**	**Pd**	**Bd**	**K_0**
	(grams/cm^3)		**(cm/hour)**	**(grams/cm^3)**		**(cm/hour)**	**(grams/cm^3)**		**(cm/hour)**
	0 to 0.1 m depth								
Cultivated	2.14Bb	1.02Bb	1.21Aa	2.54Aa	1.50Aa	1.12Aa	2.52Aa	1.50Aa	1.28Ba
Pasture	2.44Aab	1.41Aa	0.33Bb	2.33Ab	1.58Aa	0.67Bb	2.61Aa	1.58Aa	1.70Aa
	0.1 to 0.2 m depth								
Cultivated	2.30Ab	1.18Ab	0.47Ab	2.54Aab	1.57Aa	1.70Aa	2.63Aa	1.57Aa	1.81Aa
Pasture	2.44Ab	1.40Aa	1.19Bb	2.52Aab	1.57Aa	1.78Aa	2.70Aa	1.57Aa	1.78Aa

* The soil characteristics measured included microporosity (Micro), macroporosity (Macro), total porosity (TPo), particle density (Pd), bulk density (Bd), and hydraulic conductivity (K_0). Means followed by equal uppercase letters in the same column and equal lowercase letters in the same row do not differ significantly from each other, as shown by the Kruskal-Wallis test at a 5% confidence level.

3.2.2. Soil Losses and Surface Runoff in the Caiabi River Sub-Basin

The dry weight of vegetative cover in plots that were subjected to simulated rainfall in the Caiabi River basin ranged from 7.26 to 11.91 metric tons (t) per hectare (Table 1). There were no significant differences between the treatments, using the Kruskal-Wallis test to compare sub-basin regions and land use. This condition allows us to understand the soil and water losses in the absence of these crops and their relationship with the physical and hydric characteristics of the soil (Tables 4 and 5), as well as the surface runoff variable resulting from the simulated rainfall in the Caiabi River sub-basin. There were significant differences in soil scarification for the other soil cover/management conditions in pasture areas. However, there were no significant differences between the positions in the sub-basin for this same use (Table 5).

Table 4. Average values of soil loss (grams/square meter) under different uses, soil cover/management, and regions of the Caiabi River sub-basin.

Cropland Use	Soil Loss (Grams/Square Meter) in Sub-Basin Region *			
	Soil Cover	**Upper**	**Middle**	**Lower**
Cultivation	With other crops	16.2Aa	5.64Aa	12.1Aa
	Straw residue	14.97Aa	8.92Aa	13.6Aa
	Without other crops	31.5Aa	23.6Ba	18.6Aa
	Soil scarified	30.6Aa	27.5Ba	20.50Aa
Pasture	With cultivated	7.09Aa	9.83Aa	2.30Aa
	Without crops	42.8Bb	22.3Aa	16.8Ba
	Soil scarified	35.9Ba	32.7Ba	20.5Ba

* Means followed by equal uppercase letters in the same column and equal lowercase letters in the same row do not differ significantly from each other, according to the Kruskal-Wallis test at a 5% confidence level.

Table 5. Surface runoff (millimeters/hour) under different uses, soil cover/management, and regions of the Caiabi River sub-basin.

Cropland Use	Surface Runoff (millimeters/hour) in Sub-Basin Region *			
	Soil Cover	**Upper**	**Middle**	**Lower**
Cultivated	With other crops	45.30Aa	39.50Aa	26.20Aa
	Straw residue	48.90Aa	44.75Aa	23.22Aa
	Without other crops	49.80Aa	44.70Aa	37.70Aa
	Scarified soil	35.40Aa	33.54Aa	21.70Aa
Pasture	With cultivated	68.60Ba	60.10Ba	61.70Ba
	Without crops	69.60Ba	58.90Ba	66.10Ba
	Scarified soil	30.00Aa	38.50Aa	47.60Aa

* Means followed by equal uppercase letters in the same column and equal lowercase letters in the same row do not differ significantly from each other, according to the Kruskal-Wallis test at a 5% confidence level.

3.3. Renato River Sub-Basin

3.3.1. Soil Characteristics in Renato River Sub-Basin

Unlike the Caiabi river basin, the soil attributes of the Renato River basin did not vary by region (Table 6). A similar presence of clay and sand was observed in the upper, middle, and lower parts of the basin. The same occurred with bulk density and particle density, porosity, and hydraulic conductivity, which showed a similar distribution in the different regions. The hydrographic basin of the Renato River is located in the Amazon Forest biome, unlike the Caiabi River basin, which is located predominantly in the Cerrado biome. These two biomes have different geological formations, although the soil classes are the same [25].

Table 6. Physical and hydric characterization of the Renato River sub-basin soils in pasture and cultivation areas.

