

Division - Soil Use and Management | Commission - Soil and Water Management and Conservation

# Interrill erodibility of different sandy soils increases along a catena in the Caiuá Sandstone Formation

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**ABSTRACT:** Soil erosion in tropical areas is a major problem for sustainability in agriculture and soil stability. In the Northwest of Paraná, cassava crop is produced using a conventional tillage system along a catena consisting of different soil classes: Ferralsols (near the summit), Lixisols (mid-slope), and Arenosols (foot-slope). Therefore, differential soil erosion rate and soil degradation are expected along the catena. Here, we test the erodibility of the three sandy soil classes in a representative catena of the Caiuá Sandstone Formation. Disturbed soil samples were collected from a depth of 0.20 m. The soil erodibility test was performed in the laboratory through a multi-drop rainfall simulator. A rainfall intensity of 55 mm h<sup>-1</sup> with an energy of 453 Jm<sup>2</sup> h<sup>-1</sup> was applied for the rainsplash tests (splash pan), whereas a rainfall intensity of 65 mm h<sup>-1</sup> with an energy of 534 Jm<sup>2</sup> h<sup>-1</sup> was applied for the soil erodibility tests (using a small flume). The three soils showed differences in soil particles detached by raindrop on very fine sand class <0.15 mm as follows: Ferralsols 10 %, Arenosol 12 %, and Lixisol 15 %. The maximum soil erodibility increased gradually according to the soil position on the catena: Ferralsols (1.81 × 10<sup>6</sup> kg s m<sup>-4</sup>), Lixisols (2.83 × 10<sup>6</sup> kg s m<sup>-4</sup>), and Arenosols (3.41 × 10<sup>6</sup> kg s m<sup>-4</sup>). Finally, the position of the soil along the catena and total sand were the best in explaining soil interrill erodibility. Therefore, farmers and stakeholders should be cautious about applying a homogeneous tillage system from the summit to the foot-slope along a catena with different sandy soils.

**Keywords:** Hillslope, soil-geomorphology, hydopedology, conventional tillage, soil detachment.

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## INTRODUCTION

Modern society is currently facing a two-faceted problem. In one hand, there is a necessity to produce more food for a growing population (Kaack and Katul, 2013; Nature-Editorial, 2014). On the other hand, the pressure on agricultural systems to increase food production causes soil degradation, soil erosion, nutrient depletion, and subsequently a decrease in overall yield (Montgomery, 2007; United Nations, 2015).

The no-till system is an efficient practice for soil conservation and long-term agroecosystem sustainability. However, the no-till system has not yet seen widespread use worldwide and there are several constraints for its adoption in poorer countries; or for some crop types (e.g., technology available, input prices, marginal lands, etc.). Therefore, the practice corresponding to about 11 % of field cropland of the cultivated land in the world (Lal, 2007; Huggins and Reganold, 2008; Kassam et al., 2015).

Cassava crop is produced mainly using conventional tillage systems. In Brazil, the cultivation of cassava promotes heavy soil losses due to water erosion (Merten and Minella, 2013). In the Northwest of Paraná, the soil erosion increases especially during mechanized soil preparation of Lixisols (with a topsoil sandy texture) for the conversion of pasture areas (Merten et al., 2016). Moreover, cassava cultivation is carried out along long catena. This catena is characterized by different soils along the gradient (i.e., Ferralsols near the summit, Lixisols mid-slope, and Arenosols near the foot-slope (IUSS Working Group WRB, 2006). Therefore, soil loss occurring in South American sandy soils can affect the conditions for cassava cultivation and compromise the availability of raw material for the agroindustry in the states of Paraná, Mato Grosso do Sul, and São Paulo (Howeler et al., 2001; Fasinmirin and Reichert, 2011).

There have been no studies on the soil erodibility for the major sandy soil classes of the Caiuá Sandstone Formation, with the exception of interrill water erosion and erodibility studies conducted on the sandy soil (Reichert and Norton, 1995, 1996). In addition, these sandy soils that are used for cassava cultivation are associated with pasture recovery in the Northwest of Paraná, Brazil. This region has good edaphic-climatic and agronomic conditions for cassava production (Visses et al., 2018). However, studies indicate that soil erosion is a major problem in this particular agricultural landscape (Cunha et al., 1999, 2016; Merten et al., 2016).

