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Application of growth rings and scars in exposed roots of *Schizolobium parahyba* as a tool for dating geomorphic processes in the State of São Paulo, Brazil

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ABSTRACT

Water erosion is an important degradation process, which results in loss of soil, reduction in agricultural productivity, and causes severe environmental impact. Dendrogeomorphology has methods in which the structure of the wood of the stem and roots of tree and shrub species affected by sediment deposition or by root exposure is analysed, to establish the chronology of erosive events. The objective of the present work was to describe the modifications and scar formation in *Schizolobium parahyba* growth rings, attributed to the effect of roots exposure for determining the first year of exposure. The study area presents erosion features, such as gullies, with the consequent exposure of tree roots. The growth rings and the scars formed by the flow of water and soil particles were analysed in cross-sections of exposed roots to date the erosion processes. This paper demonstrates the potential of *S. parahyba* for dendrogeomorphological studies, validating dendrogeomorphology as a research tool in tropical climate. Scars used for erosion dating in cross-sections have been proven as good indicators of geomorphic processes. The relevance of this work is to become the first attempt in tropical regions to date erosion processes using dendrogeomorphological techniques on exposed roots.

1. Introduction

Water erosion is responsible for the degradation of one billion hectares of soil on the planet causing damages estimated at US$ 400 billion/year, representing the costs of recovery plans for degraded areas and loss of productive potential of the soil (Lal et al., 1998). The rainfall indices for countries with tropical climates are high and concentrated in specific periods of the year, making rainfall one of the principal causal agents that accelerates the soil erosion processes (Guerra et al., 2010). The process of water erosion begins with precipitation and is characterised by the disintegration of soil aggregates and the running-off of surface water. The literature reports many traditional methods for the measurement and estimation of soil erosion rates, which sometimes were successfully used (Xinbao and Walling, 1990; Martínez-Casasnovas et al., 2002; Boix-Fayos et al., 2006). However, the high cost and long-time frames needed for the traditional methods may be the primary reasons for the use of the dendrogeomorphological approach (Chartier et al., 2009). Dendrogeomorphology, referring to the application of plant ecology and dendrochronology to research in the field of morphogenic and morphochronological geomorphology (Alestalo,1971), is especially powerful in studies of landscape morphodynamics and morphochronology, where, in comparison to other traditional techniques, it has the advantage of possessing annual resolution. In dendrogeomorphology, the anatomical structure of the wood and the growth rings of the roots of trees and bushes exposed to soil erosion processes are analysed. Through this information, it is possible to obtain the patterns of soil erosion or deposition, values for the mean rate of soil erosion, as well as indicators of the impact of extreme rainfall events (Bodoque et al., 2005; Chartier et al., 2009; Bodoque et al., 2011; Ballesteros-Cánovas et al., 2013).

Most of the dendrogeomophological studies have been restricted to the trees from temperate climate zones (Stoffel et al., 2013), whose roots (and stems) show distinctive growth rings, arising from the contrast between the seasons of the year. However, the results of many

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studies have demonstrated dendrochronological potential in certain tree species of tropical and subtropical climate zones. These rings result from intermittent variations in the pace of growth (Ridder et al., 2013; Ohashi et al., 2014; Vlam et al., 2014) caused by the seasonality of the cambium activity induced by climatic variations (precipitation, temperature, photoperiod).

The growth rings of the stem and roots are efficient indicators for the dating of geomorphic events, such as soil erosion processes, which leave evidence in the form of scars, eccentricity and other deformations of the wood (Diez-Herrero et al., 2007; Stoffel and Bollschweiler, 2008; Chartier et al., 2016). Wounds in the region of the bark and the wood are commonly recorded for trees affected by geomorphic processes (Stoffel and Bollschweiler, 2008). Scars in exposed roots have been demonstrated chronological coincidences with the first year of wood anatomical changes after exposure (Chartier et al., 2016). The occurrence of scars in exposed roots has been previously demonstrated as an accurate indicator of the first year of the exposure (Carrara and Carroll et al., 1979; Chartier et al., 2016) and past geomorphic process activity (Stoffel and Corona, 2014).

The aim of this study was to describe the modifications and scar formation in *Schizolobium parahyba* growth rings, attributed to the effect of roots exposure in a Brazil southeast forest. In this paper, we present the use of a tropical tree species in the analysis of scars present in exposed roots at different position transversally distributed across a gully for determining the first year of exposure. This approach could be particularly useful for monitoring the effects of land management practices on water soil erosion. The present study is the first attempt to apply the analysis of growth rings and scars in exposed roots of tropical trees.

2. Study area and specie

The study was carried out in the Tupi Experimental Station, located in the county of Piracicaba, State of São Paulo, Brazil (47° 32′ 30″ W and 22° 43′ 21″ S; Fig. 1). The landscape is characterised by altitude that ranges between 505 and 565 m, with slopes varying from 12 to 57%. The climate is of type Cwa (Köppen classification), humid tropical, with wet summers and dry winters (Alvares et al. 2013a). The period from December to February is the wettest, with an average of 610 mm of rainfall, while the period from June to August is the driest, with an average of 101 mm of rainfall; the average total precipitation is 1275 mm/year. The mean annual temperature is 21.4 °C, with annual maximum mean of 28.2 °C and annual minimum mean 14.8 °C (Alvares et al. 2013b). The climate displays a characteristic seasonality, with the dry season having a rapid onset, while the entrance into the wet season is gradual.