Cropland Use	**Renato River Sub-Basin Region ***								
	Upper			**Middle**			**Lower**		
	Micro	**Macro**	**TPo**	**Micro**	**Macro**	**TPo**	**Micro**	**Macro**	**TPo**
	(m^3/m^3)								
	0 to 0.1 m depth								
Cultivated	0.43Aa	0.09Aa	0.52Aa	0.29Ab	0.08Aa	0.37Ab	0.28Ab	0.09Aa	0.37Ab
Pasture	0.40Aa	0.02Aa	0.42Aa	0.37Aa	0.06Aa	0.43Aa	0.33Aa	0.04Aa	0.37Aa
	0.1 to 0.2 m depth								
Cultivated	0.40Aa	0.07Aa	0.47Aa	0.27Ab	0.08Aa	0.35Aa	0.24Ab	0.11Aa	0.35Aa
Pasture	0.37Aa	0.06Aa	0.43Aa	0.33Aa	0.10Aa	0.43Aa	0.21Ab	0.14Aa	0.35Aa
	Pd	**Bd**	**K_0**	**Pd**	**Bd**	**K_0**	**Pd**	**Bd**	**K_0**
	(grams/cm^3)		**(cm/hour)**	**(grams/cm^3)**		**(cm/hour)**	**(grams/cm^3)**		**(cm/hour)**
	0 to 0.1 m depth								
Cultivated	2.71Aa	1.57Aa	0.79	2.73Aa	1.53Aa	1.22	2.65Aa	1.56Ba	0.68
Pasture	2.78Aa	1.53Ab	1.22	2.63Aa	1.59Ab	0.57	2.69Aa	1.75Aa	0.90
	0.1 to 0.2 m depth								
Cultivated	2.71Aa	1.66Aa	0.49Bb	2.69Aa	1.64Aa	0.78Ba	2.74Aa	1.71Aa	0.47Bb
Pasture	2.70Aa	1.51Ab	0.78Ac	2.76Aa	1.53Ab	1.30Ab	2.69Aa	1.70Aa	1.65Aa

* Soil characteristics measured included microporosity (Micro), macroporosity (Macro), total porosity (TPo), particle density (Pd), bulk density (Bd), and hydraulic conductivity (K_0). Means followed by equal uppercase letters in the same column and equal lowercase letters in the same row do not differ significantly from each other, according to the Kruskal-Wallis test at a 5% confidence level.

3.3.2. Soil Losses and Surface Runoff in the Renato River Sub-Basin

Significant increases in soil loss were observed under the scarified soil treatment when compared to plots with vegetation, regardless of the sub-basin region and land use (Table 7). This was similar to what was reported in the Caiabi River sub-basin, with higher soil losses for uncovered and scarified soils. Therefore, soil cover and limiting the soil surface turnover and soil exposure in areas of farming expansion are important for soil conservation, regardless of the biome. This sub-basin is characterized by the abundant presence of the Amazon rainforest (Figure 2), unlike the Caiabi River sub-basin, which is located in the Amazon-Cerrado ecotone [33]. Differences in soil losses in pasture areas with cover (vegetation) in different regions of the Renato River sub-basin are related to soil granulometry, since there is, on average, 80% of sand in the lower region (Table 4). In soils with higher sand contents, infiltration tends to be greater than in clayey soils.

Table 7. Average values of soil loss (grams/square meter) under different uses, soil cover/management, and the regions of the Renato River sub-basin region.

Cropland Use	**Soil Loss (Grams/Square Meter) in Sub-Basin Region ***			
	Condition	**Upper**	**Middle**	**Lower**
Cultivated	With vegetation	4.55Aa	10.20Aa	3.50Aa
	Without other crops	13.20Aa	42.20Ba	10.10Aa
	Scarified soil	66.01Ba	90.79Ca	60.02Ba
Pasture	With vegetation	8.70Ab	5.15Ab	1.01Aa
	Without crops	20.91ABa	25.20ABa	10.07ABa
	Scarified soil	42.01Ba	49.60Ba	17.50Ba

* Means followed by equal uppercase letters in the same column and equal lowercase letters in the same row do not differ significantly from each other, according to the Kruskal-Wallis test at a 5% confidence level.

Regarding surface runoff, a behavioral inversion was observed under scarified soil treatments when compared to other soil cover types, since there was a reduction in the runoff in the uncovered and scarified soils of pasture areas (Table 8). This inversion is the result of the rupture of the surface layers, which are usually compacted in areas of farming and pasture, thus increasing the roughness that limits runoff and promotes water infiltration into the soil. The differences between the average values of surface runoff, especially in the lower regions between the Caiabi and Renato River basins, result from differences in the saturated hydraulic conductivity in the soils (Tables 3 and 6).

Table 8. Surface runoff (millimeters/hour) according to the different uses, soil cover/management, and regions of the Renato River sub-basin.

Cropland Use	Surface Runoff (Millimeters/hour) in Sub-Basin Region *			
	Condition	**Upper**	**Middle**	**Lower**
Cultivated	With vegetation	51.6Aa	51.7Aa	47.7Aa
	Without other crops	59.2Aa	59.6Aa	57.0Aa
	Scarified soil	61.7Aa	61.8Aa	61.0Aa
Pasture	With vegetation	47.2Aa	64.3Ba	58.5Ba
	Without crops	55.2Aa	67.0Ba	59.1Ba
	Scarified soil	34.4Aa	35.0Aa	33.2Aa

* Means followed by equal uppercase letters in the same column and equal lowercase letters in the same row do not differ significantly from each other, according to the Kruskal-Wallis test at a 5% confidence level.

4. Discussion

4.1. Erosion Drivers and Implications

Agricultural crops (soybean + straw, only straw, maize, and *Brachiaria* grass species) are responsible for minimizing the direct impact of raindrops, acting as rain droplet buffers, preventing the disaggregation of particles, and reducing the sediment load in surface runoff [34]. According to the authors of [7], well-managed pastures can be considered sustainable, as they maintain soil quality in terms of the physical, chemical, and biological aspects and prevent erosive processes. In this sense, the pastures of the three sub-basin regions, with an average height of 50 cm, achieved satisfactory phytomass productivity (Table 2). Similar to soybean under a no-tillage scheme, the data are in accordance with the authors of [35], who observed similar results in the Cerrado latosols.

When studying the different levels of cultivated crops, such as soybean, maize, and pasture, prior researchers [12,16] concluded that soil losses increase with the reduction and removal of vegetative cover. Similar results were observed in our study, as soil losses in the Caiabi River sub-basin indicated significant differences between soil treatments with and without vegetative cover. In general, areas covered with vegetation (including straw) provided lower soil losses, revealing the importance of vegetative cover for reducing soil degradation (Table 5).