The critical shear stress (Pa) necessary for particle detachment of sandy soils is three times lesser than clay soils (Knapen et al., 2007). The tillage system impacts on the critical shear stress and the threshold to soil particle detachment. Overall, the resistance of the topsoil to concentrated overland flow is in the following order: no-tillage has the greatest resistance, followed by reduced tillage, followed lastly by conventional tillage (Knapen et al., 2007). Moreover, the conventional tillage system has great variability on the critical shear stress response. Therefore, it is important to assess the soil erodibility with conventional tillage. In particular, to test the differences in the erodibility of sandy soil within the same pedo-geomorphological context (Wang et al., 2013).

The soil erodibility concept is defined as the susceptibility of the soil to be eroded due to its intrinsic properties. Then, when rainstorms, slope, land cover, and management conditions are kept constant, some soil will be more erodible than others (Wischmeier and Smith, 1978; Bryan et al., 1989). In addition, soil erodibility varies depending on erosion sub-processes (i.e., interrill and rill erosion). Here, the interest is on the interrill erodibility, which is the first stage of erosion. It is defined as where raindrops impacting over a shallow flow exert more hydraulic energy on the overland flow, which enhances sediment detachment and transport (Emmett, 1970; Kinnell, 1990). Concentrated overland flow may result in rill flow (Slattery and Bryan, 1992; Nearing et al., 1997). Therefore, laboratory experiment is of utmost importance in determining soil erodibility,

as it is possible to isolate the factors controlling soil erosion (Bryan, 2000; Knapen et al., 2007; Bennett et al., 2015).

Our hypothesis is the erodibility of sandy soils increases along the catena due to pedo-geomorphological transformations (e.g., the proportions of clay and sand fraction in different soils). Here, we test the erodibility rate of three different soil classes in a representative catena of the Caiuá Sandstone Formation.

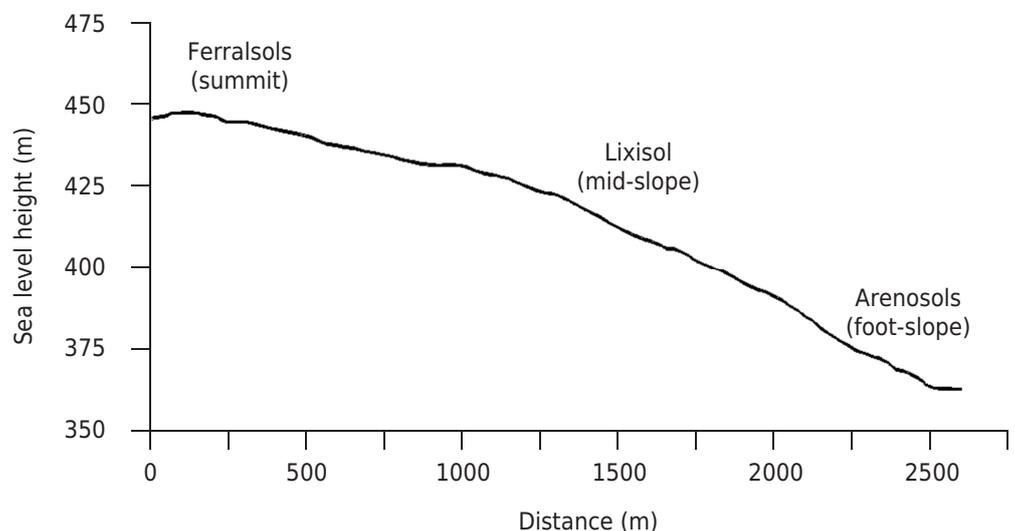
## MATERIALS AND METHODS

The study area is in Paranavaí in the northwest of Paraná State, Brazil (coordinates for the mid-slope: 25° 04' 37.6" S, 52° 30' 00.8" W). The catena is 2600 m in length and the slope is ~5 %. The pedology consists of Caiuá Sandstone Formation from the Cretaceous (65 million years) (Mineropar, 2001). The distribution of the soils along the catena from the top to the bottom is as follows: Ferralsols (summit), Lixisols (mid-slope), and Arenosols (foot-slope) (IUSS Working Group WRB, 2006) (Figure 1), and all soils were cultivated with cassava (*Manihot esculenta* Crantz). These soils in the Brazilian Soil Classification System are *Latosolo Vermelho típico*, *Argissolo Vermelho abrupto*, and *Neossolo Quartzarênico*, respectively (Santos et al., 2013). The Arenosol was cultivated with pasture and cropped recently with cassava (Table 1). Therefore, the organic matter content was greater than that in other soils.