Up until 1949, the Tupi Experimental Station saw agricultural use, with the cultivation of various crops (cotton, coffee, and sugar cane). After this period, the area was reforested with both exotic and native species. Currently the area shows signs of advanced water soil erosion, observed as rill, gully, and subsurface erosion. In this scenario, gullies are the most frequent landform due to soil erosion in the selected area and are the primary cause of the exposure of roots, although the arboreal vegetation is dense (Fig. 2). The study area is characterized by a hilly landscape made up of low-cohesive soils derived from sandstones belonging to the Perm-Carboniferous Itararé Group. This group presents a high degree of lithological complexity, due to the alternation of materials from different local sedimentation environments (Vidal-Torrado and Lepsch, 1999). Moreover, there is evidence of geological faults near the study area, which, according to Vidal-Torrado and Lepsch (1999), must be prior to the deposition process since it cuts different types of sediments. The soil was classified as Typic Haplustults (Soil Survey Staff, 2010). Soils have a depth of approximately 1.7 m. A and E horizons are moderately well-drained and have sandy loamy texture with clay content less than 10% and sand contents between 70% to 80%. In depth, Bt horizons, there is an increase in clay content with values ranging from 20% to 22%, and sand content from 60% to 70%. Consequently, the soil texture is classified as sandy clay loam (Bovi et al.,

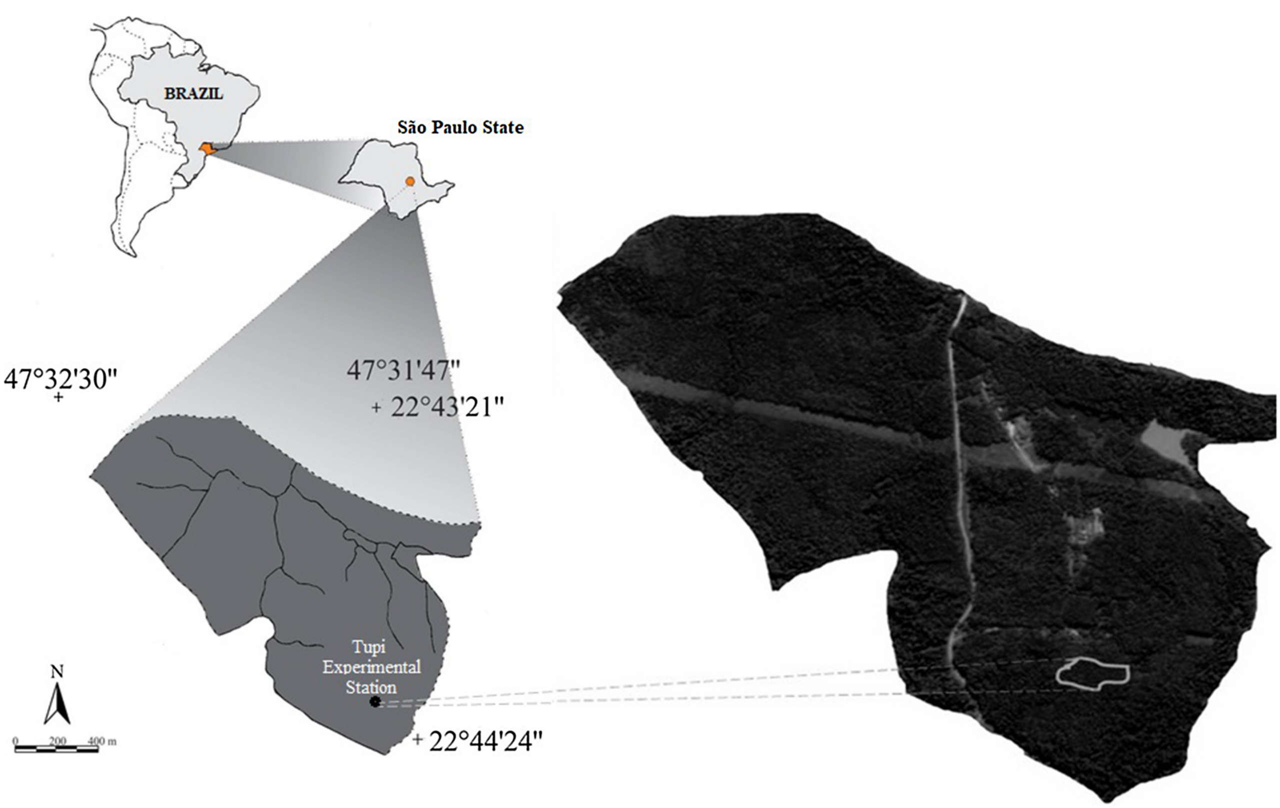

Fig. 1. The study area, located in Tupi Experimental Station, county of Piracicaba, State of São Paulo, Brazil.