The occurrence of differences in soil losses for the types of crops and soil scarification demonstrates the need to maintain vegetation cover or straw, regardless of land use (cultivation or pasture), with minimal soil turnover. Due to the distinct physical and hydric characteristics in the sub-basin regions (Tables 3 and 6), a reduction in soil loss was observed from the upper to the lower region for those soils without crops and that were scarified, regardless of land use. The upper region has soils with a predominantly clayey texture, while the middle and lower regions have soils with a more sandy texture (Table 2). In this case, surface sealing may occur in clayey soils, which makes infiltration difficult and promotes an increase in runoff and consequent soil losses, due to the reduction in roughness [36,37]. Moreover, this sub-basin is located in an ecotone area (Cerrado/Amazon rainforest). In this transition area, there are geological, morphological, and pedological variabilities, as well as in the phytophysiognomy of the region [33], affecting the erosive processes along the sub-basin.

In terms of pastures, even though the pasture evaluation did not include soil covered only with straw, soil losses were still reduced with such live vegetative cover. These results are in accordance with [12,14,15], who, while studying simulated rainfall in uncovered soil treatments in different regions of Brazil, observed an intensification of losses due to erosion compared to covered soils. In general, unprotected soils tend to be lost due to the direct impacts caused by raindrops, which provoke detachment and the consequent transport of particles [38].

In addition to vegetative cover, water infiltration into the soil depends on other intrinsic factors, such as texture, porosity, bulk density, and compaction levels, which may compromise hydraulic conductivity (Table 6). Therefore, even in covered soil treatments that reduce soil losses, surface runoff may be high, as observed in this study. In this sense, the lowest values of runoff flow observed in the scarified plots resulted from the roughness formed in the layer that was turned over, along with soil aggregate rupture, which not only facilitates infiltration in areas of low slopes in the short term but also intensifies greater soil losses. Soil turnover in pasture and cultivated areas (e.g., plowing, sub-soiling) disrupts the aggregates, which facilitates this rupture due to rainfall. This facilitates the erosive transport of soil after tillage breaks up the soil layer compacted by animal trampling and wheel slippage from the tractors, planters, sprayers, harvesters, and trucks used during harvesting. Consequently, some researchers [13,39,40] recommend minimal turnover, combined with leaving the straw from crops in-field or using alternate turnovers (e.g., the planting of crops such as maize after the soybean harvest) as ways to minimize soil and water losses by erosion.

The increased values of water loss due to surface runoff in pasture areas with vegetation and without crops (Tables 5 and 8) may be related to precipitation falling directly on the straw, which covers the soil in no-tillage soybean cultivation. This condition may favor water runoff by its running off directly onto the upper surface of the straw. Nevertheless, the water loss depends on fragment sizes, layer height, and straw density, which can reduce infiltration [41]. To reduce soil and water losses, adopting crops with the purpose of protecting the soils and providing better conditions for the use and sustainability of production systems, including good water infiltration, is recommended [42]. Therefore, soil and water conservation management practices should be adopted, such as the use and incorporation of straw to increase infiltration, level terraces, no-tillage systems, minimum tillage, conserved pastures with rotational grazing, and crop rotation. By adopting these practices, it is possible to reduce the exposure and consequent soil loss, in addition to avoiding nutrient and carbon losses, as well as river aggradation [13,38–40,43,44].

According to our results observed in the scarified plots, the vulnerability of soil particles is evident with regard to transport. This confirms greater soil losses in those areas where conventional planting involves traditional management using soil tillage, typically involving one plowing stage and two harrowing stages, in addition to the minimum use of soil cover. Several authors obtained similar results in different regions of Brazil in studies with natural rainfall [39,40,45] and also in studies with simulated rainfall [13].

Raindrops and the surface runoff of water during rain events can lead to soil erosion, with the amount and type of vegetation covering the soil being a significant factor in reducing soil erosion [46]. Soil losses in the two sub-basins that we studied with vegetative cover (pasture, soybean, soybean with straw, and maize) can happen, especially during the early stages of plant development when there is more soil exposure. After the rainfall interception, infiltration, and saturation of the soil surface layers, the water surplus moves depending on the topographic gradients. Therefore, vegetative cover does not entirely eliminate erosion in those areas used by farming production systems. However, it drastically decreases erosion when compared with badly managed and/or unprotected areas, as was shown in the understory of olive orchards, with both the lower-cost natural regeneration of early successional weeds and intentionally planted cover crops in Minas Gerais State, Brazil [47].

Vegetative cover is naturally responsible for protecting the soil from the direct action of rainfall, and it might not necessarily eliminate all losses, except for some cases in native forests. In this context, several studies show the absence of soil losses in areas of preserved native forest or their drastic reduction in comparison with agricultural land use, such as pasture and cultivated crops [17,42,48,49]. In other words, the soil losses observed in this study may be directly related to the conversion of native forests into farming land. Furthermore, they indicate the need for new studies on simulated and natural rainfall in the Teles Pires River sub-basin region and other rivers in the Cerrado and Amazon biomes, with their transitory ecotones.

In agricultural frontiers such as the Teles Pires River basin and, consequently, in the drainage sub-basins studied, soil and water losses lead to numerous environmental problems. These problems include the pollution and contamination of rivers and streams by the transport of chemical products, the deposition of particles that cause aggradation, the exposure of stocked carbon, removal of the surface layer responsible for farming production, damage to cart roads by the formation of gullies, dam bursts, and the destruction of local biodiversity [2]. Thus, an alternative method to circumvent and/or mitigate erosive processes is to adopt conservationist practices, especially those involving vegetative cover, or the combination of such practices with edaphic or mechanical practices, such as terracing, catchment basins, drainage channels, and the construction of dams on the sides of plantations.

