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Evaluation of water erosion in sugarcane crops using erosion plots and photo comparison technics

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ABSTRACT

The objective of this study was to evaluate processes of water erosion in sugarcane crops using experimental plots and photo comparison technics. Soil losses were quantified in four erosion monitoring plots located in two watersheds in the center-east region of the state of São Paulo, Brazil. Soil physical and chemical analysis were performed, and precipitation and slope data were collected. These data were analyzed together with soil vegetation cover indexes obtained from the classification of digital photographs. Photo comparison and classification methods were used to follow the sugarcane crop development, and quantify and qualify the soil cover. The physical and chemical characteristics of the soils caused lower vegetation development and greater soil susceptibility to erosive processes. The management of the sugarcane crops evaluated were inadequate; physical and slope limitations of the soils that compose the landscapes were not considered. Sugarcane areas are expanding in the state of São Paulo, and the months with higher rainfall rates coincide with the periods in which this crop is not covering the soil, thus, adopting adequate soil management practices, and land use planning is necessary.

Keywords: *Saccharum officinarum* L., erosion monitoring plots, soil loss, physical and chemical characteristics.

A erosão hídrica na cultura canavieira: uma avaliação a partir de parcelas de erosão e técnicas de fotocomparação

RESUMO

O objetivo do presente artigo é avaliar os processos de erosão hídrica em cultivos de cana-de-açúcar utilizando parcelas experimentais e técnicas de fotocomparação. Foram quantificadas perdas de solo em 4 parcelas de monitoramento de erosão localizadas em duas bacias hidrográficas do centro-leste paulista. Foram realizadas análises físicas e químicas dos solos, levantados dados de precipitação e de declividade, os quais foram analisados conjuntamente com os índices de cobertura vegetal, obtidos a partir da classificação supervisionada de fotografias digitais verticais. A utilização dos métodos de fotocomparação e classificação supervisionada permitiram acompanhar o desenvolvimento da cultura avaliada, bem como quantificar e qualificar a cobertura do solo. Características físicas e químicas dos solos foram responsáveis pelo menor desenvolvimento vegetal e maior susceptibilidade dos solos frente aos processos erosivos. Nos cultivos de cana-de-açúcar avaliados foi possível observar a realização de manejos inadequados, onde não foram consideradas as limitações físicas dos diferentes solos e declives que compõem as paisagens. Tendo em vista a expansão da cultura de cana-de-açúcar no cenário paulista e considerando a coincidência dos meses de maiores índices pluviométricos com a ausência da cobertura total do solo por esta cultura, torna-se necessária a adoção de adequadas práticas de manejo de solo e planejamento do uso da terra.

Palavras chaves: *Saccharum officinarum* L., parcelas de monitorando de erosão, perdas de solo, características físicas e químicas.

Introduction

Sugarcane (*Saccharum officinarum* L.) crops stand out as one of the main crops in Brazil,

which is the largest sugar and ethanol producer in the world. This crop stands out among the various

land uses in Brazil, with 9.7 million hectares of planted area.

Sugarcane areas are expanding over pastures and permanent crops in the Brazilian center-south region in recent years. The state of São Paulo is responsible for 53% of the sugarcane national production, and presented an increase of 94% in the planted area from 2002 to 2012 (UNICA, 2015). According to Zanella (2015) and Adami *et al.* (2013), this expansion is connected to many changes occurring in São Paulo, such as the reduction of pasture areas and producing areas of staple foods, reduction of biodiversity, and increase of erosive processes (Corrêa *et al.*, 2015).

Regarding the impacts on the soils, soil preparation for sugarcane crops is conducted in some regions with excessive surface harrowing, burning of residues, and compaction due to mechanization that changes its physical attributes. These changes are evidenced by the decreased soil macropore volumes and aggregate sizes, reduced water infiltration rate, and increased resistance to root penetration and soil density (Dias Junior and Pierce, 1996; Figueiredo *et al.*, 2000; Guerra, 2014; Casagrande, 2001). Changes in the soil physical attributes make soils more susceptible to water erosion processes.

Soil degradation processes cause losses of nutrients and organic matter, and changes in the soil textures. The intensification of the erosive processes transforms the landscape with linear erosive features, which result in degraded landscapes with extensive gullies. Thus, the soil degradation process has become an essential subject in geomorphological science (Tricart, 1968; Guerra and Marçal, 2006).

The impacts of soil degradation are determining factors on economic losses of farmers, decreasing their production, and increasing the applied inputs (Schaefer *et al.*, 2001). Increases in sediment detached, carried, and deposited along silted beds of watercourses that supply urban areas increase the costs of public water treatment.

Water erosion is intensified by inadequate land use, and natural characteristics of the landscape, such as rainfall, soils, and relief.

The higher the rainfall intensity the higher the kinetic energy of the raindrops, which can disaggregate soil particles, and generate the splash effect (Guerra, 2005). Considering the subtropical and tropical climates predominant in Brazil, the more intense erosion processes are caused by the high precipitation indexes of December to February (Corrêa, 2016).

The soil physical (texture, structure, permeability, density), chemical, mineralogical, and biological characteristics affect its resistance to processes of detachment and carrying of particles by rainwater, and define the soil erodibility level (Bertoni and Lombardi Neto, 2010; Correchel, 2003; Silva, 2005). The soil erosive potential increases when processes of detachment and carrying of particles occurs in high slope areas (Morgan, 2005).

