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Diagnosis of the Accelerated Soil Erosion in São Paulo State (Brazil) by the Soil Lifetime Index Methodology

Grasiela de Oliveira Rodrigues Medeiros(1)*, Angelica Giarolla(2), Gilvan Sampaio(3) and Mara de Andrade Marinho(4)

(1) Instituto Nacional de Pesquisas Espaciais, Programa de Pós-graduação em Ciência do Sistema Terrestre, Centro de Ciência do Sistema Terrestre, São José dos Campos, São Paulo, Brasil.
(2) Instituto Nacional de Pesquisas Espaciais, Centro de Ciência do Sistema Terrestre, São José dos Campos, São Paulo, Brasil.
(3) Instituto Nacional de Pesquisas Espaciais, Centro de Ciência do Sistema Terrestre, Cachoeira Paulista, São Paulo, Brasil.
(4) Universidade Estadual de Campinas, Faculdade de Engenharia Agrícola, Campinas, São Paulo, Brasil.

ABSTRACT: The soil is a key component of the Earth System, and is currently under high pressure, due to the increasing global demands for food, energy and fiber. Moreover, the management of agricultural systems is often inadequate and ignores the agricultural suitability of lands, and particularly the vulnerability of soils. This paper demonstrates the application of the concept of the Soil Lifetime Index (SLtI) for the entire state of São Paulo, at a spatial resolution of 30 m. The SLtI methodology represents a tolerance criterion and a diagnostic tool to assess the level of soil degradation by water erosion, based on estimated soil loss rates and on an average soil renewal rate. Two approaches were applied to determine: i) the remaining time (years) until the *solum* (horizons A + B) is removed by water erosion to a critical depth of 1.0 m (original approach); ii) the remaining time (years) until the top 0.25 m of the nutrient-rich soil surface is removed by water erosion (new approach). Several areas in the state have reached a very critical soil depletion level, due to the predominance of consolidated agricultural activities, mainly of sugarcane and livestock production (as in the mesoregions of Ribeirão Preto, Bauru, Assis, Itapetininga and Araraquara). Only 35 % of the study area is in conserved state; 65 % of the study area is in the state of resource degradation, requiring intervention to diminish soil loss rates - and of this total, SLtI is zero in 1 and 0.25 % of the study area, respectively, for the original (critical depth of 1 m) and the new approach (0.25 m). It was estimated that at the current soil loss rates, within 100 years, 20,000 km^2 of the total area of the state of São Paulo (248,209 km^2) will have reached the critical depth of 1.0 m, and the top 0.25 m of the soil surface from an area of approximately 76,000 km^2 will have been completely removed if the current pace of resource exploitation is maintained.

Keywords: soil erosion modeling, soil loss rates, soil loss tolerance, USLE, GIS.

*** Corresponding author:**
E-mail: grasielarodrigues@gmail.com

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INTRODUCTION

Economic development based on farm land exploration over the past decades has taken a toll with severe consequences for the planet (Camargo et al., 2010; Bellacasa, 2015). Furthermore, projections of demands for food, fiber and energy indicate that the pressures on natural resources, particularly on soil, will be intensified beyond the resilience capacity of the planet, which could lead humanity into an even deeper ecological crisis (Rockström et al., 2009; Reid et al., 2010). One billion hectares of land in the world are already degraded and the ecosystem functions of 70 % of this total are severely compromised (Lal, 2003).

Thus, the intensive agricultural land use without taking the necessary precautions of management and conservation was cited as the main cause of the accelerated erosion which in turn creates the enormous challenge of taking into account preservation, economic growth and the sustainable use of ecosystems (Bertol et al., 2014; Bouma, 2014). In addition to soil and water degradation, erosion processes cause serious economic and environmental damage (Manzatto et al., 2002; Telles, 2010). Data published by the soil conservation section of the *Instituto Agronômico de Campinas/Agência Paulista de Tecnologia dos Agronegócios* in the 1980s indicated an annual soil loss of 130 million tons in the state of São Paulo, representing about 25 % of the soil loss throughout Brazil (Bertoni and Lombardi Neto, 2012). These soil loss data were updated by Medeiros et al. (2016) and the authors reported that the annual loss in the state reaches about 600 million Mg yr^{-1}. Moreover, it is estimated that the erosion tolerance limits are exceeded in 80 % of the cultivated areas (CDA, 2014).

A factor further complicating the control of the erosion process is that, in spite of different degradation levels in the agricultural areas, there are often no immediate impacts on crop yield, since some aspects of soil degradation by erosion can be compensated by management, e.g., replacement of minerals by fertilizers (Telles, 2010); for some time, agricultural management can mask the decrease in soil quality. Therefore, associating soil degradation with productivity loss is a complex and sometimes impossible task (Stocking, 2003). For different regions of the world, studies addressed the establishment of a mean value of crop production loss associated with erosion (Oyedele and Aina, 1998; Schumacher et al., 1999; De la Rosa et al., 2000; Stine and Weil, 2002; Wieber, 2003; Bakker et al., 2004; Telles, 2010; Duan et al., 2011; Zhao et al., 2012). For example, Bakker et al. (2004) stated that a loss of 0.10 m of the soil surface in agricultural ecosystems would cause a mean loss in crop productivity of 4 %. In Brazil, for several reasons, but mainly due to the complexity of tropical agricultural systems (Sparovek et al., 1993; Pugliesi et al., 2011), little evidence was found for this relationship. For an *Argissolo* at an experimental site in the region of Santa Maria/RS, Albuquerque et al. (1996) found a direct relationship between the horizon thickness and maize grain yield, i.e., a decrease of 43 kg ha^{-1} for each 0.01 m of lost surface layer.

Thus, the soil loss tolerance concept (T) as was defined as “the maximum annual soil erosion rate that still allows a high level of crop productivity” (Wischmeier and Smith, 1978) and it has been used to interpret soil loss rates. For the state of São Paulo, T assumes values from 4.5 to 13.4 Mg ha^{-1} yr^{-1} and 9.6 to 15 Mg ha^{-1} yr^{-1} for soils with textural B and B Latosolic, respectively (Lombardi Neto and Bertoni, 1975). For shallow soils are considered tolerable soil losses average 2 to 4 Mg ha^{-1} yr^{-1} (Bertoni and Lombardi Neto, 2012). Generally, for soil deep, permeable and well drained, soil loss tolerance considers that an average loss of up to 12.5 Mg ha^{-1} yr^{-1} is tolerable.