4.2. Policy Recommendations

Environmental conservation policies that are already implemented in Brazil have contributed to reducing soil and water losses, including those that encourage the direct planting system (i.e., no-till farming), the recovery of springs and degraded pasture areas, carbon sequestration, and the adoption of agroforestry systems included in the Low Carbon Agriculture Plan, present in Law 12,187 [50] and regulated by Decree 7390 of 9 December 2010 [51]. The protection of native forests is also regulated by federal law (12,651, of 25 May 2012), known as the "Forest Code," which establishes general rules on the protection of native vegetation, including permanent preservation areas, legal reserves, and areas of restricted use [52].

With regard to water resources, the National Policy on Water Resources (Law 9433 of January 8, 1997) has the following main objectives. The first objective is to ensure the necessary availability of water for current and future generations, with adequate quality standards for the respective uses. The second objective is the rational and integrated use of water resources. The third and final objective is to prevent and defend against critical hydrological events, either of natural origin or arising from the inappropriate use of natural resources, and to encourage and promote the capture, preservation, and use of rainwater [53].

In addition to minimizing soil losses, these initiatives contribute to increasing carbon stocks, conserving the biodiversity of biomes, and preserving rivers and lakes from the silting up caused by constant erosion processes [2]. The soil's ground cover, in addition to protecting against the direct impact of raindrops, also protects agroecosystems from wind erosion and solar rays, which affect the soil microbiology [54,55]. From 2009 to 2020, Brazil made progress in achieving the goals of establishing policies for the conservation of natural resources, with a focus on reducing climate change [56]. However, due to recent increases in deforestation, these environmental challenges are omnipresent.

In the present study, the impacts of agricultural land cover were evaluated on soybeans (in the Caiabi River basin) and maize (in the Renato River basin). The maintenance of bare soils, combined with scarification, promotes greater soil loss regardless of the crop and the region of the watershed. According to Borrelli et al. 2017 [2], the presence of cover and the absence of soil disturbance are the quickest ways to conserve pedological and edaphic resources. In this sense, the correct management of the soybean crop with the direct planting system and contour planting are alternative methods capable of stopping or mitigating erosion [10]. The no-till system has been used in Brazil since the 1960s in the southern region of the country; the results point to an increase in the capacity of water infiltration into the soil, with a reduction in surface runoff, in addition to favoring the microbial community, improving the soil structure, and nutrient cycling [2,12,40,44]. Contours or contour planting avoids the formation of preferential lines for surface water flow, minimizing sediment transport.

For maize cultivation, soil and water conservation practices are also important, although, in the state of Mato Grosso, most areas use this crop immediately following soybean cultivation as a second planting (*safrinha*), when the rains are less frequent. Even so, in the months of March and April, rainfall can still be enough (288 and 121 mm/month, respectively [27]) to require attention when it comes to soil conservation. Technical assistance, combined with rural extension, can encourage rural producers to keep residual straw (e.g., stover) on the ground after the maize harvest, protecting the soil during the fallow period of the dry season (June through September). Maize stover can anchor soil prior to planting the soybean crop again at the start of the wet season in October.

Most of the cultivated areas with pastures in Brazil are still degraded or are in the process of degradation. This is due to misuse, such as exceeding the pasture-carrying capacity, a lack of pH correction and fertilization practices, and a lack of planning efforts to avoid erosion [14,15]. Another important factor that must be taken into account in the conservation of pastures is the criterion for animals entering the pasture, which can favor the loss of surface protection, increasing the vulnerability of the soil to erosion [7].

In addition to the existing sustainable agricultural development policies, new policies are needed, with targets that reach all agricultural and livestock producers. In studies in southern Brazil, previous researchers [57] concluded that one of the biggest limitations in combating water erosion is the lack of information on the subject for rural producers. These new policies can be specific for each crop or can be integrated as a sustainability plan for the production systems of soybeans, maize, and pasture. Incentives can be included for crop succession and rotation, intercropping grasses with legumes, and combating degradation with rotational grazing. In an evaluation of erosion processes under different agricultural management scenarios, integrated soil conservation practices were found to have a greater effect on combating soil erosion [57].

Although all the landscapes evaluated in the present study are considered relatively flat, in the state of Mato Grosso, there are agricultural areas on sloping land [14,55]; therefore, new initiatives should pay special attention to those areas with steep slopes above a gradient of 15%. The greater the slope of an area, the greater the potential for soil and water losses [1,58]. One study measured the effect of slopes of 15%, 25%, 35%, and 45% on soil and water losses and concluded that the greater the local slope, the greater the losses of water and soil resources [14]. Consequently, greater soil losses can accelerate the silting up of watercourses, as well as increase the exposure of stored carbon in soils, which can increase CO_2 emissions, thus compromising the biodiversity of biomes [59].

Soils are providers of ecosystem services; when these are compromised, civilizations can be in imminent danger of existential instability. Soil degradation affects the hydrological cycle, compromising food security in the countryside and in urban centers. Therefore, it is necessary to adopt management practices that ensure sustainability, especially in biomes with high levels of deforestation, such as the Cerrado and the Amazon [60]. In this regard, article 225 of the Federal Constitution of Brazil states that "everyone has the right to an ecologically balanced environment, an asset for common use by the people and essential to a healthy quality of life, imposing on the public authorities and the community the duty to defend and preserve it for present and future generations" [61]. The sustainability of natural ecosystems and agricultural production systems is necessary to optimize the use of natural resources linked to soil and water, preserving them for current and future generations.