The soils (at a depth of 0.20 m) were collected using a shovel (Table 1). Overall, the soils contain around 900 g kg<sup>-1</sup> sand (sandy soils) and are poor in organic matter. Moreover, the soils are composed of low activity clay (kaolinite) and oxides (Fe and Al) (Melfi and Pedro, 1977; Ker et al., 2012)

The catena is a sequence of soil distributed along a slope originating from the same base material, which differentiated because of pedogeomorphic processes (e.g., water movement; figure 1) (Milne, 1935). The soils in the study area are characterized by a transported-limited pedological system, resulting in thick soils distributed along a convex-concave hillslope (Gerrard, 1992).

More broadly, this catena supports the nine unit landsurface model and the effects of erosion on the pedogeomorphic processes (Conacher and Dalrymple, 1977). At the interfluvial position (Ferralsols at the summit), the predominant pedogenic processes are associated with vertical subsurface soil water movement. In the seepage slope (Lixisols



**Figure 1.** A schematic of the catena displaying different soils in the Caiuá Sandstone Formation.

**Table 1.** Soils A horizon (0.00-0.20 m) properties along the catena

Soil properties	Ferralsols	Lixisols	Arenosols
Sand <sup>(1)</sup> (g kg <sup>-1</sup> )	890	930	950
Silt <sup>(1)</sup> (g kg <sup>-1</sup> )	20	10	20
Clay <sup>(1)</sup> (g kg <sup>-1</sup> )	90	60	30
Coarse sand >0.25 mm (%)	19	21	28
Medium/fine sand <sup>(2)</sup> (%)	70	64	61
Bulk density (Mg m <sup>-3</sup> )	1.40	1.39	1.51
Soil organic matter (Walkley-Black) (g kg <sup>-1</sup> )	11.57	14.75	16.40
pH(CaCl <sub>2</sub> ) <sup>(3)</sup>	4.47	4.37	4.10
P (Mehlich) (mg kg <sup>-1</sup> )	4.79	3.10	5.74
Base saturation (%)	31.47	32.87	28.07
Cation Exchange Capacity (cmol <sub>c</sub> kg <sup>-1</sup> )	5.44	6.03	6.64

<sup>(1)</sup> Silva et al. (2011). <sup>(2)</sup> 0.053 < medium/fine sand < 0.25 mm. <sup>(3)</sup> pH (CaCl<sub>2</sub>): pH in CaCl<sub>2</sub> 0.01 mol L<sup>-1</sup> at a ratio of 1:2.5 soil:solution.

at the mid-slope) the pedogenic processes are related to mechanical and chemical eluviation by lateral subsurface water movement. As a result, a soil with a Bt horizon is formed (i.e., argillic horizon). Finally, colluvial footslope and alluvial toeslope (Arenosols at the footslope), several pedogeomorphic process are dominant, such as: re-deposition of material from upslope, transportation of material, subsurface processes, alluvial deposition close to the fluvial channel, and water movement. The soil formation resulted from hillslope processes and water table oscillation caused by the river system. In short, this area is dominated by a combination of hillslope and river processes which affects soil development (Conacher and Dalrymple, 1977).

### Rainfall simulation and experimental design

Simulated rainfall was produced using a multi-drop simulator consisting of a framework of pipes (diameter 20 mm). The simulator is composed of a SPRACO stationary cone jet nozzle (Spraying Systems Co.) (Luk et al., 1986). Water was supplied by an electric water pump. The simulated rainfall was launched from a height of around 5.2 m above the splash pan and a small flume test area.

The characteristics of the rain applied for the rainsplash test were: water pressure 96 kPa, rainfall intensity 55 mm h<sup>-1</sup>, number of drops produced per minute was 4,833, the median drop size produced was 1.75 mm, and the rain energy was 453 J m<sup>2</sup> h<sup>-1</sup>. In comparison to natural rain of the same intensity, the simulated rain had 67 % of the number of raindrops and 78 % of the kinetic energy. The rain characteristics applied for the interrill soil erodibility test were: water pressure 96 kPa, rainfall intensity 65 mm h<sup>-1</sup>, number of drops produced per minute was 6,766, the median drop size produced was 1.87 mm, and the rain energy was 534 J m<sup>2</sup> h<sup>-1</sup>. The rain characteristics were determined using a laser precipitation monitor (Thies Clima).

Rainsplash was measured using a pan of 0.30 × 0.45 × 0.10 m in dimension (width, length, and depth, respectively) (Moldenhauer and Long, 1964) (Figure 2a). The splash pan was enclosed by a shield collector to measure the splash detachment. The soil was transferred gradually into the splash pan and was gently crushed and compacted (Agassi and Bradford, 1999). The splash pan was adjusted to a slope of 5° and was subjected to the simulated rain for 45 min. The splashed particles were dried, weighed, and sieved using a set of sieves with openings of 2.0, 1.0, 0.5, 0.25, 0.15, 0.125, 0.75, and <0.75 mm. The particle size distribution (%) was then determined.