The Soil Lifetime Index - SLTI (Weill and Sparovek, 2008), developed from studies of Stamey and Smith (1964), Skidmore (1982) and Sparovek and Jong van Lier (1997), and from the operational sustainability concept proposed by Hansen (1996) and Kruseman et al. (1996), is in turn an operational criterion developed from the concept of soil loss tolerance and described as a time-related function.

At the conceptual level, the SLTI is a tool with high quantitative diagnostic potential in relation to the current approaches of Environmental Sciences. Many scientists engaged in predicting the needs and future of Soil Science believe that addressing soil-related issues in a conventional way, focusing research on agricultural goals and a high production capacity, has become inappropriate in view of the current problems of the planet, particularly of the soil (McDonagh, 2014; Bellacasa, 2015). The focus of traditional approaches has become unsatisfactory as the environmental context and needs have changed. Significant climatic fluctuations have occurred on the planet (Parmesan et al., 2013), which may be exacerbated in the near future by the increase in the world population and the depletion of natural resources to meet the demands for food, food and energy. Considering this environmental framework and forecasts for the future of the planet (Bouma, 2014), the SLTI can be an essential diagnostic tool underlying measures of soil protection and erosion control, to ensure a habitable planet and supplies for the current and future generations.

The original approach of SLTI is based on the "remaining time" in years until a previously defined situation of permanent impact is reached. This condition occurs when soil degradation by erosion reduces the soil thickness until a depth considered critical is reached. Thus, this methodology can be understood as a spatially explicit measure with diagnostic potential at the soil sustainability level. The studies of Weill and Sparovek (2008) and Rocha (2013) are examples of the application of the original SLTI concept on the hydrographic and regional basin-scale, respectively, where results were obtained for the planning of agricultural use and management in the short, medium and long-term for the study sites.

Describing a soil as depleted only when the profile reaches a certain depth, however, may lead to misinterpretations. Long before a soil is reduced to a depth considered critical, the area may be degraded and abandoned mainly due to the partial or total loss of its surface horizons, which is the portion rich in soil organic matter. This soil surface layer is the primary source of nutrients, regulates hydrological processes, is sensitive to changes by soil management (Gregorich et al., 1994) and its reduction is directly related to an increase in susceptibility to erosion.

The application of the SLTI methodology to calculate the remaining time until the occurrence of topsoil loss is a complementary indicator to the original SLTI approach and appropriate from the point of view of establishing planning horizons for the promotion of soil conservation and sustainability of agricultural productivity. This new approach focuses on highlighting the most critical situations of very fast loss of this nutrient-rich topsoil layer, associating the uses and translating the results into information that can support public policies to stimulate a shift towards more conservation-oriented managements. Therefore, the two approaches are complementary for including different information for a sustainable planning.

Based on the foregoing, the purpose of this study was to calculate the SLTI for the state of São Paulo by: i) the original approach, which calculates the remaining time until the soil reaches a critical depth, determined as 1 m in this study, and ii) a novel approach that indicates the remaining time until the surface layer of 0.25 m is completely removed by erosion.

MATERIALS AND METHODS

Study area

This study addressed the whole area of the state of São Paulo (Figure 1) (between the parallels 19° 50′ S and 24° 30′ S and the meridians 44° W and 53° 30′ W), with an area of 248,209.4 km^2. From the standpoint of soil conservation, the heavy soil exploitation

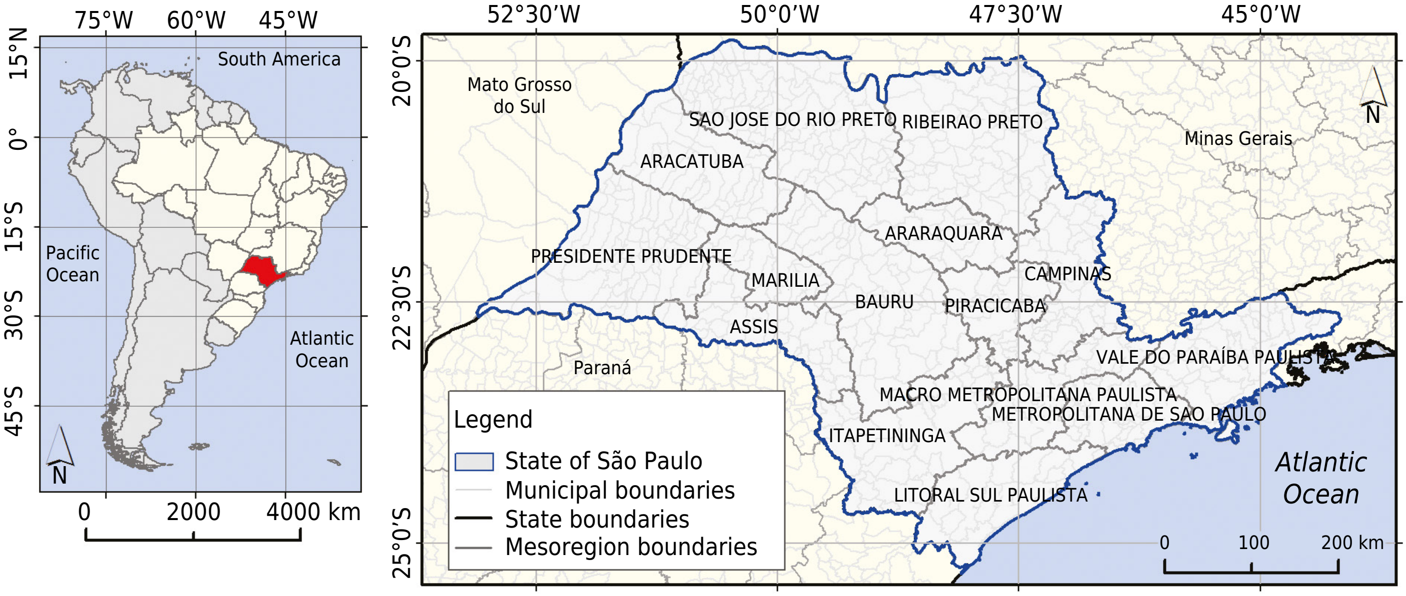

Figure 1. Localization of the study area, state of São Paulo (Brazil).

by intense agricultural use has damaged many areas in the state (Medeiros et al., 2016). From the biophysical point of view, the state is part of the regional complex Southeast which comprises a wide variety of soils, for being located in the transition region between the semi-arid ("Drought Polygon", in the North of Minas Gerais) and humid climate (coastline and mountains, including the Serra do Mar and Serra da Mantiqueira), as well as an extensive sedimentary region in the highlands to the West of the mountainous areas (Lepsch, 2010).