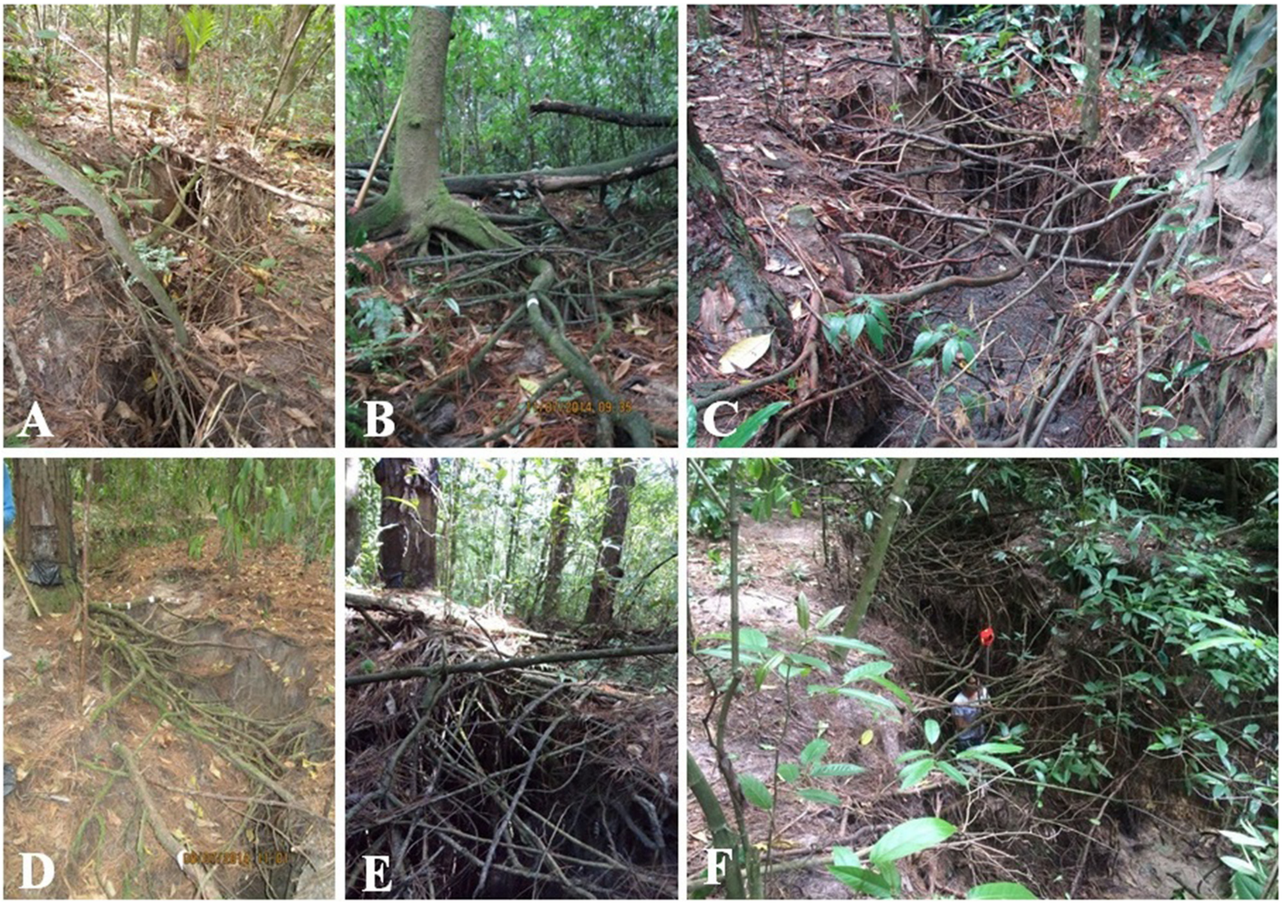

Fig. 2. Photographs of the study area showing roots exposed by water erosion from which cross-sections were collected: A to F: Gullies with roots exposed by soil erosion formed on slopes in the Tupi Experimental Station, Brazil.

2017). The bulk density is 1.5 $Mg\,m^{-3}$ and 1.76 $Mg{\cdot}m^{-3}$, and the total porosity 0.4 $m^3{\cdot}m^{-3}$ and 0.3 $m^3{\cdot}m^{-3}$, respectively, for surface and subsurface horizons (Bovi, unpublished results).

Trees of *Schizolobium parahyba* (Vell.) Blake - Caesalpinaceae were selected for the study. This is a native species of the Atlantic Rain Forest, which forms annual growth rings in the stems (Tomazello Filho et al., 2004; Lisi et al., 2008; Marcati et al., 2008; Callado and Guimarães, 2010; Costa et al., 2015). The trees of *S. parahyba* originate from natural regeneration by seed, mainly transported by anemochory (Turchetto-Zolet et al., 2012).

3. Material and methods

3.1. Field sampling procedure

We selected six trees of *S. parahyba* that presented 11 exposed roots due to soil erosion processes, together with approximately 30 buried roots from 14 trees without evidence of soil erosion. The trees were randomly distributed and ranging in age from 15 to 44 years for the trees not affected by erosion and from 29 to 39 years for the trees with exposed roots. All the trees of this specie located in the study area were collected.

In June 2012, one or two buried roots per tree were sampled from all the trees (affected and not affected by erosion processes). In addition, for each tree affected by soil erosion, one or two exposed roots were also sampled.

From each selected root (buried and exposed), we collected 5 cross-sections (2 cm wide) by serial-sectioning 10–15 cm apart, approximately. In the case of the exposed roots, the importance of studying various slices of the same root distributed transversally across the gully was done considering that one root can yield information about multiple erosion events, depending on its position relative to the gully.

Cross-sections of the roots were obtained with a saw. Root samples were taken at a minimum distance from the stem to avoid anomalies in the growth pattern because of the mechanical stresses exerted by the stem base (LaMarche, 1968; Fayle, 1976; Gärtner, 2007). The distance between the upper part of the exposed root and the current level of the soil was measured and graphs were constructed to determine the specific root location in relation to the gully (Fig. 3).

3.2. Laboratory methods and data analysis

In all cases, root cross-sections were allowed to air-dry for approximately 30 days and then sanded sequentially with 60 to 1200 grit sanding belts. Three or four radial lines were laid down on each polished root section, with the aid of a stereoscopic microscope, and then the cross-sections were scanned at a resolution of 1200 dpi. The growth rings widths were determined from the digital images with the software Image-Pro Plus (version 4.5.0.29). Additionally, for the anatomical characterization of the growth rings and scars, one histological thin section (15–20 microns) was made of one sample of an exposed root, using a microtome, according to the methodology proposed by Johansen (1940) and SASS (1951).

Visual dating was performed from ring width series of buried and exposed roots using standard dendrochronological methods (Stokes and Smiley, 1968). The quality of this crossdating was verified by means of the COFECHA program (Holmes, 1983), where the annual growth series were filtered with a cubic spline function for a period of 32 years, each one of them being divided into 20-year segments with an overlap of 10 years.