In contrast, the interrill soil erodibility was determined using a small flume with the dimensions 1.00 × 0.20 × 0.05 m (length, width, and depth, respectively) (Bryan and De Ploey, 1983; Verhaegen, 1987) (Figure 2b). The flume was adjusted to a slope of 6°. The rainfall simulation was run for 60 min; however, the sediment sampling collection was carried out in the last 30 min along the stable runoff. In addition, the runoff (overland flow) and detached sediment were collected for 30 s at regular intervals of 5 min each. Seven samples (consisting of flow and sediment) were collected for each experiment. There were 28 samples collected in total (4 replicates × 7 samples = 28 samples for each soil type).

After the data on the hydraulics and sediment were obtained, a set of equations (Equations 1 to 4) were applied to determine the soil detachment rates and soil interrill erodibility. These equations are from the Water Erosion Prediction Project Model (WEPP) (Sharma, 1996; Bezerra and Cantalice, 2006).

$$Di = \frac{D}{A \times Dsc} \quad \text{Eq. 1}$$

In which:  $Di$  = interrill detachment rate ( $\text{kg m}^{-2} \text{s}^{-1}$ );  $D$  = dry mass of detached soil (kg);  $A$  = plot area ( $\text{m}^2$ ); and  $Dsc$  = duration of the sampling collection (s).

$$SL = \frac{\sum (Q \times Sc \times t)}{A} \quad \text{Eq. 2}$$

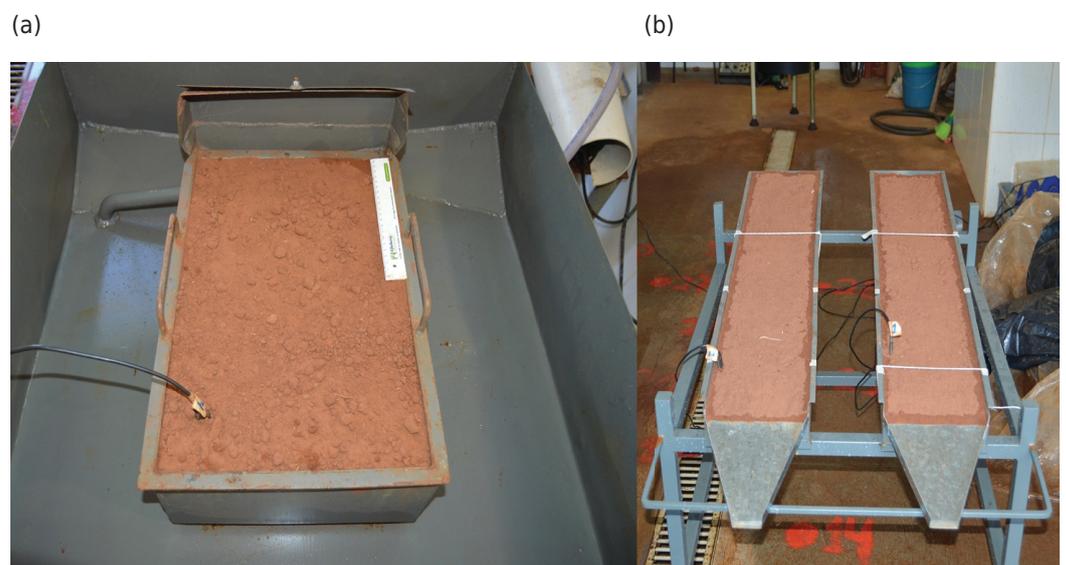
In which:  $SL$  = soil loss ( $\text{kg m}^{-2}$ );  $Q$  = discharge ( $\text{L s}^{-1}$ );  $Sc$  = sediment concentration ( $\text{kg L}^{-1}$ );  $t$  = interval between collections (s); and  $A$  = plot area ( $\text{m}^2$ ).

$$Ki = \frac{Di}{I^2 \times Sf} \quad \text{Eq. 3}$$

In which:  $Ki$  = interrill erodibility ( $\text{k s m}^{-4}$ );  $Di$  = interrill detachment rate ( $\text{kg m}^{-2} \text{s}^{-1}$ );  $I$  = rain intensity ( $\text{m s}^{-1}$ );  $Sf$  = the slope factor correction, equation 4 (dimensionless).

$$Sf = 1.05 (0.85) \text{EXP}^{-4\theta} \quad \text{Eq. 4}$$

In which:  $Sf$  = slope factor; and  $\theta$  = slope angle ( $\text{m m}^{-1}$ )



**Figure 2.** Splash pan with a shield to collect the splashed soil particles (a) and small flume to determine interrill soil erodibility (b).