The climate of the macroregions of São José do Rio Preto, Araçatuba, Presidente Prudente, and part of Ribeirão Preto in the southern part of the state as predominantly tropical with dry winters (Aw). In the South-central part with the mesoregions of Assis, Bauru, Itapetininga, Marília and part of the southern coastline and Macro metropolitan region of São Paulo, the climate is mostly subtropical humid oceanic, with no dry season and hot summers (Cfa); in the Northeast of the state, in the mesoregions of Araraquara, Ribeirão Preto, Piracicaba, and Campinas, the dominant climate is humid subtropical, with dry winters and hot summers (Cwa); in the eastern region with the mesoregions of Vale do Paraíba Paulista, Metropolitan and Macro Metropolitan region of São Paulo and part of the mesoregion of Itapetininga, the climate is mostly subtropical humid oceanic, with no dry season and with temperate summers (Cfb), and the climate along the coast is tropical with no dry season (Af) (Alvares et al., 2013).

Latossolos/Oxisols and *Argissolos*/Ultisols are the predominant soil types and are distributed across plateaus and the peripheral depression. The *Latossolos*/Oxisols are pedogenetically very well-developed, deep and unsaturated soils, whereas the *Argissolos*/Ultisols are also well developed, but their main distinguishing property is the textural gradient in the subsurface due to clay accumulation in the B horizon, which makes these soils erosion-prone. The mountainous region consists mostly of *Cambissolos*/Inceptisols and litholic *Neossolos*/Entisols and along the coast *Gleysolos*/Aquoll, *Histosolos* and *Fluvisolos*/Fluvents (Oliveira et al., 1999).

Cartographic material, basic data and programs

By the Geographic Information System (GIS) ArcGIS version 10.1 (ESRI, 2014), digital data were used as entries in the database, to perform the analysis and present the results, consisting of: 1) vector map of the soil use and cover in 2005, at a scale of 1: 100,000 (São Paulo, 2013) (Figure 2a); 2) soil density map with (spatial resolution of 1 km) of the International Soil Reference and Information Center (ISRIC, 2014) (Figure 2b); and 3) data of *solum* (A and B horizons) depth of 387 mapping units described by Oliveira (1999), representing the soil types of the state of São Paulo (Figure 2c). These specific soil depth data were spatialized with software ArcGIS and interpolated by the cokriging method using altitude as a secondary variable, resulting in a raster with a regular 30 m grid.

Methodology of the Soil Lifetime Index (SLtI)

This study considered the estimated soil loss rates (Mg ha^{-1} yr^{-1}) for the state of São Paulo at medium resolution (30 m), previously obtained by Medeiros et al. (2016) (Figure 3). The results were obtained by the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1965; 1978). The SLtI is applied in two methodological steps: the first, "Characterization of planning situations" addresses the planning of situations based on the ratio between the estimated soil loss rates and the assumed soil renewal rate; the second, "Soil Lifetime Index" calculates the SLtI according to the original approach described by Weill (1999) and Weill and Sparovek (2008), and proposes the calculation for a novel approach that estimates the remaining time until a topsoil layer of 0.25 m is eroded.

Characterization of planning situations

Initially, the soil loss rates (A, in Mg ha^{-1} yr^{-1}) estimated by Medeiros et al. (2016) were converted into thickness of the lost soil layer (h, in mm yr^{-1}). This conversion was calculated from the bulk density (Bd, Mg m^{-3}) (Figure 2b), according to equation 1.

$$h = \frac{0.1 \times A}{B_d} \qquad \text{Eq. 1}$$

where h is the soil loss rate (mm yr^{-1}), A is the soil loss rate (Mg ha^{-1} yr^{-1}), and B_d is the soil density (Mg m^{-3}).

Thereafter, the net soil loss rate (h_L) was calculated as the difference between the soil loss rate (h) and the assumed soil renewal rate (r) of 0.2 mm yr^{-1} (Skidmore, 1982), as shown in equation 2.

$$h_L = h - r \qquad \text{Eq. 2}$$

where h_L is the net soil loss rate (mm yr^{-1}), h is the soil loss rate (mm yr^{-1}), and r is the assumed soil renewal rate of 0.2 mm yr^{-1}.

Based on the relationship between h and r, two planning situations were identified: i) Resource Conservation - occurs in places where $r > h$, indicating that there is no soil depletion; ii) Resource Degradation - occurs in places where $h > r$, indicating that the soil is being degraded by erosion (Weill and Sparovek, 2008). This result was related with soil depth and land-use data by GIS (ESRI, 2014) algebra maps, generating analyses for each of the categories indicated in the mapping of the planning situations.

Soil Lifetime Index (SLtI)

For the areas in the situation of Resource Degradation, the SLtI was calculated, indicating the remaining time (years) until the soil will reach a predefined critical depth ($D_{critical}$) according to the estimated erosion rates. The critical depth can be interpreted as a threshold, which means that, once reached, the resource is irreversibly degraded. In this study, we determined a critical depth ($D_{critical}$) of 1 m, in other words,