Vegetation cover is important on erosion processes; it reduces the impact of raindrops on the soil surface and dissipates the energy of moving particles in the surface runoff water, reducing the detachment and carrying of particles (Bertoni and Lombardi Neto, 2010; Cassetti, 1991). Thus, vegetation is important to the balance of geosystems (Tricart, 1977); and evaluations of the effects of different crops and their particularities on erosive processes is needed.

Even though the sugarcane is a semi-perennial crop with replanting intervals of approximately five years, periods with higher rainfall indexes (December to February) can coincide with the off-season, when the soil is partially unprotected and thus susceptible to processes of detachment and carrying of particles.

Despite the numerous impacts on the environment and economy, few field studies on soil water erosion are conducted and, in general, little information on the dynamics of erosive soil processes in South America based on field experiments is found (Garcia Ruiz *et al.*, 2015). However, some studies in Brazil present scientific evidences of soil degradation processes in sugarcane crops (Martinelli and Filoso, 2007).

Bertoni *et al.* (1972) evaluated soil losses in sugarcane crops with experimental plots in the state of São Paulo and found estimated losses of 12.4 Mg ha⁻¹ year⁻¹. Sparovek and Schnug (2001) estimated soil losses of 31 Mg ha⁻¹ year⁻¹ using modeling technics in sugarcane crops in São Paulo. Moreover, Almeida (1981) and Schmidt (1989) evaluated agricultural crops in Brazil and found average soil losses in experimental plots of 19 Mg ha⁻¹ year⁻¹, and 40 Mg ha⁻¹ year⁻¹, respectively.

Vegetation cover is one of the main factors in erosive processes, and it is determined mainly by agricultural activities, thus, some researchers have used photo comparison of erosion monitoring plots to evaluate quantitatively the soil vegetation cover. This method makes possible to assess the vegetation cover and degradation conditions, and assists in

understanding soil degradation processes (Ippoliti Ramilo, 2002).

Pinese Junior *et al.* (2008) assessed the ratio between protected and unprotected areas by vegetation in erosion monitoring plots and concluded that the vegetation cover conditions (grass, soybean, and common bean) contributed to the soil losses found. Bezerra *et al.* (2011) evaluated the development rates of the vegetation cover in plots with geotextiles and grasses and concluded that the photo comparison was efficient in identifying the protective action of the geotextiles to the splash effect, surface runoff, and particle removal processes.

Considering the continuing expansion of sugarcane plantations in the state of São Paulo, the objective of this work was to evaluate water

State of São Paulo/Brazil

Figure 1. Location of the study areas.

The climate of the watersheds was classified as Cwa, subtropical, with dry winter and rainy summer, according to the classification of Köppen.

Figure 2 shows the historical average precipitation of the D4-036 (Ipeúna SP) and D4-112 (Rio Claro SP) stations of the Department of

erosion processes in sugarcane crops using experimental monitoring plots under natural rainfall, and photo comparison techniques.

Characterization of study areas

Experimental erosion monitoring plots were installed in the Jacutinga (Rio Claro and Corumbataí SP), and Monjolo Grande (Ipeúna SP) watersheds, both located in the center-east of the state of São Paulo (Figure 1). The study areas were similar in area and land use, and different in pedological and relief characteristics, thus, the evaluation of the erosion processes were carried out using different soil physical conditions with similar land uses.

Water and Electric Energy of the state of São Paulo (DWEE). They were the stations with the best historical series and the closest to the study areas. Figure 2 also shows the monthly precipitation averages in the experimental period (2013/2014 crop season) according to the D4-112 station to characterize Jacutinga watershed, and a

station (Davis Vantage Pro 2 Plus) installed in the Monjolo Grande watershed.

Figure 2. Historical monthly average precipitation, and precipitation in the experiment period.

The months with the highest precipitation indexes (December 2013, and January and February 2014) had a 27% reduction in precipitation compared with the historical average from the D4-112 station. According to the station installed in the Monjolo Grande watershed (D4-036), the precipitation reduced in 29% (Figure 2).

Erosivity is dependent on the rainfall quantity and intensity. The rainfall in the 2013/2014 crop season had lower erosive potential, since reductions of approximately 30% in annual average rainfall were found in this period.

The study areas are in the geomorphological province called São Paulo Peripheric Depression. It presents a rugged topography, with predominant relief composed of hills, interfluvial areas of 1 to 4 km², flattened tops, and slopes with convex and rectilinear profiles (IPT, 1981). The western edges of the

Monjolo Grande watershed, located by the arenitic-basaltic wall, present small residual massifs with altitudes reaching 900 m, high slopes, and carved drainage.

The Jacutinga stream is a tributary of the Corumbataí River. The Jacutinga watershed is in the center-west of the São Paulo Peripheric Depression, approximately 15 km from the arenite-basaltic wall, and comprises an area of approximately 28.9 km². Its predominant soils are red-yellow Ultisol (RYU) and Inceptisol (INC). The source material of these soils are argillites of the Corumbataí formation located predominantly in the stream middle and lower courses (Figures 3a and 4a). Quartzipsamments (QT) are also found at a lower extent; its source material is the fine and medium grains of arenites of the Pirambóia formation in the stream upper course (Corrêa, 2016; Moraes, 2014).