The slope factor (Sf) is 0.20 for a flat slope of 0°, 1.0 for a slope of 45°, and the maximum possible Sf is 1.05 for a vertical slope of 90°. The slope factor on the interrill processes reflects the overland flow transport limitation in flatter slopes (Liebenow et al., 1990; Flanagan and Nearing, 1995). In the present study, Sf was estimated to have a coefficient of 0.49.

One-way analysis of variance (ANOVA) was applied to compare the response of each soil sample according to the catena position. Statistical significance was identified using p values as follows: ns (nonsignificant  $p > 0.05$  and significant  $p < 0.05$ ). The post hoc t-test (LSD) was applied at a significance level of 0.05 to compare the differences of the samples average. Finally, a simple correlation analysis was performed to evaluate the increase in soil erodibility as a function of soil type along the catena.

## RESULTS

### Rainsplash and sheetwash

The soil loss through rainsplash was similar in the Ferralsols and Lixisols (Table 2). However, the soil loss in the Arenosols was 22 % higher than the Ferralsols and Lixisols. As expected, raindrop impact was responsible for 91 % of the total soil loss in the splash pan test. Sheetwash was of relatively minor importance in sediment transport (9 % of the total soil loss). This proportion of the impacts was similar on all three soils.

The soil particles detached by raindrop was different among the three soils (Table 3). For Ferralsols, 89 % ( $p < 0.05$ ) of the detached particles were in the range of fine sand ( $\geq 0.15$  mm to  $\leq 0.25$  mm), and the ratio was similar for Lixisols and Arenosols (84 and 82 %, respectively;  $p > 0.05$ ). However, the three soils showed different soil detached particles in the very fine sand class ( $< 0.15$  mm), where Ferralsols was 10 %, Arenosols was 12 %, and Lixisols was 15 % ( $p < 0.05$ ).

**Table 2.** Average of soil loss, flow characteristics, interrill detachment, and interrill erodibility according the soil type along the catena

Soil type	Total soil loss		Hydraulics parameters			Soil detachment and erodibility	
	R + S	S	q	V	h	Di	Ki
	kg m <sup>2</sup> h <sup>-1</sup>	kg m <sup>-2</sup>	m <sup>2</sup> s <sup>-1</sup>	m s <sup>-1</sup>	m	kg m <sup>-2</sup> s <sup>-1</sup>	kg s m <sup>-4</sup>
Ferralsols	2.79b	1.98b	$2.03 \times 10^{-5}$ a	$4.71 \times 10^{-2}$ a	$4.35 \times 10^{-4}$ a	$1.05 \times 10^{-3}$ b	$1.58 \times 10^6$ b
Lixisols	2.78b	1.60b	$2.10 \times 10^{-5}$ a	$4.84 \times 10^{-2}$ a	$4.37 \times 10^{-4}$ a	$1.57 \times 10^{-3}$ a	$2.37 \times 10^6$ a
Arenosols	3.40a	3.14a	$1.98 \times 10^{-5}$ a	$4.69 \times 10^{-2}$ a	$4.66 \times 10^{-4}$ a	$1.66 \times 10^{-3}$ a	$2.51 \times 10^6$ a

R+S = rainsplash (R) plus sheetwash (splash pan); S = sheetwash (small flume); q = unit of discharge; V = flow velocity; h = flow depth; Di = interrill detachment; Ki = interrill erodibility. Columns with same letter did not differ statistically (from t-test at a significance level of 0.05).

**Table 3.** The soil particles detached in percentage by raindrop according to soil type

Particle size <sup>(1)</sup>	Ferralsols	Lixisols	Arenosols
mm	%		
>2.00	0.01	0.03	0.00
1.00	0.06	0.05	0.26
0.50	0.78	0.70	5.93
0.25	41.79	41.19	43.42
0.15	46.81	43.03	38.34
0.125	3.57	4.11	3.87
$\geq 0.075$	6.98	10.88	8.18
<b>Total</b>	<b>100.00</b>	<b>100.00</b>	<b>100.00</b>

<sup>(1)</sup> Dry sieve method (Kemper and Rosenau, 1986).