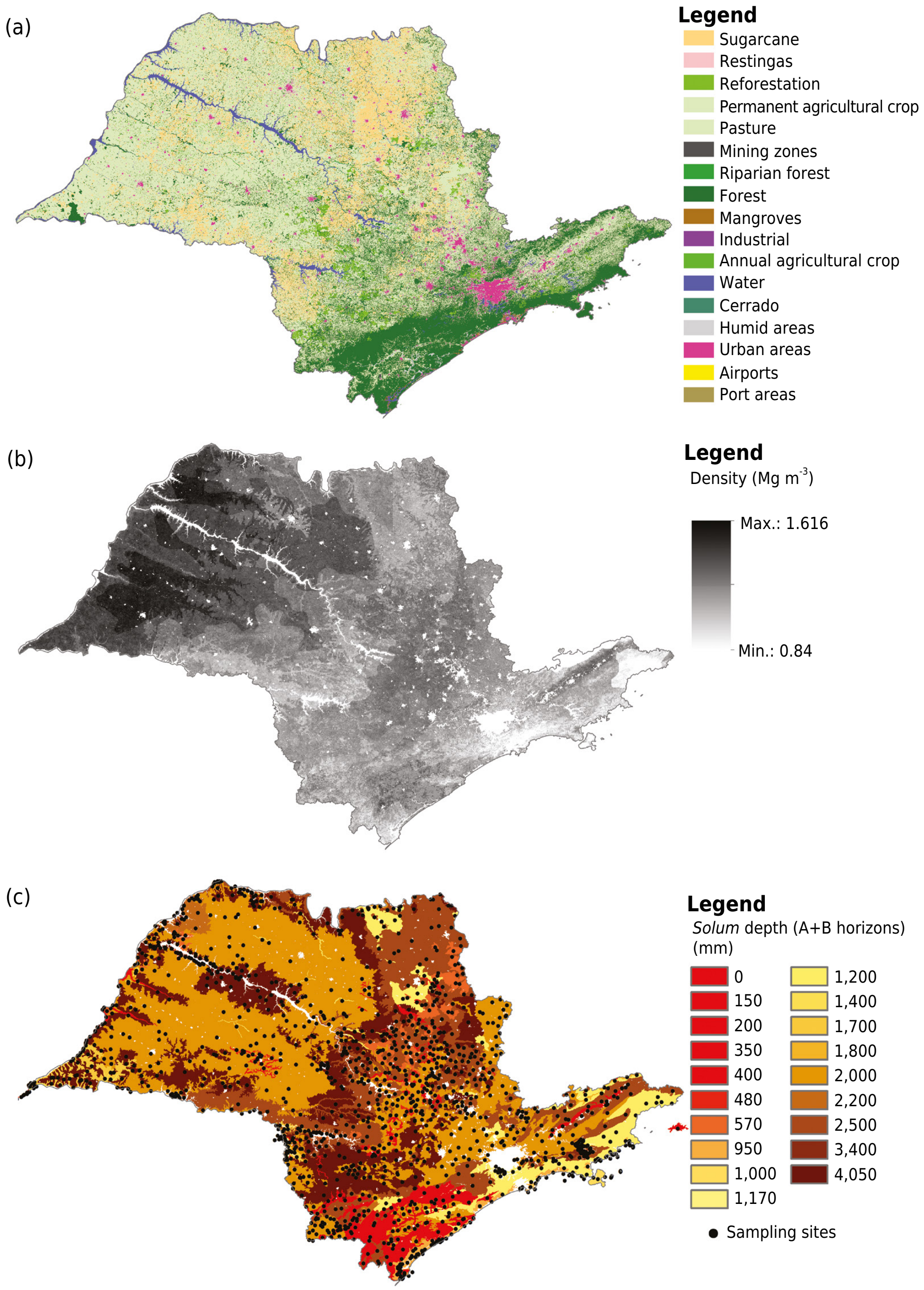

Figure 2. Data used: (a) Land use map of 2005; (b) Soil density map and (c) Soil depth map obtained by interpolation of data of Oliveira (1999).

the results show the remaining time in years until the soil is degraded to a thickness of only 1 m.

However, when an area is in the situation of resource degradation, soil resource is being explored beyond the tolerance limits and conservation should be adopted. Therefore, to consider a condition as critical only when the critical depth is reached is a mistaken interpretation from the point of view of conservation and should be considered with restrictions. The SLtl map should be interpreted as an indication of the areas requiring the most rapid conservation interventions, considering the time until the state of irreparable degradation will be reached.

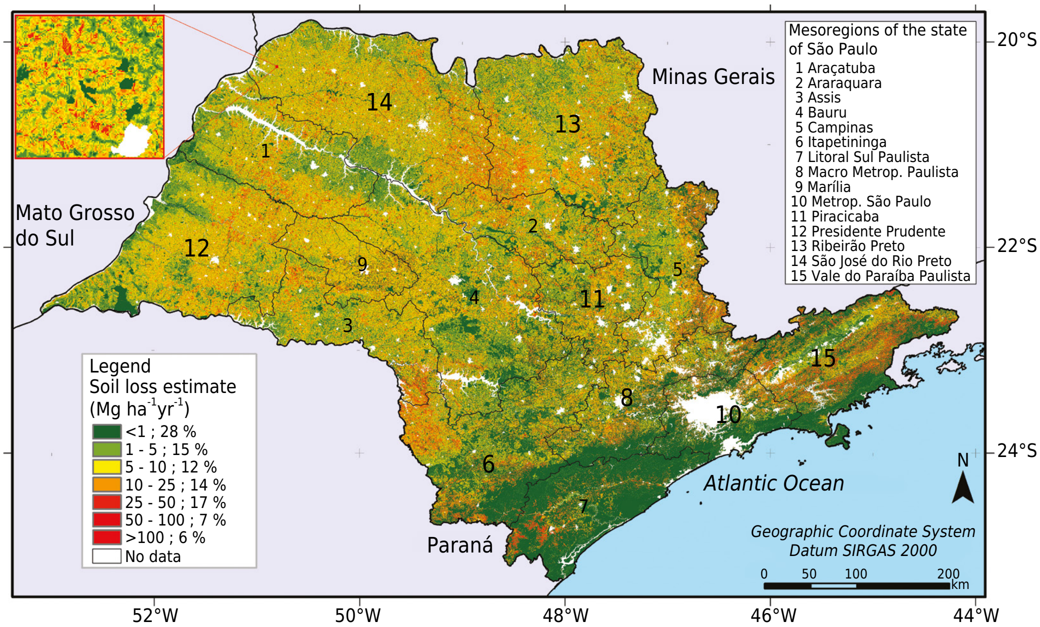

Figure 3. USLE-based map of soil loss rates in São Paulo State. Source: Medeiros et al. (2016).