Figure 3. Geological maps of the Jacutinga (A) and Monjolo Grande (B) watersheds. Source: Environmental Atlas of the Corumbataí River Basin (CEAPLA, 2012). Organization: the authors, and Moraes (2014).

Figure 4. Geological maps of the Jacutinga (A) and Monjolo Grande (B) watersheds. Source: Environmental Atlas of the Corumbataí River Basin (CEAPLA, 2012). Organization: the authors, and Moraes (2014).

Figure 5. Pedological maps of the Jacutinga (A) and Monjolo Grande (B) watersheds. Source: Corrêa (2016) and Moraes (2014).

INC = Inceptisol, RYO = Red-yellow Oxisols, RYU = Red-yellow Ultisols, LO = Lithic Orthents, QT = Quartzipsamments, ALF = Alfisols.

According to the universal soil loss equation used by Moraes (2016), the most susceptible areas to processes of laminar water erosion in the Jacutinga watershed are those located next to the first order channels (Strahler, 1952), where the Inceptisols predominate, and in transitional areas between Quartzipsamments and red-yellow Ultisols.

The Monjolo Grande stream is a tributary of the Passa Cinco River that belongs to the Corumbataí River basin. The Monjolo Grande watershed comprises an area of approximately 28 km², with predominance of Quartzipsamments in the interfluvial areas, and red-yellow Ultisol in medium and low slopes, with slopes of up to 20% (Figure 4b). The areas located close to the arenitic-basaltic wall, and high slope areas along the first order channels present Lithic Orthents and Inceptisol (Corrêa, 2016; Moraes, 2014). The texture of all soils of this area vary from loam to sandy; these soils originate predominantly from the fine and medium grains of arenite of the Botucatu and Pirambóia formations (Figure 3b).

The Monjolo Grande watershed presents a natural predisposition to laminar erosion; 40% of its area has loss potential above 100 Mg ha⁻¹ year⁻¹.

¹. These areas are in undulate to strongly undulate reliefs, with slopes higher than 8%, and occurrences of soils with high erodibility, such as red-yellow Ultisol, Inceptisol, and Lithic Orthents (Corrêa *et al.*, 2015).

The entire state of São Paulo, including the study areas, have been subjected to intense anthropic occupation, mainly due to the expansion of sugarcane cultivation and pasture areas (Koffler, 1994; Pereira and Pinto, 2007). Thus, studies on the impacts of erosive processes in areas with sugarcane crops are important

Methodology

Collection and quantification of eroded material

Two soil erosion monitoring plots of 20 m² (2 m x 10 m) were installed in each watershed. They were delimited by galvanized sheets of 40 cm high—10 cm buried into the ground and the remainder above the surface (Figure 5)—and composed of Gerlach flumes (Guerra, 2005), and water collecting tanks. A control plot with no vegetation cover was installed alongside each plot with vegetation cover, according to Wischmeier and Smith (1978).

Figure 6. Erosion monitoring plots with sugarcane crops: (A) Plot 1 located in the Jacutinga watershed. (B) Plot 1 located in the Monjolo Grande watershed (Source: Edvania A. Corrêa).

The plots were installed in the most representative slope classes of each watershed. The choosing of units in Inceptisol and red-yellow Ultisol was due to the availability of the areas for experimentation. Table 1 provides a more detailed description of the physical characteristics of the sites used.

All plots were planted after harvesting or planting of sugarcane. Conventional soil preparation was used in both study areas, consisting of revolving the soil surface layers to reduce compaction, plowing, heavy and intermediate harrowing, and leveling. The

conservation practices consisted of using contour banks, and terraces. The plots were installed perpendicularly to the contour banks and located in the medium slope.

The plots located in the Jacutinga watershed were composed of sugarcane plants after the 3rd cut. The cut had been mechanically performed on June 02, 2013, and the plant remains (straws) were kept on the soil surface. The plots in the Monjolo Grande watershed were composed of sugarcane plants before the first cut; the planting was carried out on July 22, 2013; and

plant residues from previous crops were removed from the soil surface.

Precipitation data were collected from a weather station (Davis Vantage Pro 2 Plus) installed in the Monjolo Grande watershed. These data were compared to the losses obtained in the

Monjolo Grande watershed. In addition, it was used as a reference to estimate soil losses in the Jacutinga basin, UNESP Rio Claro meteorological station (station DAEE D4-112).

Table 1. Characteristics of the erosion monitoring plots.

Watershed	Plot	Slope (%)	Soil Classification
Monjolo Grande	1	6 ± 12%	Inceptisol, eutrophic Ta, typical, moderate A horizon, sandy loam texture
	2	12 ± 20%	Inceptisol, dystrophic Ta, typical, moderate A horizon, loamy sandy to sandy loam texture
Jacutinga	1	3 ± 6%	Red-yellow Ultisol, eutrophic Ta, clayey texture, moderate A horizon
	2	6 ± 12%	Inceptisol, eutrophic, typical, moderate A horizon, clayey texture

Data on water and sediment losses were collected from June 2013 to May 2014, following the methodology described by Cogo (1978). The materials retained in the flumes during each erosive event were collected and added to the material stored in the tanks. The sediment and water were homogenized, and samples of approximately 500 mL were collected. The runoff heights inside the collecting tanks (cm) were measured with a ruler and, together with the dimensions of the collecting tanks, the volume of water from the surface runoff in each plot was calculated.