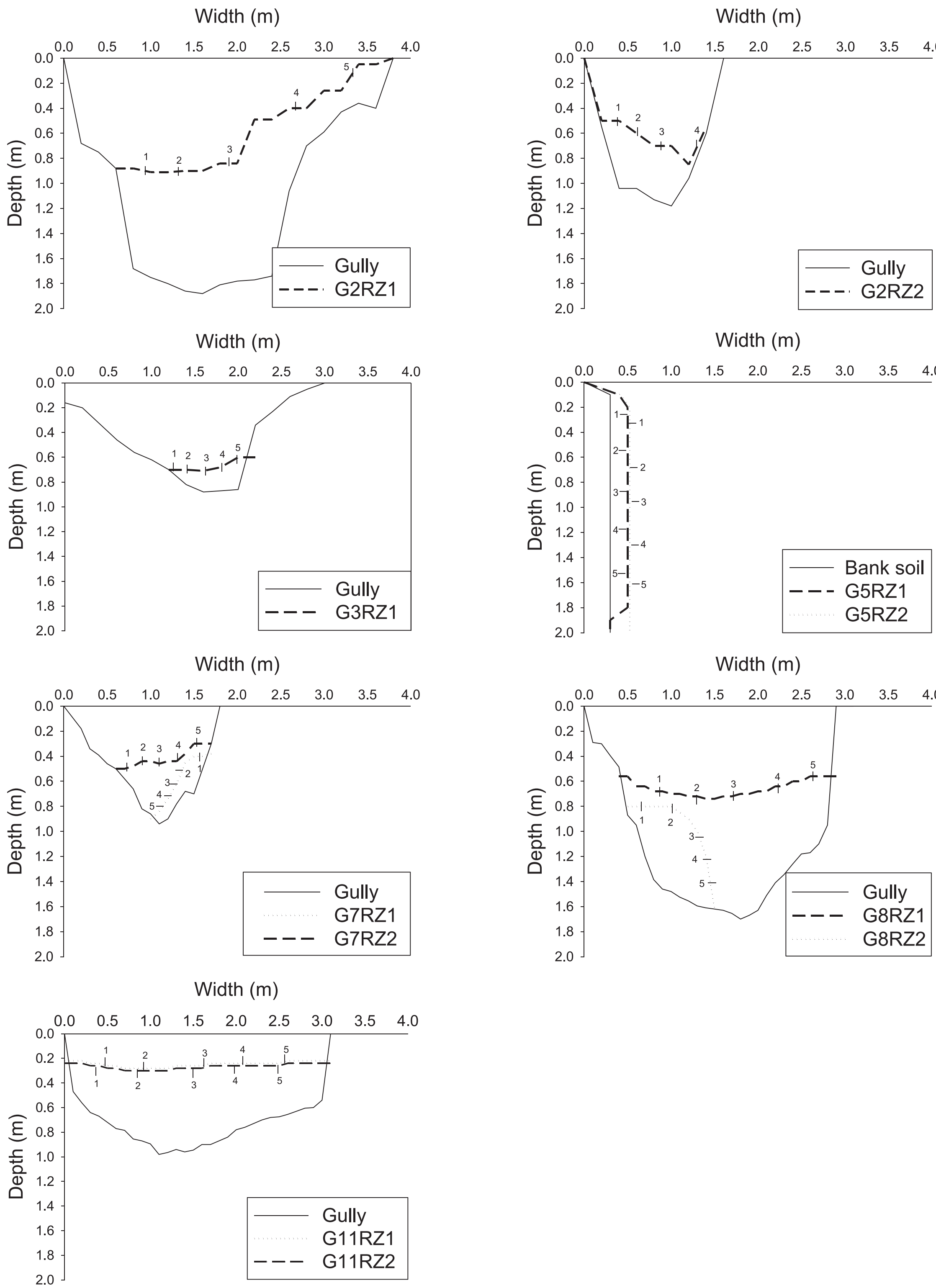

Fig. 3. Cross-section through gullies showing the locations of the exposed roots, from which samples were collected for the study. The numbers in the roots indicate the cross-section studied.

Two growth ring master series were constructed: one for the exposed roots and the other for the buried roots. Some exposed roots were very eccentric, and the series of their growth rings did not correlate with other series. Consequently, they were eliminated from the final chronology. Roots that did not show correlation are indicated in the results.

The dating of the year of exposure of the roots was based on the scars present in the cross-section of exposed roots (Fig. 4). The year of formation of the first innermost scar was considered to be the first year of the exposure. Finally, all the scars present in the cross-sections of the exposed roots were dated and these were related to winter and summer precipitation. The precipitation data was obtained from the Meteorological Station of the University of São Paulo in Piracicaba, SP, Brazil (47° 38′ 00″ W and 22° 42′ 30″ S).

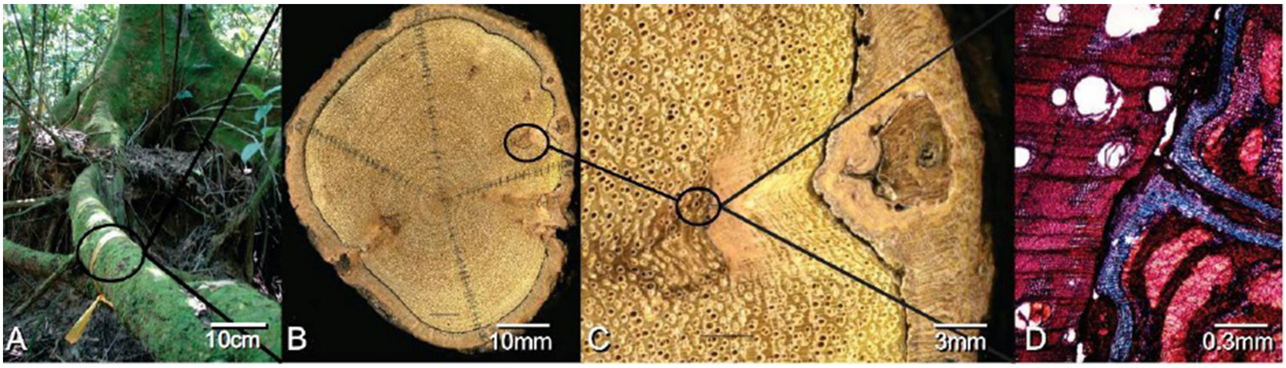

Fig. 4. Dating of scars in exposed roots: A) Collection of a sample of an exposed root; B) Cross-section of an exposed root, after sanding and polishing; C) Detail of scars in the cross-section of B– the presence of a scar in the xylem and another in the phloem of the root can be noted; D) Anatomical slide of the same section of exposed root, on the left: normal tissue, on the right: callus tissue formed after scarring.

4. Results

4.1. Wood anatomy of root and tree-ring width chronology

The root cross-sections of *S. parahyba* growth rings produced recognizable annual growth rings, demarcated by a thin marginal parenchyma band (1–3 cells) and thick-walled and radially flattened latewood fibres. In addition, a subtle reduction in the diameter of the vessels, mainly solitary, can be observed in the growth rings limits (Fig. 5A–C).