When calculating the SLtI, the *solum* (sum of thicknesses of the horizons A and B) depth is considered as "stock". *Solum* depth data of the main representative soil profiles of taxonomic units of the state of São Paulo were used, as described by Oliveira (1999), indicated here as $D_{profile}$ (depth of *solum* profile). Thus, the net *solum* depth (D_{net}) (Equation 3) is the difference between $D_{profile}$ and $D_{critical}$ (1 m). Thus, in areas where $D_{profile}$ is lower than $D_{critical}$, the SLtI is zero ($SLtI_{zero}$), which means that the state of permanent degradation is already reached.

$$D_{net} = D_{perfil} - D_{critical} \qquad \text{Eq. 3}$$

where D_{net} is the net *solum* depth (mm), $D_{profile}$ is the *solum* depth (mm), and $D_{critical}$ is the critical depth, in this case 1 m (1000 mm).

Then, if h_L expresses the estimated net loss of soil erosion depth (mm yr^{-1}), SLtI is obtained from the relation between the net *solum* depth, D_{net}, and h_L, as shown in equation 4.

$$SLti = \frac{P_{net}}{h_L} \qquad \text{Eq. 4}$$

where SLtI is the Soil Lifetime Index (years), P_{net} is the net *solum* depth (mm), and h_L is the net soil loss rate (mm yr^{-1}).

Complementing the original approach of SLtI, this study presents a new focus for SLtI, i.e., by calculating the remaining time (years) until the upper 0.25 m of the soil surface are completely lost by erosion. This approach is important to estimate the time until the layer of the most fertile soil, rich in organic matter and nutrients, will be lost if no conservation measures are adopted. This consideration is valid since the soils, long before being reduced to the critical depth, are already permanently degraded. It is however worth emphasizing that the spatial variability in depth of the soils of São Paulo was taken into account, because a loss of 0.25 m from the surface horizon from one soil can represent a major part, while for another deeper soil the loss is less crucial, but nevertheless relevant, for being the surface horizon. For this reason, areas with a soil depth of less than 0.25 m were excluded from the analyses.

The SLtI is the relationship between the thickness of the surface layer L (0.25 m), and the net soil loss rate (h_L), as shown in equation 5.

$$SLti = \frac{L}{h_L} = \frac{250\ mm}{h_L} \qquad \text{Eq. 5}$$

where SLtI is the Soil Lifetime Index considering the soil loss of the upper 0.25 m (years), L is the topsoil thickness (mm) in this case the upper 0.25 m (250 mm), and h_L is the net soil loss rate (mm yr^{-1}).

RESULTS AND DISCUSSION

The results of the estimated soil loss rates used in this study were obtained by Medeiros et al. (2016). These authors describe the limitations of the USLE and the generalization of some factors caused by adaptation of the methodology to a regional scale. As is well-known, this empirical model was originally designed for erosion studies at the local level and without considering sediment deposition, but only the potential estimates of soil loss required by the SLtI methodology. By the USLE, the above authors found an average soil loss rate of 30 Mg ha^{-1} yr^{-1} and that the land uses directly linked to high erosion estimates are agricultural (annual, semi-evergreen and evergreen crops).

Characterization of "planning situations" of the study area (h_L)

The planning situations were defined as the ratio between the soil loss rate (*h*) and the presumed soil renewal rate (r) (Figure 4). Only 35 % of the soils of the state of São Paulo are in a "conserved stage", i.e., the presumed soil renewal rate exceeds the estimated soil loss rate. Therefore, soil formation occurs instead of degradation by erosion at these locations. These areas account for about 84,000 km^2 and the predominant uses and covers are forest and pasture, accounting for 62 and 25 % of the conserved area, respectively. This total includes most of the remaining fragments of Atlantic Forest covering the mountainous region of the state. The predominant soil types in these conservation areas are *Latossolos*/Oxisols, *Argissolos*/Ultisols and *Cambissolos*/Inceptisols, respectively, in 43, 29, and 18 % of the conserved area. With regard to the soil depth of the conserved areas it was found that 17 % of the soil of the area are 1 m; 12 % between 1 and 2 m and 71 % less than 2 m deep.

The areas in "degraded stage", in which the assumed soil renewal rate is lower than the estimated soil loss rate, corresponding to 65 % of the state of São Paulo, account for

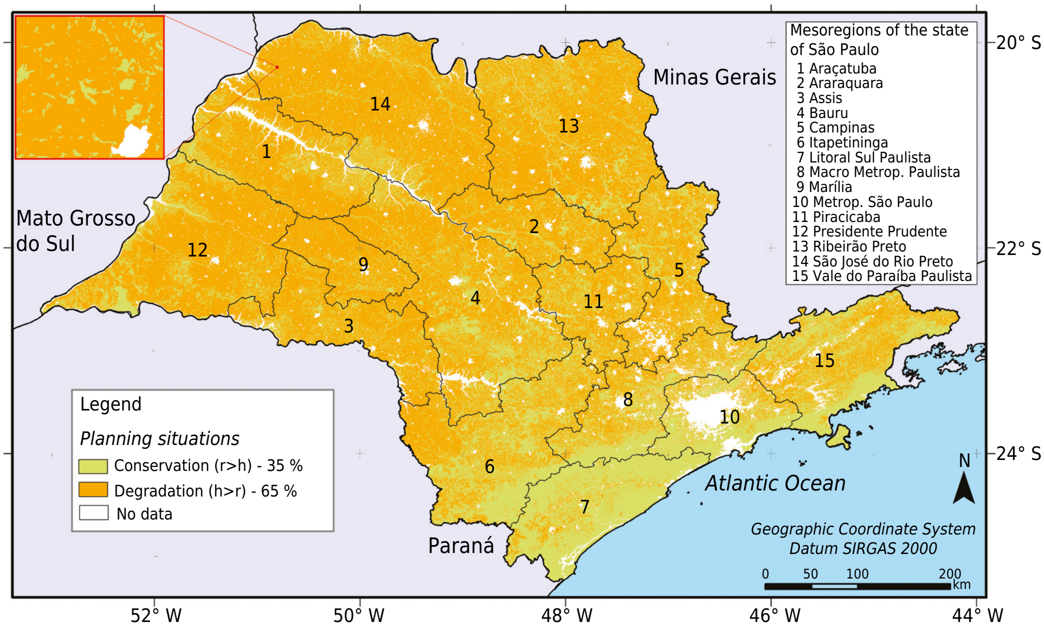

Figure 4. Map of planning situations in state of São Paulo.

approximately 154,000 km^2 and are characterized by the predominance of sugarcane plantations and pastures, at proportions of 25 and 75 %, respectively. The dominant soil types in these areas are *Argissolos*/Ultisols in 51 % of the area, and *Latossolos*/Oxisols in 41 %. With regard to the *solum* depth, 90 % of the soils are deeper than 2 m, 5 % are up to 1 m deep and 5 % between 1 and 2 m deep. These areas need intervention urgently, since if the assumed renewal rate of 0.2 mm yr^{-1} is lower than the computed soil loss rates, the soil will consequently be exhausted in terms of available soil quantity in the future if the current exploitation rates are maintained. The time when this depletion will occur is defined by calculating the SLtI by the two approaches presented and discussed below.