### Interrill soil erodibility

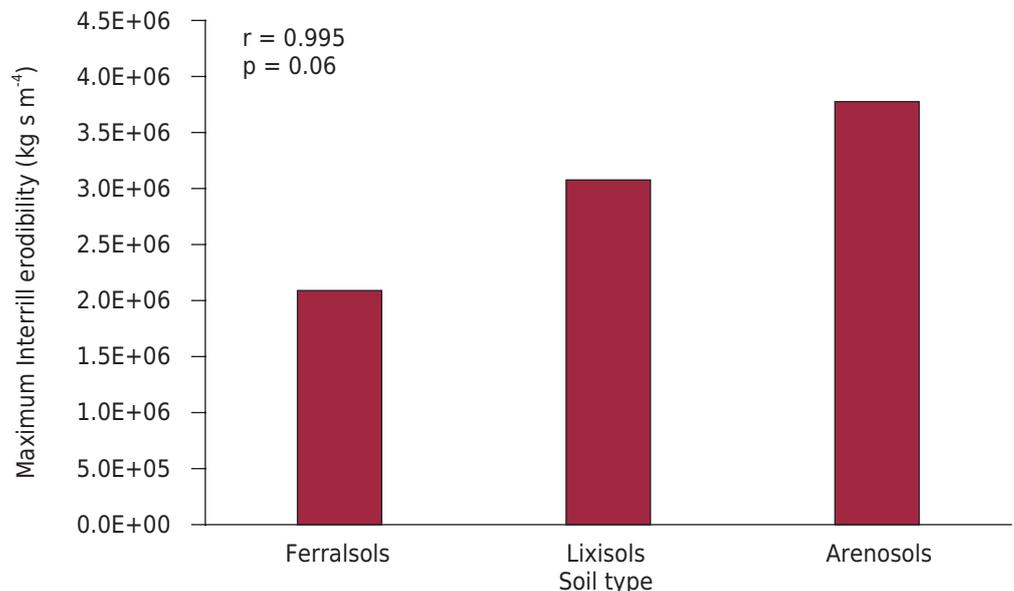
The soil loss through sheetwash (measured on the small flume) was similar in Ferralsols and Lixisols. This result reflects the rainsplash measurements described above. In addition, the soil loss for the Arenosols was 58 and 96 % higher than the soil loss measured in the Ferralsols and Lixisols, respectively (Table 2). However, all the hydraulic parameters measured during the experiments [e.g., unit of runoff discharge ( $q$ ), flow velocity ( $V$ ), and flow depth ( $h$ )] were similar across the three soil types (Table 2).

Although the hydraulic parameters were similar among the three soil types, the interrill detachment and interrill erodibility were different (Table 2). The soil interrill detachment and interrill erodibility in Lixisols and Arenosols were more than 49 % higher than those of Ferralsols. Considering that the average of the maximum interrill erodibility registered on each soil type ( $n = 4$ , data not shown), the erodibility increased gradually according to the position of the soils on the catena (Ferralsols on the summit, Lixisols was midslope, and Arenosols on the footslope). The soil erodibility from Ferralsols ( $1.81 \times 10^6 \text{ kg s m}^{-4}$ ) to Lixisols ( $2.83 \times 10^6 \text{ kg s m}^{-4}$ ) increased by 56 %; next, from Lixisols to Arenosols ( $3.41 \times 10^6 \text{ kg s m}^{-4}$ ) the interrill erodibility increased by 20 %. Finally, in comparing Ferralsols to Arenosols, the interrill erodibility increased by 88 %. The average of the maximum interrill erodibility of each soil type was different ( $p < 0.05$ ).

The same soil erodibility pattern was maintained when the maximum interrill erodibility measured from each soil was considered. Hence, the position of the soil along the catena explained >90 % ( $p = 0.06$ ) of the soil interrill erodibility and the interrill detachment rates (Figure 3). In addition, the total sand content further described more about the soil erodibility on the catena (99 %;  $p < 0.05$ ).

## DISCUSSION

The interrill soil erodibility increased significantly dependent on the soil position on the catena, increasing from the footslope to the summit (Ferralsols < Lixisols < Arenosols). Slope and rain were kept constant in the experiment, and the hydraulic variables such as the unit of discharge, the flow velocity, and the flow depth were equivalent to each soil. Therefore, the response of the soils was attributed to their intrinsic physical-chemical



**Figure 3.** Increase of maximum interrill soil erodibility following the soil position on the catena: Ferralsols (summit), Lixisols (mid-slope), and Arenosols (foot-slope).

properties. The most contextual effects (local variables) were already isolated on the interrill tests using disturbed soil samples (Thomaz and Pereira, 2017). In short, the soil evolution-transformation along the catena exhibited different rates of erodibility due to the changes in soil texture composition, the grain size of the sand, and its proportion in the topsoil.