The samples rested for 24 hours for sediment settling. The excess liquid was sieved in a 0.052-mm mesh sieve. The remaining material was dried in an oven at 60°C and the sediment was quantified. Then, the soil loss (g m^{-2}) of each plot was calculated considering the total volume of water in the tanks (Carvalho *et al.*, 2000).

Soil physical and chemical analyses

Soil samples of the experiment area were collected with an auger, following the procedures described by Embrapa (2013). The depth of collection of the samples were 0-40 cm for the Inceptisol, due to their low depth, and 0-60 cm for the Ultisol.

The samples were stored and analyzed in laboratory. Granulometric analysis using the Pipet method, and chemical analyzes—pH, CaCl_2 , organic matter, Al, H+Al, K, Ca, and Mg, sum of bases, cation exchange capacity at pH 7, and base saturation and aluminum saturation—were carried out (EMBRAPA, 1997). The soils were classified according to the Brazilian Soil Classification System (EMBRAPA, 2013) at the 3rd subgroup level, and textural grouping.

The soil physical parameters soil density (paraffin-coated clod method), macro and micro porosity (tension table method), total porosity, and hydraulic conductivity (constant head permeability test) (EMBRAPA, 1997) were analyzed. Four trenches were opened nearby the plots, and volumetric rings were used to collect undisturbed soil samples at depth of 15 cm for these analyzes. The soil mechanical resistance to penetration (MRP) was evaluated in the areas with crops using a 7-kg impact penetrometer with free fall course of 40 cm (IAA/Planalsucar-Stolf). The tests were carried out to a depth of 50 cm with 3 replicates for each plot (Barbosa, 2010). Twelve test points were assessed and the data was processed to obtain the values in MPa (CORRÊA, 2016).

Collection and digital classification of photographs for soil cover estimation

Vegetation cover was evaluated on October 23, 2013 and May 21, 2014, using the photo comparison method (Azevedo *et al.*, 2005) or digital image processing (Ferreira *et al.*, 2001).

A digital camera was manually positioned upright at approximately 2.00 m from the soil surface and digital photographs of each erosion monitoring plot were taken perpendicularly to the soil surface; a quadrant of 1 m² was placed on the soil surface and used as a reference.

The ages of the sugarcane crops were 9 (Monjolo Grande watershed) and 11 (Jacutinga watershed) months in May 21, 2014, when photographs were taken from 1.50 m above the plant canopies. The 1-m² quadrant was placed on the uncovered soil next to the experimental plots as a reference for the classification and quantification processes.

The digital photographs were classified using the maximum likelihood Gaussian distribution algorithm (Ippoliti Ramilo, 2002 and Azevedo *et al.*, 2005) in the ENVI-5.0 software (*Environment for Visualizing Images; Research Systems, Inc.*) to obtain the cover maps. The classes used were green vegetation, exposed soil, shade, and dry vegetation. Thirty training samples were collected for classification of each class, and a filter of 3x3 pixels was applied to exclude isolated pixels.

The maps were evaluated by comparison with visual interpretations of the photographs. Thirty randomly chosen samples were selected in

each scenario (October 2, 2013 and May 21, 2014), matrices were created, and the global accuracy and Kappa indexes were calculated. Kappa indexes were analyzed according to the procedure described by Landis and Koch (1977).

Results and discussion

The photo comparison of the two scenarios (October 23, 2013 and May 21, 2014), used to evaluate the development of vegetation cover in the studied period, was carried out using 8 vertical photographs, 4 of each scenario (Figure 6).

Figure 7. Photo comparison of scenarios to estimate vegetation cover in the Plot 1 of the Monjolo Grande watershed. A is digital photographs and B is digital classified photographs.

Regarding the reliability of the photo classification, the global accuracy values ranged from 0.78 to 0.96, and Kappa indexes ranged from 0.67 to 0.93, indicating significant correlation of the information in the photographs with the classified images (Table 2).

The lowest global and Kappa accuracy was found in Plot 2 of the Monjolo Grande watershed (May 21, 2014), which presented several samples with dry vegetation classified as exposed soil. This divergence was due to the spectral similarities between the dry vegetation and sandy soils.

The sugarcane crops were 133 (Jacutinga) and 93 (Monjolo Grande) days old in October 23, 2013, and 355 (Jacutinga) and 305 (Monjolo Grande) days old in May 21, 2014.

The sugarcane coverage rates found in the scenario October 23, 2013 were below the ones found by Doorenbos and Pruitt (1977), which were 25% a 50% at 2 to 3 months (crops before the first cut), and 75% to 100% at 4 to 9 months (crops after the first cut). The percentages of soil cover (green and dry vegetation) in the Monjolo Grande watershed were 12.83% for Plot 2 and 23.42% for Plot 1; and 40.1% for Plot 2 and 67.82% for Plot 1 in the Jacutinga watershed

(Figures 7 and 8). The significant variation between plots of the two watersheds was due to the different phenological stages of the evaluated crops.

The crops should have completely covered the soil by May 21, 2014 (Doorenbos and Pruitt, 1977), however, all plots had coverage below 100% (Figures 7 and 8).

Table 2. Correlation coefficients in the two scenarios.

	Plot	October 23, 2013		May 21, 2014	
		Kappa	Global accuracy	Kappa	Global accuracy
Monjolo Grande	1	0.88	0.93	0.89	0.93
	2	0.93	0.96	0.67	0.79
Jacutinga	1	0.7	0.78	0.89	0.93
	2	0.82	0.88	0.79	0.87

Figure 7. Soil cover in plots with sugarcane crops in the Monjolo Grande watershed.