This survey of planning situations is a fundamental preliminary result for discussions on exploitation limits both at a local scale, since the data resolution allows analyses in small regions (micro-watersheds, for example), as well as at the regional level. With regard to regional scales, the conceptual objective of this methodological application consists in including pedology in quantitative terms in the discussions on global environmental change, Sustainable Development Goals (SDGs) (Bouma, 2014) and on planetary limits (Rockström et al., 2009), due to the criticism of the inactivity of Soil Science with regard to these issues (Hartemink, 2008; Bockheim and Gennadiyev, 2010; Amundson et al., 2015).

In this context of soil exploitation with not only environmental, but social and economic implications, the diagnosis that 154,000 km^2 of land in the state of São Paulo are approaching a state of exhaustion is a threatening situation. This diagnosis suggests that in a future determined by SLtI (in how much time - years), vast formerly productive areas may be abandoned if the erosion rates are not controlled and the cultivation systems replaced by more sustainable techniques.

Soil Lifetime Index for a critical depth of 1 m

The first consideration with respect to SLtI is about the soil depth. It is worth mentioning that, in the case of a regional scale approach (for the entire state of São Paulo), the representation of the soil depth by interpolated data from 387 points, as done here, cannot express the complete range of soil thickness variability (Figure 2), although this does not completely compromise the results since these data correspond to the most representative classes.

In general, soils in the state of São Paulo are deep. According to the spatialized data of *solum* depth sampled by Oliveira (1999) (Figure 2c), 10 % of the state has *solum* depths of less than 1 m; 49 % are between 1 and 2 m deep and 41 % 2 to 4 m deep. The corresponding SLtI for a critical depth of 1 m is shown in figure 5.

The areas where the *solum* depth is already below the critical depth (highlighted in pink), named $SLtI_{zero}$, account for 9 % of the state and occur in the mesoregion of the Vale do Paraíba of São Paulo and the southern mesoregion of Itapetininga, in the mountainous region of the state (with predominantly *Cambissolos* and forest cover, but shallow soils) and in the state interior, in the mesoregions of Araraquara and Piracicaba and in the southern and southwestern mesoregion of Ribeirão Preto, with litholic dystrophic *Neossolos*/Entisols Quartzipsamments Ortics and dystrophic Ortics and Litholic eutrophic *Neossolos*/Entisols, apart from the dominant use of pastures. For this planning situation where SLtI is zero, the methodology foresees a land use that reduces the soil loss rate to the soil renewal rate, so that no more soil can be lost. In other words, the recommendation is to freeze agricultural uses and invest in the preservation of the area (restoration of natural vegetation). In this case, shallow soils generally have narrow limitations for agricultural uses, in view of the restrictions for plant root growth and the low water storage capacity, and for tending to a markedly lower infiltration capacity.

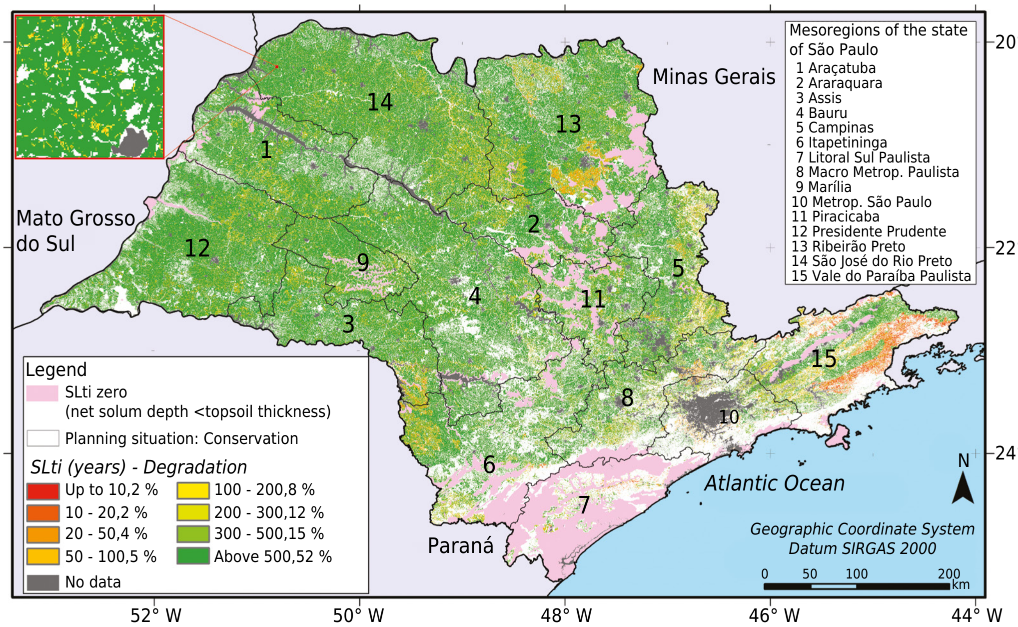

Figure 5. Soil Lifetime Index map of state of São Paulo (critical depth 1 m).

The SLtI considers the time until soil degradation by erosion reaches a critical depth of 1 m, ranging from very low values near zero until about 200,000 years (Figure 5). The parts of the state where agricultural uses are consolidated are the most critical, for which Medeiros et al. (2016) found mean soil loss estimates for annual, semi-evergreen and perennial crops, respectively, of 118 Mg ha^{-1} yr^{-1}, 78.09 Mg ha^{-1} yr^{-1} and 38 Mg ha^{-1} yr^{-1}. This is mainly the case in most of the mesoregion of Ribeirão Preto, east of the mesoregion of São José do Rio Preto and in parts of the mesoregions of Araçatuba and Presidente Prudente, among others.