5. Conclusions

In this study, we evaluate the erosion process in agricultural production systems in the Cerrado-Amazon transition region, using the InfiAsper rainfall simulator. The erosive process is independent of soil texture and is closely related to management and use systems associated with vegetation cover and soil scarification, regardless of the area's position within the sub-basins. The removal of the vegetation cover formed by soybean, maize, and pasture negatively affects soil–water dynamics, with a significant increase in soil losses in all regions of both sub-basins. Areas subjected to soil management with surface scarification (soil turnover) experience greater soil losses, regardless of the sub-basin region and land use. The results indicate the need for agricultural producers and farmers to make use of management practices that prioritize the maximum vegetation cover for crop cultivation and animal husbandry areas, as well as minimal soil turnover, as a path to the sustainability of production systems by reducing erosive processes. Future rainfall simulator studies can quantify changes in soil erosion by (1) using cover crops (e.g., *Crotalara juncea*) following soybeans–maize, (2) growing cotton (*Gossypium* spp.) as a second crop after soybeans in Brazil, and (3) in sugarcane (*Saccharum* spp.) and other large-scale commodity crops in Brazil and around the world, to support more sustainable agricultural systems and development.

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References

1. Van Oost, K.; Govers, G.; Desmet, P. Evaluating the effects of changes in landscape structure on soil erosion by water and tillage. *Landsc. Ecol.* **2000**, *15*, 577–589. [CrossRef]
2. Borrelli, P.; Robinson, D.A.; Fleischer, L.R.; Lugato, E.; Ballabio, C.; Alewell, C.; Bagarello, V. An assessment of the global impact of 21st century land use change on soil erosion. *Nat. Commun.* **2017**, *8*, 2013. [CrossRef]
3. García-Ruiz, J.M.; Beguería, S.; Nadal-Romero, E.; González-Hidalgo, J.C.; Lana-Renault, N.; Sanjuán, Y.A. Meta-analysis of soil erosion rates across the world. *Geomorphology* **2015**, *239*, 160–173. [CrossRef]
4. García-González, I.; Hontoria, C.; Gabriel, J.L.; Alonso-Ayuso, M.; Quemada, M. Cover crops to mitigate soil degradation and enhance soil functionality in irrigated land. *Geoderma* **2018**, *322*, 81–88. [CrossRef]
5. Lenka, N.K.; Jaiswal, S.P.; Thakur, J.K.; Lenka, S.; Mandal, A.; Dwivedi, A.K.; Yashona, D.S. Soil degradation effect on soil productivity, carbon pools and soil enzyme activity. *Curr. Sci.* **2017**, *112*, 2434–2439. [CrossRef]