Figure 8. Soil cover in plots with sugarcane crops in the Jacutinga watershed.

The Plots 2 of the two scenarios stood out in both study areas, presenting lower soil cover rates than the Plots 1. These results are due to the physical-chemical characteristics of the soils, slope conditions of the terrains, and rates of soil losses.

The Plot 2 of the Monjolo Grande watershed was in an area of Inceptisol of sandy loam texture, with rectilinear slopes varying from

12% to 20%. The first 20 cm of this soil depth presented 90.9% of sand and 3.95% of clay (Table 3). High contents of sand in the soil surface layers generated low water storage capacity and low nutrient availability to plants (Table 4). This was observed through the lower development of the plants in the evaluation of soil cover (Figures 7 and 8).

Table 3. Granulometric fractions of the soils of the erosion plots.

	Plots	Depth cm	Total sand	Coarse sand	Fine sand	Silt	Clay
			----- % -----				
Monjolo Grande	1	0-20	78.5	23.4	55.2	5.5	16
		20-40	77.4	25.2	52.2	4.5	18.2
		40-60	75	26.3	48.7	4.2	20.8
	2	0-20	90.9	10.6	80.3	5.2	4
		20-40	74.6	8.5	66.1	2.4	23
		40-60	20.4	8.9	63.4	3.4	24.3
Jacutinga	1	0-20	33.3	11.5	21.8	15.1	51.6
		20-40	28.1	14.9	13.1	13.6	58.4
		40-60	19.1	8.3	10.8	9.1	71.8
	2	0-20	23.4	9.5	14	35.3	41.3
		20-40	23.7	15	8.8	34	42.3
		40-60	22.7	16.2	6.5	36.3	41

Table 4. Physical characteristics of the soils of the experimental plots.

Physical characteristic	Monjolo Grande		Jacutinga	
	Plot 1	Plot 2	Plot 1	Plot 2
Micro porosity (m ³ m ⁻³)	0.30	0.24	0.32	0.38
Macro porosity (m ³ m ⁻³)	0.13	0.21	0.32	0.13
Total Porosity (dm ³ dm ⁻³) *	0.42	0.45	0.63	0.52
Soil Density (kg dm ⁻³)	1.51	1.49	1.00	1.25
Hydraulic conductivity (cm h ⁻¹)	5.07	10.85	5.43	5.43
Mechanical resistance to penetration (MPa)	2.25	3.02	3.99	4.31

* determined by the equation: total porosity (dm³ dm⁻³) = 1 - soil density / particle density.

The absence of residual cover at planting (Figure 6) increased the soil temperature and, together with the granulometric characteristics described, led to a lower water availability to the plants, affecting the absorption of nutrients, and development of the root and shoot of the plants.

However, the low rates of Ca²⁺, which is essential for the root cell division and cellular

membrane functioning, hindered the root growth (Table 5) (Vasconcelos and Garcia, 2005). Moreover, the lower cation exchange capacity in Plot 2 of the Monjolo Grande watershed caused lower nutrient retention and availability, increasing their leaching.

Table 5. Chemical analysis of the soils of the experimental plots.

Area	Plot	P	K ⁺	Ca ²⁺	Mg ²⁺	Al ³⁺	H + Al	OM	TC	SB	CEC	BS	AS	pH
		mg dm ⁻³		----- mmolc dm ⁻³ -----				g kg ⁻¹		mmolc dm ⁻³		%		CaCl ₂
Monjolo	1	83	7.3	25	8	8.5	22	18	10.6	40	63	64	17	5.6

Grande	2	17	2.4	10	3	0	28	18	10.4	15	44	35	0	4.7
Jacutinga	1	9	2.8	30	12	0	22	28	16	45	67	67	0	5.6
	2	8	3.7	17	8	6.3	32	20	11.8	29	61	47	18	5

OM = organic matter, TC = total carbon, SB = sum of bases, CEC = cation exchange capacity, BS = base saturation, AS = aluminum saturation

The physical and chemical properties of the sandy soils caused a lower development of the plants, and the occurrence of erosive processes. A high content of fine sand and low content of organic matter favors the granular structuration

and decreases the amount of stable aggregates. Thus, when higher rainfall occurs, fine sand particles are easily detached from the soil surface and carried through the runoff (Figure 9).

Figure 9. Laminar erosions in sugarcane crops in the Monjolo Grande watershed.

In addition to the intrinsic characteristics of the soils, the slope variation found (12% to 20%) also intensified erosive processes; the greater the slope, the greater the runoff velocity, and the soil losses.

The highest soil losses were observed in the rainiest months, which coincided with absence

of soil protection by the vegetation cover. The highest soil losses observed in Plot 2 of the Monjolo Grande watershed were due to the physical and chemical conditions of the sandy soils, lower vegetation cover, and higher slope of this area (Figure 10).

Figure 10. Soil losses and monthly precipitation in erosion monitoring plots in two study areas.

The Plot 2 of the Jacutinga watershed was in an area of eutrophic, typical Inceptsol, with moderate A horizon, clay texture, and rectilinear slope of 6% to 12%. It presented a smaller area with green cover, greater area with dry cover, and lower soil coverage in all scenarios, compared to the Plot 1 of the same area (Figure 8).