These results can be discussed based on the conceptual model of SLtI (Figure 6), which is a function of the soil depth and the net soil loss rate. For areas where soils are shallow and the net loss rate is high, SLtI is low, i.e., the remaining time until the soil is eroded to a minimum depth of 1 m is short. At these locations, the problems of resource degradation by erosion are alarming and these are priority areas for the application of measures to reduce and eradicate erosive processes. On the other hand, in areas where soil loss levels are lower and soils are deeper, the SLtI is high and erosion control is less urgent than in the above situation, although attention is required.

The Soil Lifetime Index for the state of São Paulo, considering a critical depth of 1 m, was represented in a graph (Figure 7). Within a short period of 100 years, 13 % of the areas in which the estimated soil loss rate exceeds the assumed renewal rate can reach the critical depth. These areas cover almost 20,000 km^2, approximately, and are distributed throughout the state, especially in the mesoregions of Ribeirão Preto and São José do Rio Preto where, despite the typically deep soils characteristic of much of the state, the estimated soil loss rates are high. At the same time, in the mesoregion of Vale do Paraíba Paulista many areas have a short soil lifetime, because the soils are generally shallow.

In a systemic approach, in which physical, biological, chemical, and social processes define the conditions of the Earth System functioning by the interactions between atmosphere, hydrosphere, geosphere, biosphere, and pedosphere (Bockheim and Gennadiyev, 2010), a geological period of 5000 years was analyzed, showing that 80 % of the erosion-degraded areas of the state of São Paulo will be exhausted if the current forms of exploitation and management systems are maintained.

This would cause a widespread environmental collapse with economic and social consequences, particularly with regard to food safety.

Based on these results, two considerations are relevant. The first indicates the need to focus attention on the soils of São Paulo in view of to the severity of the erosion problems. The second is that, although determining the Soil Lifetime Index until the *solum* profile is reduced to a critical depth of 1 m is an important diagnostic approach to represent the current state of the soil, this methodology can mask the severity of problems related to soil conservation. In other words, for many areas, as mentioned before, even before reaching a critical depth, the soils are already in a severe degradation stage with partial or total loss of their ecosystem functions. Therefore, although this approach is important for studies on sustainable land use, it is a limited measure and

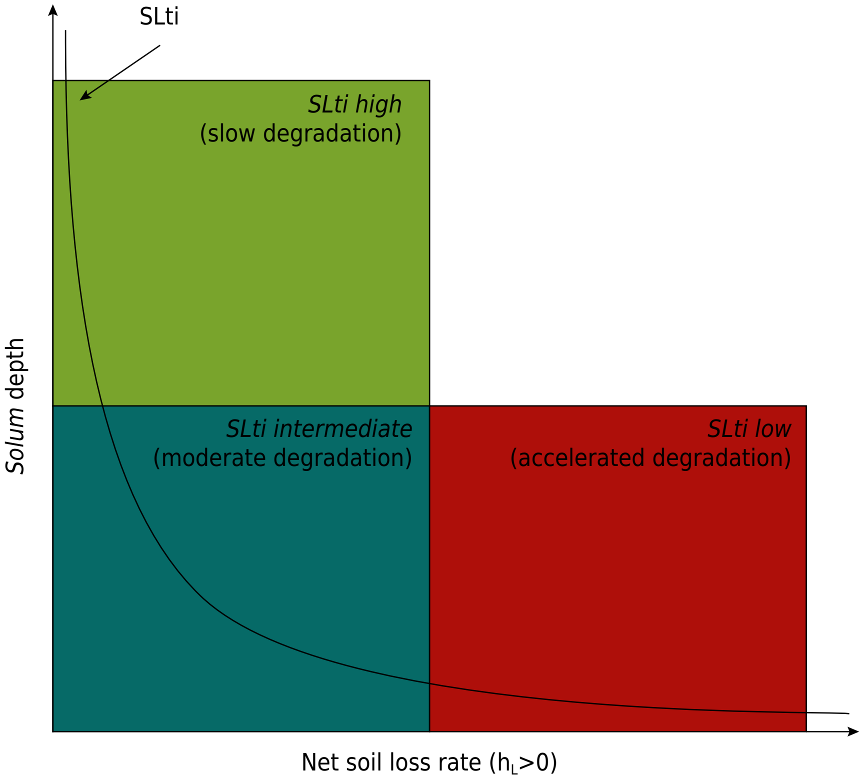

Figure 6. Sltl is a function of soil depth and net soil loss rate, estimated by an erosion model.

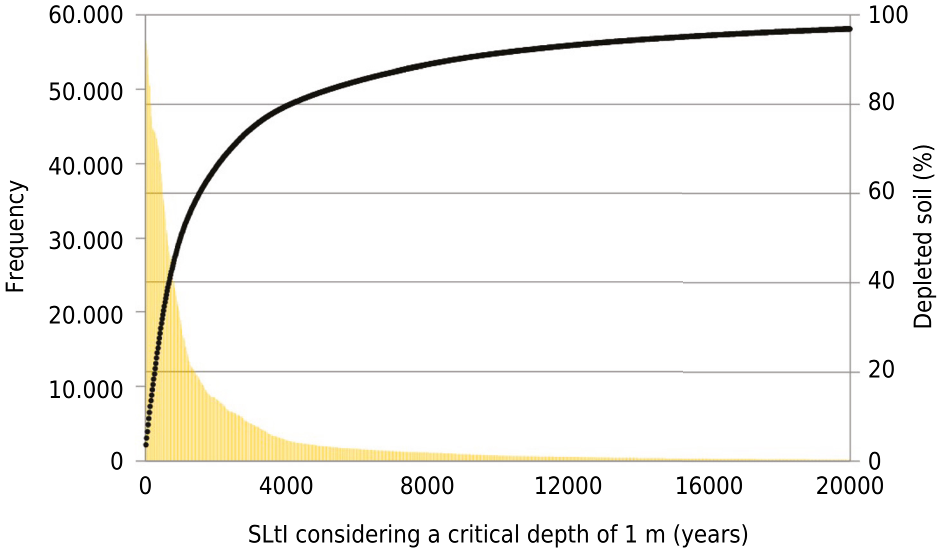

Figure 7. Histogram of the Soil Lifetime Index (SLtI) considering a critical depth of 1 m.

must be interpreted with precaution. Thus, complementarily, the approach of the Soil Lifetime Index until a layer of 0.25 m of the surface soil is lost was applied and the results were described below.