In general, the three soil types distributed along the catena are classified as sandy. However, the clay content was higher in Ferralsols ( $90 \text{ g kg}^{-1}$ ), followed by Lixisols ( $60 \text{ g kg}^{-1}$ ) and Arenosols ( $30 \text{ g kg}^{-1}$ ). During the rain simulation for the rainsplash test, we observed that only the first two soils, especially, Ferralsols, displayed scattered resistant aggregates on the topsoil after the rainfall. Probably, even with little clay content, the resistance of the soil surface increased proportionally against the impact of raindrop and overland flow. Soil strength is a key factor for particle entrainment and soil erodibility as well. Moreover, clay content is extremely important in this process (Bryan, 2000; Knapen et al., 2007).

The soils distributed along the catena displayed a loose structure and lower aggregate stability as they a) were formed by disturbed samples crushed by tillage processes; b) had a lower organic matter content; and c) had no fine root system that can enmesh macroaggregates, since the soil was cropped with cassava. Therefore, the soils behave mostly as a non-cohesive system. Furthermore, the sand content and fraction were dissimilar among the tested soils. In addition, the total sand content strongly correlated to soil erodibility (i.e., interrill detachment and interrill erodibility). Finally, in non-cohesive sediments, the particles were significantly detached mostly as a single particle.

Non-cohesive sediments formed by different particle sizes exhibit different rates of detachment and transportation. Particles measuring  $>250 \mu\text{m}$  and  $<63 \mu\text{m}$  are resistant to detachment. Between this range ( $>250 \mu\text{m}$  and  $<63 \mu\text{m}$ ), particles with a size measuring approximately  $93 \mu\text{m}$ , followed by particles of size  $125 \mu\text{m}$ , are more susceptible to detachment (Poesen, 1981). In contrast, the most detachable particles from overland flow range in size from  $100$  to  $300 \mu\text{m}$ . In addition, the critical shear velocity required for the transportation of particles of size  $100$ - $300 \mu\text{m}$  is much lower than that required for the transportation of cohesive sediments (Morgan, 2009).

Here, the Lixisols and Arenosols topsoils are richer in fine sand fraction than Ferralsols topsoils. Therefore, the total sand content and its size fraction, with additional differences in clay content in each soil type along the catena, exert variability in soil erodibility. Therefore, in sandy soils, the sand size distribution and proportion are of utmost importance in the determination of soil erodibility (Wischmeier and Smith, 1978; Quansah, 1985).

Nevertheless, some Brazilian sandy soils exhibit a significant variability in terms of interrill erodibility (Table 4). The factor of the interrill erodibility ( $K_i$ ) for sandy soils ranges from a minimum of  $8.56 \times 10^4 \text{ kg s m}^{-4}$  (Bocuti et al., 2019) to a maximum of  $5.10 \times 10^6 \text{ kg s m}^{-4}$  (Brida and Cassol, 1996). Here, Ferralsols displayed erodibility similar to that of cultivated Ferralsols from Cruz Alta (Nunes and Cassol, 2008). However, the Lixisols and Arenosols in this study are the most erodible soils, with  $K_i$  in the range of the other cases reported in the literature (Table 4). The wide variation observed in the soil erodibility is not solely due to the texture of the soil but also to the experimental procedures and the context in which the measurement was performed.

It was not our goal to discuss the soil transformations in the catena. An in-depth discussion about soil development in systems similar to the study area could be found elsewhere (Cunha et al., 1999; Zapparoli and Gasparetto, 2010; Cunha et al., 2016; Barreiros et al., 2018). Overall, Lixisols was highlighted as the most erodible soil along the catena (Cunha et al., 1999, 2016; Merten et al., 2016). The explanations for this behavior are numerous; for example, anisotropy on the hydraulic conductivity due