6. Jin, Q.; Wang, C.; Sardans, J.; Vancov, T.; Fang, Y.; Wu, L.; Wang, W. Effect of soil degradation on the carbon concentration and retention of nitrogen and phosphorus across Chinese rice paddy fields chineses. *Catena* **2022**, *209*, e105810. [CrossRef]
7. Galdino, S.; Sano, E.E.; Andrade, R.G.; Grego, C.R.; Nogueira, S.F.; Bragantini, C.; Flosi, A.H. Large-scale modeling of soil erosion with Rusle for Conservationist planning of degraded cultivated Brazilian pastures. *Land Degrad. Develop.* **2016**, *27*, 773–784. [CrossRef]
8. Zambon, N.; Johannsen, L.L.; Strauss, P.; Dostal, T.; Zumr, D.; Cochrane, T.A.; Klik, A. Splash erosion affected by initial soil moisture and surface conditions under simulated rainfall. *Catena* **2021**, *196*, 104827. [CrossRef]
9. Antonella, D.; Maurizio, L.; Mario, C.; Severino, R. Soil Erosion Modelling on Arable Lands and Soil Types in Basilicata, Southern Italy. In *Computational Science and Its Applications—ICCSA 2017, Proceedings of the 17th International Conference, Trieste, Italy, 3–6 July 2017*; Gervasi, O., Murgante, B., Misra, S., Borruso, G., Torre, C.M., Rocha, A.M.A.C., Taniar, D., Apduhan, B.O., Stankova, E., Cuzzocrea, A., Eds.; Part V; Springer International Publishing: Cham, Switzerland, 2017; Volume 5, pp. 57–72. ISBN 978-3-319-62403-7. [CrossRef]
10. Assis, K.G.O.; Silva, Y.J.A.B.; Lopes, J.W.B.; Medeiros, J.C.; Teixeira, M.P.R.; Rimá, F.B.; Singh, V.P. Soil loss and sediment yield in a perennial catchment in southwest Piauí, Brazil. *Environ. Monit. Assess.* **2021**, *193*, 26. [CrossRef] [PubMed]
11. Bourgoin, C.; Betbeder, J.; Le Roux, R.; Gond, V.; Oszwald, J.; Arvor, D.; Baudry, J.; Boussard, H.; Le Clech, S.; Mazzei, L.; et al. Looking beyond forest cover: An analysis of landscape-scale predictors of forest degradation in the Brazilian Amazon. *Environ. Res. Lett.* **2021**, *16*, e114045. [CrossRef]
12. Almeida, W.S.; Panachuki, E.; Oliveira, P.T.S.; Silva, M.R.; Sobrinho, T.A.; Carvalho, D.F. Effect of soil tillage and vegetal cover on soil water infiltration. *Soil Tillage Res.* **2018**, *175*, 130–138. [CrossRef]
13. Panachuki, E.; Dos Santos, M.A.N.; Pavei, D.S.; Alves Sobrinho, T.; Camacho, M.A.; Montanari, R. Soil and water loss in Ultisol of the Cerrado-Pantanal Ecotone under different management systems. *Afr. J. Agric. Res.* **2015**, *10*, 926–932. [CrossRef]
14. Cantalice, J.R.B.; Nunes, E.O.S.; Cavalcante, D.M.; Barbosa, B.; Junior, G.B.; Guerra, S.M.S.; Neto, F.R. Vegetative-hydraulic parameters generated by agricultural crops for laminar flows under a semiarid environment of Pernambuco, Brazil. *Ecol. Indic.* **2019**, *106*, e105496. [CrossRef]
15. Sone, J.S.; Oliveira, P.T.S.; Euclides, V.P.B.; Montagner, D.B.; Araujo, A.R.; Zamboni, P.A.P.; Sobrinho, T.A. Effects of Nitrogen fertilization and stocking rates on soil erosion and water infiltration in a Brazilian Cerrado farm. *Agric. Ecosyst. Environ.* **2020**, *304*, 107159. [CrossRef]
16. Rieger, F.A.; Zolin, C.A.; Paulino, J.; Souza, A.P.; Matos, E.D.S.; Magalhães, C.A.D.S.; Farias Neto, A.L.D. Water erosion on an Oxisol under integrated crop-forest systems in a transitional area between the Amazon and Cerrado biomes. *Rev. Bras. Ciênc. Solo* **2016**, *40*, e0150111. [CrossRef]
17. Lense, G.H.E.; Parreiras, T.C.; Moreira, R.S.; Avanzi, J.C.; Mincato, R.L. Effect of spatial-temporal variation of land use and land cover on soil erosion. *Rev. Caatinga* **2021**, *34*, 90–98. [CrossRef]
18. Neal, A.L.; Hughes, D.; Clark, I.M.; Jansson, J.K.; Hirsch, P.R. Microbiome Aggregated Traits and Assembly Are More Sensitive to Soil Management than Diversity. *mSystems* **2021**, *6*, e01056-20. [CrossRef]
19. de Lima Moraes, A.G.; de Carvalho, D.F.; Antunes, M.A.H.; Ceddia, M.B.; Flanagan, D.C. Steady infiltration rate spatial modeling from remote sensing data and terrain attributes in southeast Brazil. *Geoderma Reg.* **2020**, *20*, e00242. [CrossRef]
20. Alves Sobrinho, T.; Gómez-Macpherson, H.; Gómez, J.A. A portable integrated rainfall and overland flow simulator. *Soil Use Manag.* **2008**, *24*, 163–170. [CrossRef]
21. Iserloh, T.; Ries, J.B.; Arnáez, J.; Boix-Fayos, C.; Butzen, V.; Cerdà, A.; Wirtz, S. European small portable rainfall simulators: A comparison of rainfall characteristics. *Catena* **2013**, *110*, 100–112. [CrossRef]
22. Macedo, P.M.S.; Pinto, M.F.; Alves Sobrinho, T.; Schultz, N.; Coutinho, T.A.R.; Carvalho, D.F. A modified portable rainfall simulator for soil erosion assessment under different rainfall patterns. *J. Hydrol.* **2021**, *596*, e126052. [CrossRef]
23. Carvalho, D.F.; Macedo, P.M.S.; Pinto, M.F.; Almeida, W.S.; Schultz, N. Soil loss and runoff obtained with customized precipitation patterns simulated by InfiAsper. *Int. Soil Water Conserv. Res.* **2022**, *10*, 407–413. [CrossRef]
24. IBGE—Instituto Brasileiro de Geografia e Estatística. Estado do Mato Grosso: Pedologia (Mapa Exploratório de Solos), p1. 2009. Available online: https://mapas.ibge.gov.br/tematicos/solos (accessed on 1 July 2022).
25. Alves, M.A.B.; Borella, D.R.; Luz, C.C.S.; Castagna, D.; Silva, W.C.; Silva, A.P.; Almeida, F.T.; Souza, A.P. Soil classes in the Caiabi and Renato river basins, tributaries of the Teles Pires river in the south of the Amazon. *Nativa* **2022**, *10*, 431–448. [CrossRef]
26. Alvares, C.A.; Stape, J.L.; Sentelhas, P.C.; Gonçalves, J.L.M.; Sparovek, G. Köppen's climate classification map for Brazil. *Meteorol. Zeitschrift.* **2013**, *22*, 711–728. [CrossRef] [PubMed]
27. Souza, A.P.; Mota, L.L.; Zamadei, T.; Martim, C.C.; Almeida, F.T.; Paulino, J. Climate classification and climatic water balance in Mato Grosso state, Brazil. *Nativa* **2013**, *1*, 34–43. [CrossRef]
28. Portaria SPA/MAPA nº 249, de 22 de 4 de julho de 2022-MAPA. Aprova o Zoneamento Agrícola de Risco Climático Para a Cultura da Soja no Estado de Mato Grosso, Ano-Safra 2022/2023. Available online: https://www.gov.br/agricultura/pt-br/assuntos/riscos-seguro/programa-nacional-de-zoneamento-agricola-de-risco-climatico/portarias (accessed on 27 December 2022).