Soil Lifetime Index – loss of 0.25 m topsoil

This new approach indicates the period (year) until a 0.25 m layer of the surface soil is lost, as shown in figure 8. The areas where the SLtI is zero is where the *solum* depth is already less than 0.25 m. In general, it is observed that the situation of the soils of São Paulo is even more worrying from the point of view of soil conservation, since this approach demonstrates that the lifetime until the fertile soil layer is eroded is low for most of the state. The results indicate, for example, that within 100 yr, about 40 km^2 of the most fertile soil layer will have been removed and within 200 yr this area will have nearly doubled. This diagnosis was quantified (Figure 9), showing that in 70 % of the areas where the estimated soil loss rate exceeds the assumed soil renewal rate, the most fertile layer will be lost within only 500 yr.

Numerous effects were indicated by this new approach, since topsoil removal can reduce the ability to provide nutrients for crop production, decrease agricultural productivity, compromise the food supply and increase production costs due to the nutrient and mineral replacement in the areas of intense erosion degradation.

These results led to a quantitative diagnostic view of soil exploitation in São Paulo, with a view to warn the government and the agriculture-based private sector about the urgency of application of conservation practices in the areas indicated by SLtI. In case no responsibility is assumed to meet these needs of soil conservation and restoration, more and more areas will be abandoned and new agricultural frontiers will be exploited beyond their tolerance limits, invariably leading to the depletion of soils, without measures that could reverse the process, in a not too distant future.

The SLtI can be considered an important methodology of a combined approach of various disciplines, to meet the real need of a mind shift with regard to soil exploitation, particularly in relation to agricultural practices. Thus, the application of SLtI, aside from being a measure of soil degradation by erosion, represents an effective warning tool with regard to the human pressures damaging the soils.

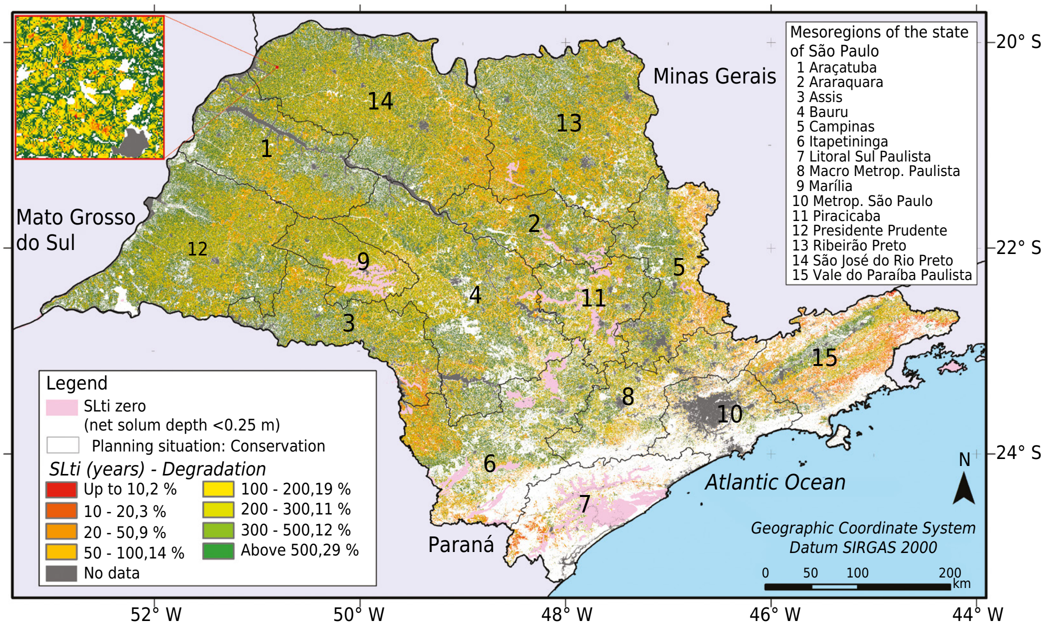

Figure 8. Soil Lifetime Index map of state of São Paulo (0.25 m).

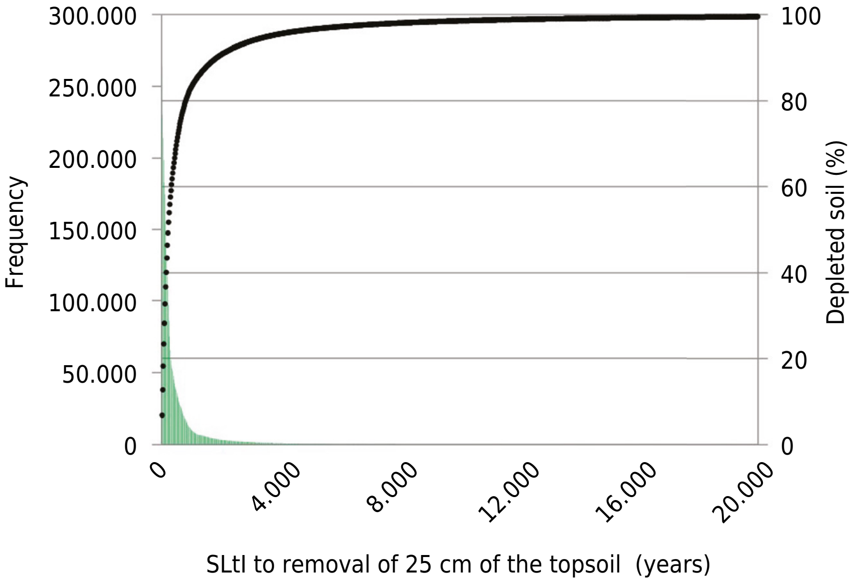

Figure 9. The Soil Lifetime Index (SLtI) to removal of 0.25 m of the topsoil.

CONCLUSIONS

The planning situations allowed the identification of the soils of the state of São Paulo that are degraded and require intervention to diminish soil loss rates, accounting for 65 % of the total area. The mesoregions of Ribeirão Preto, Bauru, Assis, Itapetininga and Araraquara require particular attention.

Given the original approach of soil lifetime and knowing that the state has an area of 248,209 km^2, the prediction for a SLtI of 100 years is that 20,000 km^2 will reach an irremediable degradation stage.

The situation is more critical, since within 100 years, about 40 000 km^2 will have lost the surface layer, and within 200 years this area will have almost doubled, when using the SLtI approach that considers a loss of 0.25 m of the surface layer.

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