Like the Plot 2 of the Monjolo watershed, the Plot 2 of the Jacutinga watershed had lower soil coverage as a consequence of the soil physical and chemical conditions, relief characteristic, and inadequate management.

Both experimental plots in the Jacutinga watershed had mechanical resistance to penetration (MRP) higher than 2.5 MPa. According to Camargo and Alleoni (1997) and Sene *et al.* (1985), MRP greater than 2.5 MPa compromises the full development of plants in clayey soils.

The MRP of the Plot 2 in the Jacutinga watershed (4.31 MPa) was higher than the MRP of the Plot 1 (3.99 MPa). Therefore, its higher compaction and soil density, and lower macro porosity (Table 5) decreased the water retention capacity of the soil. These conditions affect the water availability and plant development. The low depth of the Inceptsol in Plot 2 was also a limiting factor to the full development of the sugarcane crops (Vasconcelos and Garcia, 2005).

The soil chemical differences of the plots in the Jacutinga watershed were important factors on the plant development and soil coverage. The soil of the Plot 2 had lower organic matter, Ca^{2+} , and cation exchange capacity, indicating lower nutrient availability.

The Plot 2 of the Jacutinga watershed presented greater soil losses, especially in the Inceptsol, because of the physical and chemical conditions of the soils.

More coarse sand particles resist to carrying and very fine particles (clay) resist to releasing; thus, fine sand particles and silt particles are the most susceptible fractions to erosion processes (Denardin, 1990; Guerra, 2014). The soils of the Plot 2 had 49% of the granulometric fractions consisted of fine sand and, mainly silt (Table 3).

According to De Ploey and Poesen (1985), soils with organic matter contents equal to or less than 2% present low stability of aggregates. Thus, in addition to the granulometric characteristics, Plot 2 had low organic matter,

presenting more susceptible aggregates to erosive processes.

A high MRP combined with high soil density, low porosity and effective depth favors the soil soaking process, reducing water infiltration, increasing surface runoff and, consequently, increasing erosive processes. Such conditions were observed *in situ* during a rainfall event with rapid formation of surface impermeabilization.

The higher slope found in Plot 2 of the Jacutinga watershed, combined with its increased surface runoff due high MRP, and lower vegetation coverage, resulted in higher soil losses (Figure 10).

The factors related to soil and relief characteristics, combined with the climatic conditions in the experiment period changed the patterns of development of the sugarcane crops. According to Corrêa (2016), the monthly rainfall reduced in approximately 30% in December 2013, and January and February 2014.

Some experiments on water deficit conditions have shown a trend of sugarcane crops to show sheath drying, extensive leaf yellowing and low growth (Rodrigues, 1995). According to Inmam-Bamber (2004), leaf area decreases under water stress conditions and high temperatures, since the senescence processes of green leaves are accelerated. Therefore, the drought that occurred in the 2013-2014 crop season accelerated leaf senescence of the plants of the experiment.

The characteristics of the sandy soils of the Monjolo Grande watershed, and the compaction conditions and low depth of the soils of the Plot 2 of the Jacutinga watershed, resulted in low availability of water to the plants, increasing the amount of dry leaves. In the scenario May 21, 2014, Plots 1 and 2 (Monjolo Grande watershed) and 2 (Jacutinga watershed) had more dry vegetation than green vegetation (Figures 7 and 8).

Final considerations

The use of photo comparison and classification methods allowed the monitoring of the development of the evaluated crops, and the quantification and qualification of the soil vegetation cover.

Assessments on soil vegetation cover conditions need to be carried out considering the soil physical and chemical analysis, slope of the area, and precipitation conditions. These

correlations made possible to understand the soil loss processes in each experimental plot.

The greatest soil losses were found in areas where the vegetation cover was less developed, and where the physical and chemical characteristics of the soils favored the susceptibility to erosive processes.

Considering the coincidence of the rainiest months with the absence of soil cover by the sugarcane, adopting adequate soil management practices for this crop is necessary. Thus, the maintenance of residues from previous crops on the soil surface, the planting in flat or slightly undulating relief, and adoption of measures to maintain the physical conditions of the soils during planting and harvest processes are considered basic and fundamental actions in conservationist managements.

Only the adoption of conservation practices, and proper land use planning can preserve the physical and chemical characteristics of the soil, and avoid its degradation by erosive processes and changes in the agricultural landscapes.