29. Portaria SPA/MAPA nº 332, de 26 de Setembro de 2022-MAPA. Aprova o Zoneamento Agrícola de Risco Climático—ZARC Para a Cultura de Milho 2ª Safra no Estado de Mato Grosso, Ano-Safra 2022/2023. Available online: https://www.gov.br/agricultura/pt-br/assuntos/riscos-seguro/programa-nacional-de-zoneamento-agricola-de-risco-climatico/portarias/safra-vigente/mato-grosso (accessed on 27 December 2022).
30. Sabino, M.; Souza, A.P.; Uliana, E.M.; Lisboa, L.; Almeida, F.T.; Zolin, C.A. Intensity-duration-frequency of maximum rainfall in Mato Grosso State. *Rev. Ambiente Água* **2020**, *15*, e2373. [CrossRef]
31. Teixeira, P.C.; Donagemma, G.K.; Fontana, A.; Teixeira, W.G. *Manual de Métodos de Análise de Solo*, 3rd ed.; Embrapa Solos: Rio de Janeiro, Brazil, 2017; pp. 1–573. Available online: https://www.infoteca.cnptia.embrapa.br/handle/doc/1085209 (accessed on 5 May 2022).
32. Grossman, R.B.; Reinsch, T.G. Bulk Density and Linear Extensibility: Core Method. In *Methods of Soil Analysis*; Dane, J.H., Topp, G.C., Eds.; Part 4, Physical Methods; SSSA: Madison, WI, USA, 2002; pp. 208–228.
33. Wenzel, D.A.; Uliana, E.M.; Almeida, F.T.; Souza, A.P.; Mendes, M.A.D.S.A.; Silva, S.L.G. Physiographic characteristics of the medium and upper Teles Pires River sub-basins, Mato Grosso, Brazil. *Rev. Ciênc. Agroambient.* **2018**, *15*, 123–131. [CrossRef]
34. Uribe, M.; Peñuela, G.A.; Pino, N.J. Megathyrsus maximus and Brachiaria decumbens improve soil characteristics and select promising rhizobacteria during rhizoremediation of petroleum hydrocarbons. *Rhizosphere* **2022**, *22*, e100517. [CrossRef]
35. Bonetti, J.D.A.; Paulino, H.B.; Souza, E.D.D.; Carneiro, M.A.C.; Silva, G.N.D. Influence of the integrated crop-livestock system on soil and soybean and brachiaria yield. *Pesqui. Agropecu. Trop.* **2015**, *45*, 104–112. [CrossRef]
36. Panachuki, E.; Bertol, I.; Alves Sobrinho, T.; Oliveira, P.T.S.D.; Rodrigues, D.B.B. Soil and water loss and water infiltration in red latosol under diferent management systems. *Rev. Bras. Ciênc. Solo* **2011**, *35*, 1777–1786. [CrossRef]
37. Dalla Rosa, J.; Cooper, M.; Darboux, F.; Medeiros, J.C. Influence of tillage systems and simulated rainfall on the processo f surface crust formation. *Rev. Bras. Ciênc. Solo* **2013**, *37*, 400–410. [CrossRef]
38. Almeida, W.S.; Seitz, S.; Oliveira, L.F.C.; Carvalho, D.F. Duration and intensity of rainfall events with the same erosivity change sediment yield and runoff rates. *Int. Soil Water Conserv. Res.* **2021**, *9*, 69–75. [CrossRef]
39. Bertol, I.; Schick, J.; Bandeira, D.H.; Paz-Ferreiro, J.; Vázquez, E.V. Multifractal and joint multifractal analysis of water and soil losses from erosion plots: A case study under subtropical conditions in Santa Catarina highlands, Brazil. *Geoderma* **2017**, *287*, 116–125. [CrossRef]
40. Antoneli, V.; Lenatorvicz, H.H.; Bednarz, J.A.; Pulido-Fernández, M.; Brevik, E.C.; Cerdà, A.; Rodrigo-Comino, J. Rainfall and land management effects on erosion and soil properties in traditional Brazilian tobacco plantations. *Hydrol. Sci. J.* **2018**, *63*, 1008–1019. [CrossRef]
41. Andrade, M.A.; Mello, C.R.D.; Beskow, S. Hydrological simulation in a watershed with predominance of Oxisol in the Upper Grande river region, MG—Brazil. *Rev. Bras. Eng. Agrícola Ambient.* **2013**, *17*, 69–76. [CrossRef]
42. Falcão, K.D.S.; Panachuki, E.; Monteiro, F.D.N.; Silva, R.; Rodrigues, D.B.; Sone, J.S.; Oliveira, P.T.S. Surface runoff and soil erosion in a natural regeneration area of the Brazilian Cerrado. *Int. Soil Water Conserv. Res.* **2020**, *8*, 124–130. [CrossRef]
43. Merten, G.H.; Araújo, A.G.; Biscaia, R.C.M.; Barbosa, G.M.C.; Conte, O. No-till surface runoff and soil losses in southern Brazil. *Soil Tillage Res.* **2015**, *152*, 85–93. [CrossRef]
44. Deuschle, D.; Minella, J.P.N.A.; Hörbe, T.; Londero, A.L.; Schneider, F.J. Erosion and hydrological response in no-tillage subjected to crop rotation intensification in Southern Brazil. *Geoderma* **2019**, *340*, 157–163. [CrossRef]
45. Silva, R.M.; Santos, C.A.G.; dos Santos, J.Y.G. Evaluation and modeling of runoff and sediment yield for different land covers under simulated rain in a semiarid region of Brazil. *Int. J. Sediment Res.* **2018**, *33*, 117–125. [CrossRef]
46. Beniaich, A.; Silva, M.L.N.; Guimarães, D.V.; Avalos, F.A.P.; Terra, F.S.; Menezes, M.D.; Avanzi, J.C.; Cândido, B.M. UAV-based vegetation monitoring for assessing the impact of soil loss in olive orchards in Brazil. *Geoderma Reg.* **2022**, *30*, e00543. [CrossRef]
47. Beniaich, A.; Guimarães, D.V.; Avanzi, J.C.; Silva, B.M.; Acuña-Guzman, S.F.; dos Santos, W.P.; Silva, M.L.N. Spontaneous vegetation as an alternative to cover crops in olive orchards reduces water erosion and improves soil physical properties under tropical conditions. *Agric. Water Manag.* **2023**, *279*, 108186. [CrossRef]
48. Leite, M.H.S.; Couto, E.G.; Amorim, R.S.S.; Costa, E.L.D.; Maraschin, L. Soil and nutriente losses under diferente tillage systems in a clayey oxisol under natural rainfall. *Rev. Bras. Ciênc. Solo* **2009**, *33*, 689–699. [CrossRef]
49. Neves, S.M.A.D.S.; Motinho, M.C.; Neves, R.J.; Soares, E.R.C. Estimation of soil loss for rainfall erosion in the catchment area of Jauru, Mato Grosso State, Brazil. *Soc. Nat.* **2011**, *23*, 423–433. [CrossRef]
50. Brazil. Lei Nº 12.187, 29 December 2009. Institui a Política Nacional Sobre Mudança do Clima—PNMC e dá Outras Providências. Available online: https://www.suape.pe.gov.br/images/publicacoes/Leis/Lei_n._12.187.2009.pdf (accessed on 12 December 2022).
51. Brazil—Decreto No—7.390, 9 December 2010 Regulamenta os Arts. 6o, 11 e 12 da Lei no 12.187, de 29 de Dezembro de 2009, Que Institui a Política Nacional Sobre Mudança do Clima—PNMC, e dá Outras Providências. Available online: https://pesquisa.in.gov.br/imprensa/jsp/visualiza/index.jsp?jornal=1&pagina=4&data=10/12/2010 (accessed on 13 December 2022).
52. Brazil. Lei Nº 12.651, 25 May 2012 Dispõe Sobre a Proteção da Vegetação Nativa; Altera as Leis nºs 6.938, de 31 de Agosto de 1981, 9.393, de 19 de Dezembro de 1996, e 11.428, de 22 de Dezembro de 2006; Revoga as Leis nºs 4.771, de 15 de Setembro de 1965, e 7.754, de 14 de abril de 1989, e a Medida Provisória nº 2.166-67, de 24 de Agosto de 2001; e dá Outras Providências. 38p. Available online: https://www.planalto.gov.br/ccivil_03/_ato2015-2018/2018/lei/l13709.htm (accessed on 12 December 2022).