**Table 4.** Interrill erodibility of some Brazilian sandy soils

Soil type <sup>(1)</sup>	Locality	Soil texture	Ki	Sources
		Sand/Silt/Clay	kg s m <sup>-4</sup>	
Lixisols/Argissolo Vermelho-escuro	Santa Maria, Rio Grande do Sul	755/101/145	5.10 × 10 <sup>6</sup>	Braida and Cassol (1996)
Lixisols/Argissolo Vermelho-Amarelo distrófico	Santa Maria, Rio Grande do Sul	570/240/190	1.77 × 10 <sup>6</sup> – 2.00 × 10 <sup>6</sup>	Reichert et al. (2001) and Schäfer et al. (2001)
Lixisols/Argissolo Vermelho-Amarelo	Lavras, Minas Gerais	397/145/460	4.67 × 10 <sup>5</sup>	Lima and Andrade (2001)
Lixisols/Argissolo Vermelho-Escuro	Lavras, Minas Gerais	472/125/400	6.85 × 10 <sup>5</sup>	Lima and Andrade (2001)
Lixisols/Argissolo Vermelho distrófico típico	Viamão, Rio Grande do Sul	Not informed	2.83 × 10 <sup>6</sup>	Cassol and Lima (2003)
Lixisols/Argissolo Vermelho-Amarelo	Carpina, Pernambuco	678/94/228	1.87 × 10 <sup>6</sup>	Bezerra and Cantalice (2006)
Ferralsols/Latossolo Vermelho distrófico	Cruz Alta, Rio Grande do Sul	651/134/215	1.54 × 10 <sup>6</sup>	Nunes and Cassol (2008)
Lixisols/Argissolo Vermelho	Candiota, Rio Grande do Sul	439/269/292	1.82 × 10 <sup>6</sup>	Franco et al. (2012)
Arenosols/Neossolo Quartzarênico	Campo Verde and Santo Antônio de Leverger, Mato Grosso	926/43/32	1.56 × 10 <sup>5</sup>	Bocuti et al. (2019)
Arenosols/Neossolo Quartzarênico	Campo Verde and Santo Antônio de Leverger, Mato Grosso	946/22/32	2.47 × 10 <sup>5</sup>	Bocuti et al. (2019)
Ferralsols/Latossolo	Campo Verde and Santo Antônio de Leverger, Mato Grosso	748/117/135	8.56 × 10 <sup>4</sup>	Bocuti et al. (2019)
Ferralsols/Latossolo Vermelho típico	Paranavaí, Paraná	890/20/90	1.58 × 10 <sup>6</sup>	This study
Lixisols/Argissolo Vermelho abrupto	Paranavaí, Paraná	930/10/60	2.37 × 10 <sup>6</sup>	This study
Arenosols/Neossolo Quartzarênico	Paranavaí, Paraná	950/20/30	2.51 × 10 <sup>6</sup>	This study

<sup>(1)</sup> IUSS Working Group WRB (2006) and *Sistema Brasileiro de Classificação de Solos* (Santos et al., 2013).

to Bt horizon below of E-horizon, generation of lateral subsurface flow, the low clay content, sand grain size, and slope.

Through the laboratory experiment we were only able to test the intrinsic soil properties. Other studies carried out in field conditions, above reported, that there was too much contextual effect and certain factors were not easy to isolate. These include superficial roughness, root mechanics effects, soil compaction, slope, soil moisture, etc. However, they were realistic regarding the field conditions in comparison to the present study. However, previous studies on the Caiuá Sandstone Formation have provided a few physical explanations for the soil erodibility response along the entire catena.

Here, we demonstrated clearly for the first time that there are differences in the erodibility across the catena among the three soil types. In addition, cassava crop on the conventional tillage system is prone to intensive use of heavy machinery. However, it was not straightforward to determine the effect of deep plowing on the superficial horizon degradation of Lixisols. Perhaps part of the E-horizon was being brought up to the surface due to soil erosion and tillage processes. The leached E-horizon is poor in clay and is enriched with sand of different grain sizes (particularly fine sand). For this reason, the interrill erodibility of the Lixisols was more similar to Arenosols than Ferralsols.

Overall, the soil distribution along the catena system is dominated by approximately 60 % of Ferralsols, 30 % of Lixisols, and 10 % Arenosols. Thus, farmers and stakeholders should be cautious about applying a homogeneous tillage strategy from the summit to the footslope. Finally, good conservation tillage practices for cassava production in the tropics are available (Fasinmirin and Reichert, 2011).

## CONCLUSIONS

The total soil loss for Ferralsols and Lixisols in both rainsplash and sheetwash processes are similar. For Arenosols, soil loss is higher in both interrill subprocesses. The three soils showed differences in the soil particles detached. The topsoil sand fraction and proportion seem to be critical to the hydro-erosive response.

The maximum soil interrill erodibility increased along the catena from Ferralsols (located at the hillslope summit) to Arenosols (at foot-slope). The Lixisols topsoil erodibility is more like that of Arenosols than to that of Ferralsols.

The farmers and stakeholders should be cautious about applying a homogeneous soil use and tillage system from the summit to the foot-slope along a catena with different sandy soils.

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