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References

- Adami, M.; Mendes, F. de S.; Aguiar, D. A.; Salgado, M. P. G.; Rudorff, B. F. T. 2013. Mudança do uso da terra devido à expansão da cana-de-açúcar em São Paulo de 2005 a 2011. In: Simpósio Brasileiro de Sensoriamento Remoto, 16., 2013, Foz do Iguaçu. Anais... Foz do Iguaçu: INPE, p. 482-489.
- Almeida, J. R. 1981. Erosão dos solos e suas consequências. Informe Agropecuário 7, 17-26.
- Azevedo, M. M., Leite, L. L., Baptista, G. M. de M. 2005. The use of digital photographs to quantify vegetation ground cover in degraded areas. Sociedade & Natureza. Uberlândia, p. 674-682.
- Barbosa, C. 2010. Planejamento urbano sustentável: diretrizes de urbanização embasadas nas características geomorfológicas/pedológicas de vertentes. 2010. 123 f. Dissertação (Mestrado em Geografia) – Instituto de Geociências e Ciências Exatas, Universidade Estadual Paulista, Rio Claro.
- Bertoni, J.; Lombardi Neto, F. 2010. Conservação do solo. 7. ed. São Paulo: Editora Ícone,
- Bertoni, J.; Lombardi Neto, F.; Benatti Junior, R. 1975. Equação de perdas de solo. Campinas: IAC, 25p. (Boletim técnico, 21).
- Bezerra, J. F. R., Guerra, A. J. T., Rodrigues, S. C. 2011. Utilização da fotocomparação na reabilitação de áreas degradadas por erosão, a partir de uma estação experimental, Uberlândia – MG. Revista de Geografia (UFPE) 28, 149-164.
- Camargo, O.A.; Alleoni, L.R.F. 1997. Compactação do solo e o desenvolvimento das plantas. Piracicaba: ESALQ, 132p.
- Carvalho, N.O.; Filizola Júnior, N.P.; Santos, P.M.C.; Lima, J. E. F. W. 2000. Guia de práticas sedimentométricas. Brasília: ANEEL. 154p.
- Casagrande, A. A. 2001. Compactação e manejo do solo na cultura da cana-de-açúcar. In: MORAES, M.H.; MÜLLER, M.M.L.; FOLONI, J.S.S. Qualidade física do solo: métodos de estudo - sistemas de preparo e manejo do solo. Jaboticabal: FUNEP, p.150-97.
- Cassetti, V. 1991. Ambiente e apropriação do relevo. São Paulo: Contexto,
- Centro De Análise e Planejamento Ambiental. CEAPLA. 2012. Atlas Ambiental da Bacia do Rio Corumbataí. Disponível em: <<http://www.rc.unesp.br/igce/ceapla/atlas/>>. Acesso em 25/06/2012.
- Cogo, N.P. 1978. Uma contribuição à metodologia de estudo das perdas de erosão em condições de chuva natural. I. Sugestões

- gerais, medição dos volumes, amostragem e quantificação de solo e água da enxurrada. 1ª aproximação. In: Encontro Nacional de Pesquisa sobre Conservação do Solo, 2., 1978, Passo Fundo. Anais... Passo Fundo: Empresa Brasileira de Pesquisa Agropecuária, p.75-98.
- Corrêa, E. A. 2016. Avaliação da cultura de cana-de-açúcar como fator protetor em termos da erosão hídrica do solo e a sua associação com a resposta espectral por meio de diferentes sensores. 171 f. Tese (Doutorado em Geografia) – Instituto de Geociências e Ciências Exatas, Universidade Estadual Paulista, Rio Claro,
- Correa, E. A.; Pinto, S. Dos A. F., Couto Junior, A. 2015. Espacialização temporal das perdas de solos em uma microbacia hidrográfica com predomínio de solos arenosos. Geografia, v. 40, n. 1, p. 101-118,
- Correchel, V. 2003. Avaliação de Índices de erodibilidade do solo através da técnica da análise da redistribuição do “fallout” do ¹³⁷C. 2003. 79f. Tese (Doutorado em Ciências). Escola Superior de Agricultura Luiz de Queiroz, ESALQ, Piracicaba.
- De Ploey, J., Poesen, J. 1985. Aggregate stability, runoff generation and interrill erosion. In: Richards, K.S.; Arnett, R.R.; Ellis, S. Geomorphology and Soils, London, , p. 99-120.
- Denardin, J. E. 1990. Erodibilidade do solo estimada por meio de parâmetros físicos e químicos. 1990. 113 f. Tese (Doutorado em Solos e Nutrição de Plantas) - Escola Superior de Agricultura Luiz de Queiroz, Universidade de São Paulo, Piracicaba.
- Dias Junior, M. S.; Pierce, F. J. 1996. Revisão de literatura: O processo de compactação do solo e sua modelagem. Revista Brasileira de Ciência do Solo, v. 20, p.175-182.
- Doorenbos, J.; Pruitt, J. O. Crop water requirement. Rome: FAO, 1977, 179p. (Irrigation and Drainage Paper, n. 24)
- EMBRAPA. 1997. Centro Nacional de Pesquisa de Solos. Manual de métodos de análise de solos. 2 ed. Rio de Janeiro, , 212 p.
- EMBRAPA. 2013. Centro Nacional de Pesquisa de Solos. Sistema brasileiro de classificação de solos. 3. edição. Rio de Janeiro, , 353 p.
- Ferreira, M. E.; Andrade, L. R. M.; Sano, E. E.; Carvalho, A. M.; Junqueira, N. T. V. Uso de imagens digitais na avaliação da cobertura do solo. Planaltina, DF : Embrapa Cerrados, 2001. 50p. (Embrapa Cerrados: Boletim de Pesquisa e Desenvolvimento, 21).
- Figueiredo, L. H. A.; Dias Junior, M. S.; Ferreira, M. M. 2000. Umidade crítica de compactação e densidade do solo máxima em resposta a sistemas de manejo num Latossolo Roxo. Revista Brasileira de Ciência do Solo 24, 487-493.
- Guerra, A. J. T. 2005. O início do processo erosivo. In Guerra, A.J.T.; Silva, A.S. Da; Botelho, R.F.M. (org). Erosão e conservação dos solos: conceitos, temas e aplicações. 2.ed. Rio de Janeiro: Bertrand Brasil, p.17-56.
- Guerra, A. J, T. 2014. Degradação dos Solos - conceitos e temas. In Guerra, A. J. T, Jorge, M. Do C. O. (orgs). Degradação dos solos no Brasil. Rio de Janeiro: Bertrand, p.15-51.
- Guerra, A.J.T.; Marçal, M.S. 2006. Geomorfologia ambiental. Rio de Janeiro: Bertrand Brasil,
- Inman-Bamber, N. G. 2004. Sugarcane water stress criteria for irrigation and drying off. Field Crops Research, Amsterdam, v. 89, n. 1, p. 107-122,
- Ippoliti Ramilo, G. A. 2002. Geoprocessamento para caracterização geoambiental e estimativa da cobertura do solo de pastos em microbacia na zona da mata - MG. 2002, 95 f. Tese (Doutorado em Solos e Nutrição de Plantas). Universidade Federal de Viçosa, Viçosa.
- IPT – INSTITUTO DE PESQUISAS TECNOLÓGICAS. 1981. Mapa Geomorfológico do Estado de São Paulo. São Paulo: IPT.
- Koffler, N. F. 1994. Carta de declividade da bacia do Rio Corumbataí para análise digital (SIG). Geografia 19, 167-182.