High intercorrelations values and mean sensitivity of chronological series was observed for exposed and buried roots. Cross-dating technique showed significant intercorrelations values in the exposed (0,611, $P < 0.01$, $n = 46$ dated series of 8 roots of 5 trees) and buried roots (0.591, $P < 0.01$, $n = 53$ dates series of 11 roots of 9 trees), revealing the presence of a synchronic radial growth among the ring width series. The dendrochronological analysis indicated that the roots of the examined trees of *S. parahyba* had ages varying from 10 to 35 years (Fig. 6).

The mean sensitivity (0.452 for the exposed roots and 0.438 for the buried roots) can be applied as an indicative parameter that the trees are very sensitive to growth/site conditions and as a measure of the relative ease of cross dating.

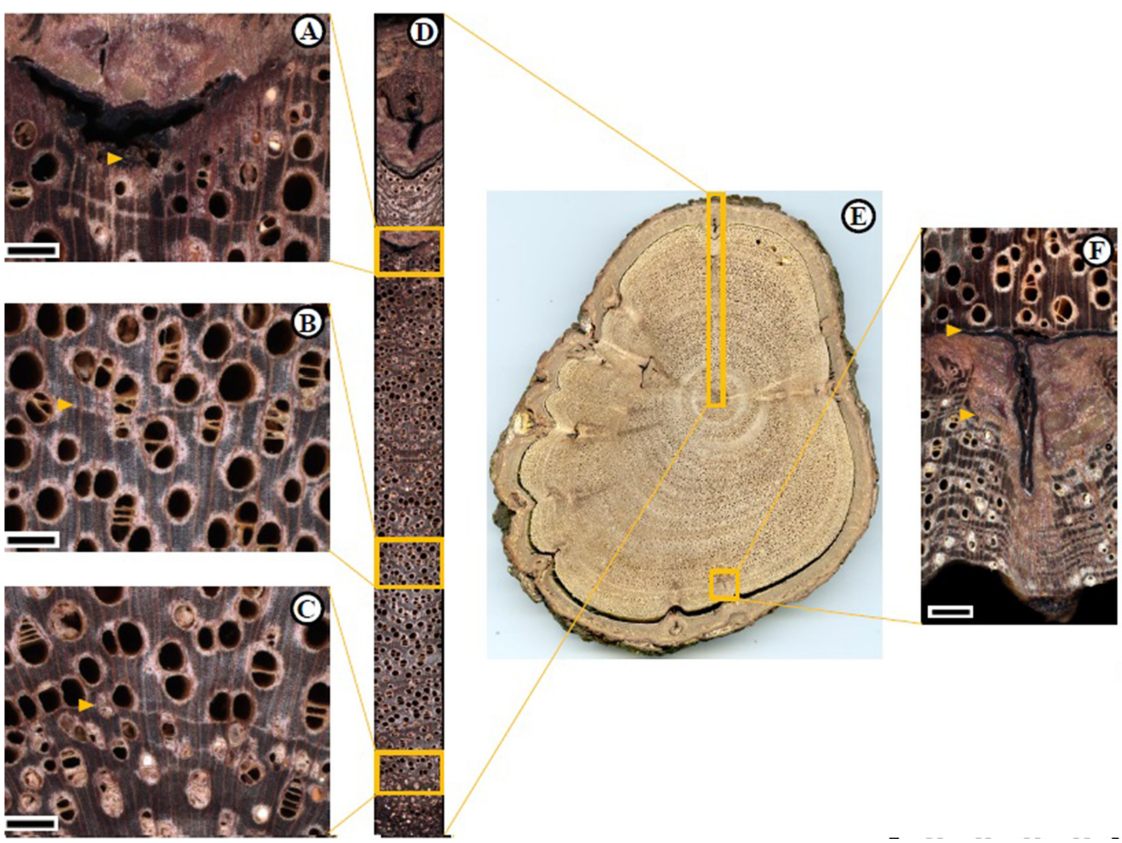

Fig. 5. Cross-sections from an exposed root of*S. parahyba*. (A): Anatomical characteristics of the wood and scar tissue formed in the peripheral region. (B): Anatomical detailed of the growth ring in the intermediate region of the root. (C) Anatomical characteristics of the growth ring in the innermost region of the root. (D) Radial section (core-bark) of a root sample. (E) Polished sample. (F) Anatomical features of the wood formed before and after the formation of scar tissue. Arrows indicate the beginning of the formation of scar tissue (A), the growth rings (B, C) and the beginning and end of the parenchymal tissue of the scar (E). Bars = 500 μm.