53. Brazil. Lei Nº 9.433, 8 January 1997. Institui a Política Nacional de Recursos Hídricos, Cria o Sistema Nacional de Gerenciamento de Recursos Hídricos, Regulamenta o Inciso XIX do Art. 21 da Constituição Federal, e Altera o art. 1º da Lei nº 8.001, de 13 de março de 1990, Que Modificou a Lei nº 7.990, de 28 de Dezembro de 1989. Available online: https://legislacao.presidencia.gov.br/atos/?tipo=LEI&numero=9433&ano=1997&ato=a12ATVU90MJpWTbaf (accessed on 20 December 2022).
54. Santos, J.P.C.; Caldas, V.I.S.P.; Silva, A.S. Susceptibility to erosion of soils of the Lagos São João Basin, in the State of Rio de Janeiro—Brazil, from the AHP method and multicriteria analysis. *Rev. Bras. Geogr. Fis.* **2019**, *12*, 1415–1430. [CrossRef]
55. Nachtigall, S.D.; Nunes, M.C.M.; Moura-Bueno, J.M.; Lima, C.L.R.D.; Miguel, P.; Beskow, S.; Silva, T.P. Spatial modeling of soil water erosion associated with agroclimatic seasonality in the Southern region of Rio Grande do Sul, Brazil. *Eng. Sanit. Ambient.* **2020**, *25*, 933–946. [CrossRef]
56. TALANOA. A Política Nacional de Mudança do Clima em 2020: Estado de Metas, Mercados e Governança Assumidos na Lei 12.187/2009. Rio de Janeiro, Brasil. 2020. Available online: https://www.oc.eco.br/wp-content/uploads/2020/12/Politica-Nacional-de-Mudanc%CC%A7a-de-Clima.pdf (accessed on 18 December 2022).
57. Didoné, E.J.; Minella, J.P.G.; Evrard, O. Measuring and modelling soil erosion and sediment yields in a large cultivated catchment under no-till of Southern Brazil. *Soil Tillage Res.* **2017**, *174*, 24–33. [CrossRef]
58. Raimo, L.A.D.L.; Amorim, R.S.; Couto, E.G.; Hunter, M.O.; Torres, G.N.; Bocuti, E.D.; Silva, L.D. Natural erosion potential in the Mato Grosso State, Brazil. *Rev. Bras. Eng. Agrícola Ambient.* **2022**, *26*, 655–661. [CrossRef]
59. Schindewolf, M.; Schönke, D.; Amorim, R.S.; Schmidt, J. Effects of contour banks and no-till measures on run-off and sediment yield in Campo Verde Region, Mato Grosso. In *Interdisciplinary Analysis and Modeling of Carbon-Optimized Land Management Strategies for Southern Amazonia*, 1st ed.; Gerold, G., Jungkunst, H.F., Wantzen, K.M., Schönenberg, R., Amorim, R.S.S., Couto, E.G., Madari, B., Hohnwald, S., Eds.; Universitätsverlag Göttingen: Göttingen, Germany, 2014; pp. 85–100. ISBN 978-3-86395-138-2. [CrossRef]
60. Klink, C.A.; Machado, R.B. A Conservação do Cerrado Brasileiro. *Megadiversidade* **2005**, *1*, 147–155. Available online: https://www.researchgate.net/profile/Ricardo-Machado-4/publication/228342037_A_conservacao_do_Cerrado_brasileiro/links/553a78670cf29b5ee4b64c2f/A-conservacao-do-Cerrado-brasileiro.pdf (accessed on 20 December 2022).
61. Brazil. Constituição da República Federativa do Brasil 1988; Senado Federal: Brasília, DF. 2016; pp. 1–496. Available online: https://www2.senado.leg.br/bdsf/bitstream/handle/id/518231/CF88_Livro_EC91_2016.pdf (accessed on 15 December 2022).