- Landis, J. R.; Koch, G.G. 1977. The measurement of observer agreement for categorical data. *Biometrics* 33, 159-174,
- Martinelli, L. A.; Filoso, S. 2007. Polluting effects of Brazil's sugar-ethanol industry. *Nature* 445, 364.
- Moraes, I. C. 2014. Análise de desempenho dos modelos de perda de solo MEUPS e WEPP: contribuição a aplicação em bacias hidrográficas. Relatório interno. Rio Claro, SP.
- Morgan, R. P. C. 2005. Soil erosion and conservation. Inglaterra: Blackwell Publishing, 298 p.
- Pereira, L. H.; Pinto, S.A.F. 2007. Utilização de imagens aerofotográficas no mapeamento multitemporal do uso da terra e cobertura vegetal na bacia do rio Corumbataí – SP, com o suporte de sistemas de informações geográficas. In: Simpósio Brasileira de Sensoriamento Remoto, 13, 2007, Florianópolis (SC), Anais..., São José dos Campos – SP: INPE, 1321-1328.
- Pinese Júnior, J. F.; Cruz, L. M.; Nogueira, T. C.; RODRIGUES, S. C. 2008. Monitoramento de processos erosivos em parcelas experimentais no município de Uberlândia, MG. *Rev. Geogr. Acadêmica* 2, 5-18.
- Rodrigues, J. D. 1995. Fisiologia da cana-de-açúcar. Botucatu: UNESP, 100p. (Apostila). Disponível em <http://www.malavolta.com.br/pdf/1071.pdf>. Acesso em 04/08/2014.
- Schaefer, C. E. R.; Souza, C. M.; Vallejos, M.; Viana, J. H. M., Galvão, J. C. C.; RIBEIRO, L. M. 2001. Características da porosidade de um Argissolo Vermelho-Amarelo submetido a diferentes sistemas de preparo de solo. *Revista Brasileira de Ciência do Solo* 25, 765-69,
- Sene, M.; Vepraakas, M.J.; Naderman, G.C.; Denton, H.P. 1985. Relationships of soil texture and structure to corn yield response to subsoiling. *Soil Science Society of America Journal* 49, 422-427,
- Schmidt, A.V. 1989. Terraceamento na região Sul. In: Simpósio sobre terraceamento agrícola, 1., 1989, Campinas. Anais... Campinas: Fundação Cargill 23-25.
- Silva, A. S da. 2005. Análise Morfológica dos solos e erosão. In: Guerra, A. J. T.; Silva, A. S.; Botelho, R. G. M. Erosão e conservação dos solos: Conceitos, Temas e aplicações. 2 ed. Rio de Janeiro.
- Sparovek, G.; Schnug. E. 2001. Temporal Erosion-induced soil degradation and yield loss. *Soil Science Society of American Journal* 65, 1479-1486,
- Strahler, A. N. 1952. Hypsometric (area-altitude) – analysis of erosion al topography. *Geological Society of America Bulletin* 63, 1117-1142.
- Tricart, J. 1968. As relações entre a morfogênese e a pedogênese. *Notícia Geomorfológica* 8, 5-18.
- Tricart, J. 1977. Ecodinâmica. Fundação Instituto Brasileiro de Geografia e Estatística. Superintendência de Recursos Naturais e Meio ambiente. Diretoria Técnica. Rio de Janeiro, p. 97.
- UNICA. 2015. União dos Plantadores de Cana-de-açúcar de São Paulo. Estatísticas do Setor Sucroalcooleiro. www.unica.com.br. Acesso em 06/03/2015.
- Vasconcelos, A. C. M.; Garcia, J. C. 2005. Cana-de-açúcar: Ambientes de Produção. Desenvolvimento Radicular da cana-de-açúcar. Ribeirão Preto: IAC/Apta, 5 p. (Encarte Técnico, 110).
- Zanella, J. 2015. Os problemas do avanço da cana em SP. *Jornal UNESP*, Ano XXI, nº 228. Disponível em <http://www.unesp.br/aci/jornal/228/cana.php>. Acesso em 10/01/2015.