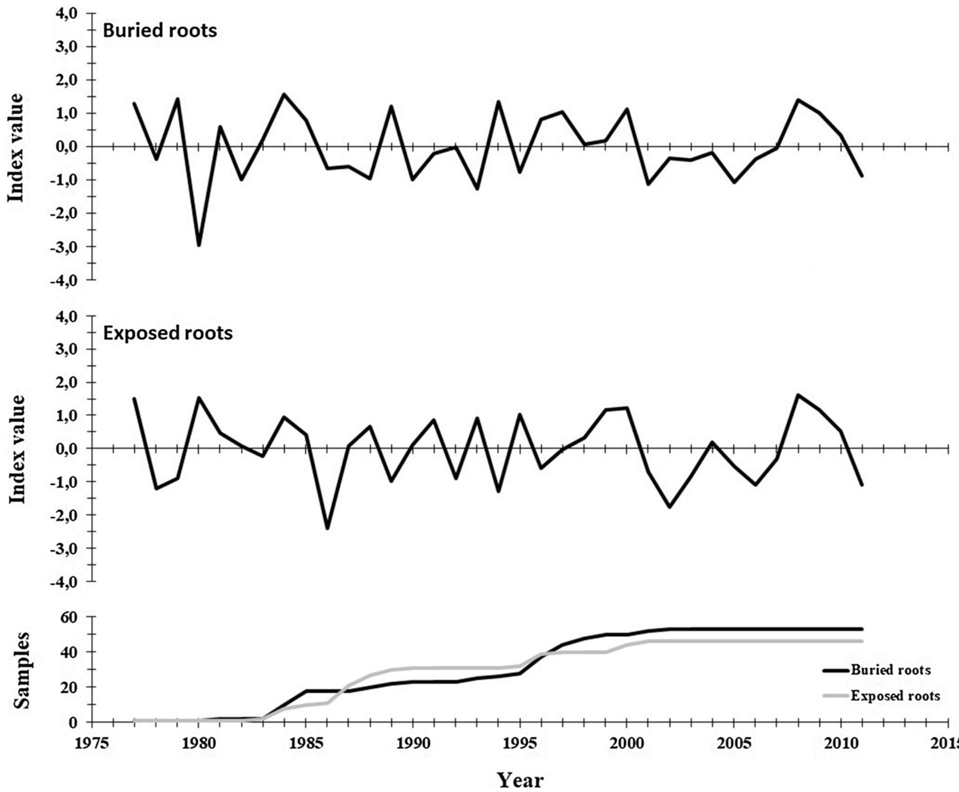

Fig. 6. Master dating series and sample size of buried and exposed roots of*Schizolobium parahyba* for the period.1977–2011.

4.2. The eccentricity of the growth rings and scar formation

All samples of exposed roots analyzed showed a change from concentricity to eccentricity of the growth rings and the presence of scars, unlike the buried roots samples, with little or no eccentricity and without the presence of scars (Fig. 5E, F and Fig. 7). The loss of concentricity of the growth rings happens concomitantly with the appearance of the first scar. In consequence, root cross-sections displaying serious deformations in growth rings were not added to the final chronology of the exposed roots. The main shortcoming was the excessive deformation observed in some roots. In consequence, some series of growth rings presented absent or very small growth rings, which made it difficult to measure and cross date. For some roots, due to high eccentricity or deformation, it was not possible to perform cross dating with other samples. These samples were eliminated from the statistical analysis.

The oldest scar in the cross section was used to date the first year of exposure of roots. The analysis of the scars on the exposed roots showed that they are distributed in a non-homogeneous way in the different cross sections analyzed from the same root (Fig. 8A and B). In some cases, such as P2 and P3 in root G8RZ1 (Fig. 8A), there are more and older scars in the cross-section present in the central part of the gully and, in other cases, such as P4 and P5 in root G11RZ1 (Fig. 8B), more and older scars are found in the cross sections near the edge of the gully. In the first situation, this demonstrates, that the initial flow concentration occurs in the middle of the gully, with later expansion towards the right or the left side with more recent scars. This behavior was observed in roots G5RZ2, G7RZ1, G8RZ1, G8RZ2 and G11RZ2 (Fig. 4). In the second situation, the initial flow occurs at the edge of the gully representing an older process with older scars as observed in roots G5RZ1, G7RZ2 and G11RZ1 (Fig. 4).

Table 1 represents the year of the first scar present in the analyzed cross sections, which in the present study represents the first year of root exposure. In some cross sections, scars were absent. However, in all of them the appearance of ring growth eccentricity was present. In some cases, for the same root, different dates of exposure were found in the

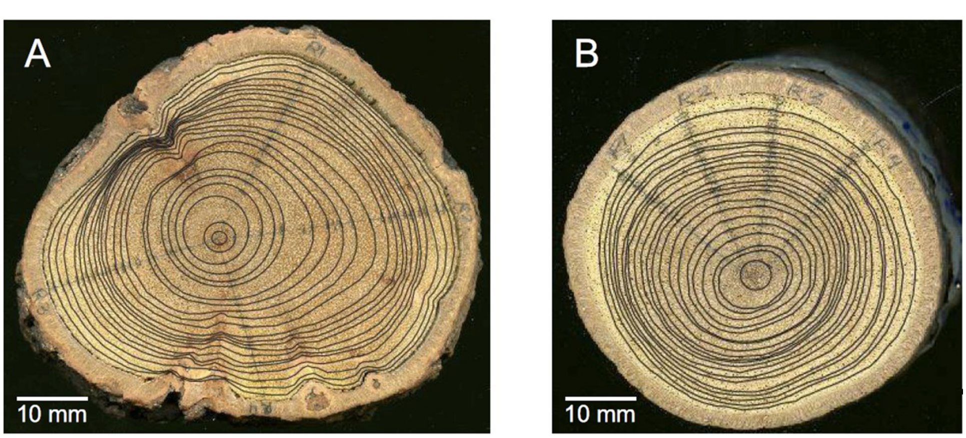

Fig. 7. Comparison of cross-sections of roots: A) Exposed root, with eccentric pith and eccentric growth rings formed after the first scars. The direction and side of impact of the erosive flux corresponds to the direction of flattening of the root and the portion where the greatest scarring has occurred, respectively. B) Buried root, with concentric pith and growth rings, no scar formation and no flattening.

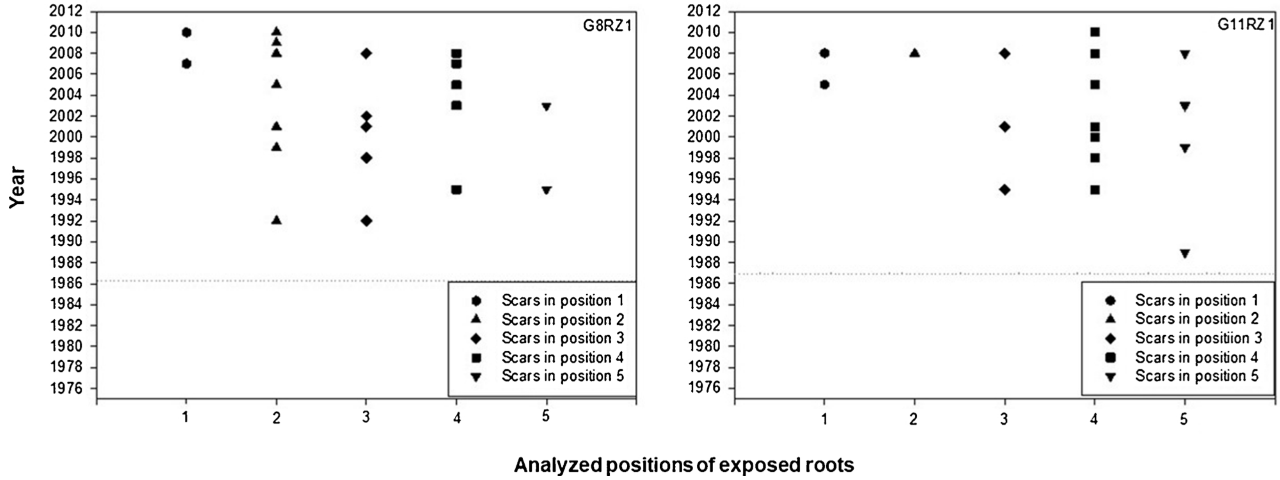

Fig. 8. Dated scars found in the root cross sections by year and positions analyzed.

Table 1
Years of the first scars in each slice along the exposed roots.

Tree	Root	Year of the first scar in each root slice				
		1	2	3	4	5
G2	RZ1	2006	2006	2006	2006	–
	RZ2	2008	–	–	–	
G3	RZ1	–	–	–	2006	2006*
G5	RZ1	2006	2006*	2010*	2010	2010
	RZ2	2000	2006	1999*	2000	2008*
G7	RZ1	–	2008	1999	–	–
	RZ2	-*	-*	1997	2006*	1995*
G8	RZ1	2007*	1992*	1992*	1995*	1995*
	RZ2	2008*	-*	1996	1995*	–
G11	RZ1	2005	2008*	1995*	1995*	1989*
	RZ2	1997*	1992	1989*	1991*	-*

* Represents root slice that showed significant correlation with the other root samples. The hyphen represents slice roots without scars.

different cross sections.

The first dated scars were related with the summer and winter rains (Fig. 9). The relation between the intensity of the summer rain and the appearance of the first scar may be noted. In this respect, Fig. 9 indicates that most of the first scars on each root were generated in the years when the summer rains were heaviest.

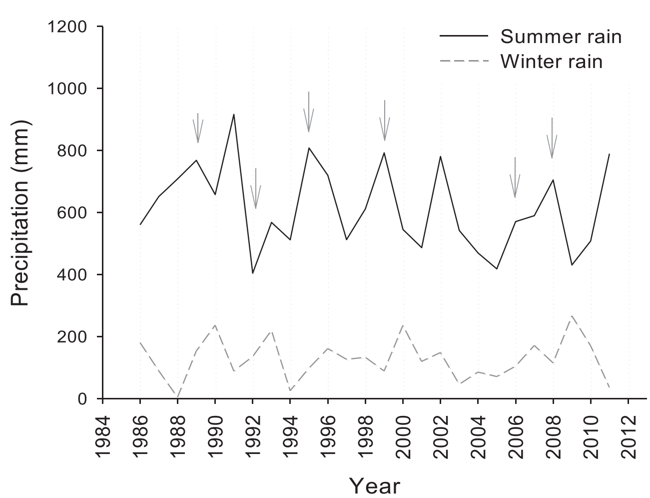

Fig. 9. Relationship showing the co-occurrence among the first scar in the exposed roots and (arrows) and the accumulated summer and winter precipitation along the years in the Tupi Experimental Station, São Paulo, Brazil.

5. Discussion

5.1. *Tree-ring width chronology and wood anatomy of S. parahyba*

Similarities in the roots growth ring width patterns were confirmed from the cross dating of *S. parahyba* growth rings. The reference chronology covered the period between 1977 and 2011 for the exposed and unexposed roots. Cross-dating technique showed significant intercorrelations values in the exposed (0,611, $P < 0.01$, $n = 46$ dated series of 8 roots of 5 trees) and buried roots (0.591, $P < 0.01$, $n = 53$ dates series of 11 roots of 9 trees). This correlation indicates a high percentage of common variability among these trees, which is a consequence of the influence of a dominant factor overgrowth. The high synchronicity of the growth rings series in the exposed and buried roots demonstrates that a limiting growth factor affects the wood formation over the years (Heinrich and Banks, 2006). Although a relative small number of trees were used in the present dendrogeomorphological study, a considerable number of samples were cross dated (46 and 53 for exposed roots and buried roots, respectively) indicating the robustness of the master dating series of each group of trees (Fig. 6).

The growth ring boundaries were very easily distinguished, well defined and wide which improves visualization; besides, the complete analysis of the cross section facilitates the detection of possible timing errors (Malik, 2008). The anatomical characteristics that identify the growth rings of *S. parahyba* roots are the same described by other authors that studied these characteristics in the stem (Lisi et al., 2008; Marcati et al., 2008; Callado and Guimarães 2010).

5.2. *The eccentricity of the growth rings and scar formation related to erosion dynamics*

We observed the presence of eccentricity in the growth rings in the exposed roots, in contrast to the concentricity found in the buried roots. The beginning of the eccentricity pattern in the growth ring was coincident with the year of the first scars after exposure. This result was coincident with early dendrochronology studies (Ballesteros-Canovas et al., 2013, Stoffel et al., 2013), that describes the eccentricity pattern as one of the most common and visible characteristics of change after exposure. Moreover, it suggests that its occurrence could be due to the dramatic variation of atmospheric conditions after root exposure (temperature variations, reduction of soil cover pressure, light, etc.) and the mechanical stresses that the root undergoes once exposed (Gärtner et al., 2001; Bodoque et al., 2005; Gärtner, 2007).

From the range of mechanical self-optimization, dendrogeomorphologists have used in particular eccentricity and reaction wood as indicators of environmental conditions (Schweingruber, 2007). Any datable change in the tree ring-growth pattern of exposed roots indicates a particular type and intensity of geomorphic event (Gärtner and Heinrich, 2013). In general, dendroclimatologists consider extreme growth changes and reaction wood as local interferences that cover the regional climatic signal. In this sense, the continuing action of rainwater and runon/runoff, sweeping soil particles and other detritus along a rill or gully erosion over a period of years, have induced significant alterations in the morphology of the exposed roots, with a characteristic horizontal flattening in the direction of the water flow. On the contrary, the buried roots, protected by the soil, present a circular section with concentric growth rings and the absence of scars, proving that the deformations and formation of scars in the exposed roots are from the effects of particle and/or detritus collisions carried by runoff (Fig. 7).

After the occurrence of a soil erosive event and the consequent root exposure there is an evident increase in the eccentricity of the growth rings. Roots, when exposed, lose ring concentricity and rapidly transition from a concentric root growth to an eccentric growth. However, root eccentricity may begin to occur before root exposure, due to soil instability in areas susceptible to erosive processes, leading to the formation of the eccentricity of these growth rings before exposure. Also, the presence of tabular roots, associated to mechanical support to *S. parahyba* trees (Fig. 4A), may be causing ring eccentricity in some root samples. Thus, for dating the first year of exposure, scar dating was essential, since only exposed roots have scars and, consequently, being a factor necessarily related to exposure.

The scar tissue formed after injury and observed in the xylem and phloem is structurally characterized by the presence of a thick parenchymal cell layer with a thin and slightly lignified cell wall, this is followed by a more robust structure classified as a chaotic callus tissue (Fig. 5F). The scars and calluses on the roots and tree stems are formed as the result of injuries to the cells of the cambium caused by soil particles, stones, fire, ice, and other agents (Winchester et al., 2007; Malik and Matyja, 2008, Chartier et al., 2016). The injuries and chaotic callus tissue is commonly regarded as a valuable and reliable indicator of past geomorphological process activity (Stoffel and Corona, 2014)

A higher frequency of scars was detected in the portion of the root that intercepts the water flow, a result of the impact caused by the flow of detritus, inducing injuries to the cambium cells. The position of the scars along the root could help explain soil erosion dynamics within the gullies. Some samples (for example P2 and P3 in root G8RZ1, Fig. 8A) located in the middle part of the root, in the center of the gully, present a higher number of scars comparing to cross sections that are located closer to the edges of the gully. In other cases (for example P4 and P5 in root G11RZ1, Fig. 8B), the scars were concentrated in the samples located at the edges of the gully. This can possibly be explained by the initial runoff that was concentrated in a linear stream eroding the middle of the gully first, resulting in older and higher number of scars in root samples in this position; and as the erosion process advanced the gully widened, resulting in younger and fewer scars in root samples closer to its sides (Fig. 8A). In other cases, the process begins and deepens in one position, and its lateral expansion occurs only towards one side (Fig. 8B). Erosion processes contributed to the gully's deepening and upstream head cutting advance. After a certain period, the deepening process can slow down, and the widening of the gully predominates as the erosion process continues (Guerra et al., 2010).

This differentiated distribution of scars along the cross sections of the same root depends on the formation dynamics of the gully, which is a complex system developed by the action of gully erosion and piping (Faulkner, 2013; Verachtert et al., 2013). Scar formation in different years and positions from the same root emphasize the importance of the study of various cross-sections along the same root. So, to infer erosion rates for example, if samples were only collected in the middle or in a specific portion of the gully, this could result in quantification errors.

Finally, scars in roots were compared with rainfall data. From the results, the first scars were formed in the years when the summer rains were heaviest (Fig. 9). Exceptions are the years of 2006 and 1992. In 2006, there was an atypical event, in which precipitation of 30 mm occurred during a period of less than one hour, accompanied by gusts of wind exceeding 100 $km\,h^{-1}$. The summer rain of 1992 was of low intensity. The evidences suggest that soil removal occurred in the years characterised by the highest volumes of summer precipitation, and this resulted in the initial uncovering of the roots by water erosion, and the formation of the first and innermost scars. Some authors already identified the relation between precipitation data with anatomic changes in the tree roots (Malik, 2008; Wrońska-Wałach, 2014). Similarly, the comparison between the scars and the rainfall data might help to confirm the accuracy of the root exposure dating.

Based on these results, it is possible to comprehend the cumulative effects of a sequence of high rainfall events, which result in the process of water erosion, and in the exposure and injury of tree roots, manifested as scars that can be dated through the growth rings. Beyond the alterations to the anatomical structure and external morphology of the roots, the growth rings and the scars, such as those observed for trees of S. *parahyba*, can be analysed and are important indicators for the study of the history of exposed roots and the dating of geomorphic processes. These findings make feasible the dating of geomorphological processes through the analysis of tropical tree roots. However, this study was based on scar analysis, future dendrogeomorphological research including other parameters, e.g. anatomical changes, should be done in tropical regions. The result of cross dating indicates the accuracy in dating the growth rings as well as the scars, inferring that localized erosion rates are highly accurate (Bodoque et al., 2011).

Furthermore, most studies related to dendrogeomorphology applied to erosive processes and exposed roots have been used in conifers species (Stotts et al., 2014). However, angiosperms have a more complex and specialized wood structure when compared to conifers and this feature can provide detailed information on the anatomical response of roots exposed to erosive events when compared to conifer species, highlighting the importance of angiosperms studies.

6. Conclusions

The present study is the first attempt to apply the analysis of growth rings and scars in exposed roots of tropical trees (*S. parahyba*) to water erosion processes. There is a known scarcity of dendrogeomorphology studies in regions with tropical climates. Results demonstrated that trees of *S. parahyba* have potential for studies applying dendrochronology and dendrogeomorphology revealing the presence of a synchronic radial growth among the ring width series. Results demonstrated the complementary dating of growth rings with scars to obtain a more reliable inference concerning the first year of exposition of the roots.

The analysis of different roots sections located in distinct positions of the same exposed root in the gully is fundamental. The results obtained from these sections brought different responses of the erosive process and its dynamics, in contrast to the analysis of only one cross-section that can lead to errors in dating, process comprehension and quantification of erosion rates.

We finally highlight that this methodology can also be applied to infer soil loss rates that can bring quantitative and qualitative information about geomorphological processes, suitable to understand the erosion dynamics and intensity. These results demonstrated that dendrochronology offers immense potential as a tool for the reconstruction of the erosion dynamics of tropical soils, mainly in areas where historical records do not exist.

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