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Suitability for agricultural and forestry mechanization of the Uruçuí-Preto River Hydrographic Basin, Piauí, Brazil

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ABSTRACT: This work aimed to characterize the suitability for agricultural and forestry mechanization in the Uruçuí-Preto River Hydrographic Basin, state of Piauí, Brazil, in order to support the planning of use, interventions, soil management and environmental management for the study area. A terrain slope map was generated with use of ArcGIS 10.0 software by using the SRTM/DEM (Digital Elevation Model) basis, and processed and analyzed from the interpretation and attribution of slope classes in degrees in order to indicate areas with restricted suitability for mechanization. A map of soil types was generated in order to assist in interpreting the capacity to mechanization according to soil parameters, and from that we obtained the final map of suitability for mechanization in the basin studied. Based on the results, classes of suitability to mechanization of presented the following distribution: Flat Relief (very high suitability: 8,702.52 km^2 or 55.15% of the basin under study), Slightly Undulating Relief (high suitability: 4,489.16 km^2 or 28.45%), Undulating Relief (moderate suitability: 1,270.33 km^2 or 8.04%), Strongly Undulating Relief (low suitability: 970.17 km^2 or 5.74%), Mountainous Relief (restricted: 357.11 km^2 or 2.26%) and Strongly Mountainous Relief (inapt: 51.0 km^2 or 0.32%).

Keywords: cerrado, land evaluation, land use planning, hydrographical basins management, Geographic Information Systems (GIS).

Aptidão à mecanização agrícola e florestal na Bacia Hidrografica Rio Uruçuí-Preto, Piauí, Brasil

RESUMO: Neste trabalho objetivou-se caracterizar a aptidão à mecanização agrícola e florestal na Bacia Hidrográfica do Rio Uruçuí-Preto, estado do Piauí, de forma a subsidiar o planejamento de uso, intervenções, manejo do solo e gestão ambiental para a área em estudo. Com uso do *Software* ArcGIS 10.0 foi gerado o mapa de declividade do terreno, a partir da base SRTM / MDE (Modelo Digital de Elevação), processado e analisado a partir da interpretação e atribuição das classes de declividade em graus para indicação das áreas com restrição a aptidão a mecanização. Foi gerado o mapa de classes de solo, a fim de auxiliar na interpretação da capacidade à mecanização por parâmetros pedológicos, e a partir disso foi obtido o mapa final de aptidão a mecanização na bacia em estudo. A partir dos resultados, as classes de aptidão das terras à mecanização, apresentaram-se de acordo com a seguinte distribuição: Relevo Plano (aptidão muito alta: 8.702,52 km^2 ou 55,15% da bacia em estudo), Relevo Suavemente Ondulado (aptidão alta: 4.489,16 km^2 ou 28,45%), Relevo Ondulado (aptidão moderada: 1.270,33 km^2 ou 8,04%), Relevo Fortemente Ondulado (baixa: 970,17 km^2 ou 5,74%), Relevo Montanhoso (restrito: 357,11 km^2 ou 2,26%) e Relevo fortemente montanhoso (inapta: 51,0 km^2 ou 0,32%).

Palavras-chave: cerrado, avaliação de terras, planejamento agrícola, manejo de bacias hidrográficas, Sistemas de Informação Geográfica (SIG).

1. INTRODUCTION

Efficient management is a basic and fundamental factor to planning and rational use of natural resources and to support mechanisms for preservation and/or conservation and consequently sustainable development, creating more effective means for decision-making of managers (FRANCISCO et al., 2014). The mechanization of the agriculture is one of the factors that promote rapid change of the use of the physical environment, particularly in areas of expanding agricultural frontiers (SILVA et al., 2011). Assad et al. (1998) state that this change in the use of the physical environment imposes the adoption of techniques

for evaluation and diagnosis and monitoring of the spatio-temporal dynamics of land use. Francisco (2014) points out that studies on the agricultural mechanization of soils, as well as its effects on the various types of soil, in the Northeast of the country are very scarce.

Lack of management and inappropriate land use have degraded soils, accelerating the impact of human activities on the environment. This is particularly observed in semi-arid regions of the Brazilian Northeast, where the environmental vulnerability is accentuated by the restrictive limits of soil attributes and by the aggressiveness of the climate (CHAVES et al., 2010). The planning of land use and management is an indispensable practice for the sustainability of agriculture and conservation of nature (PEDRON et al., 2006). Agricultural mechanization considerably increases the productive capacity in the field, making the actions in rural areas more dynamic and contributing to the development of agriculture and to increased production (CHAVES et al., 2013).

The demand and increased perspective of wood consumption in the forestry sector calls for the need to study the suitability of sites for introduction of reforestation, in order to avoid areas with high slopes, slopes oriented to the north and low agricultural suitability (FRANCELINO et al., 2012).

The southern region of the state of Piauí is known as the agricultural frontier with fastest growth in the country. The occupation of the Cerrado in Piauí by agribusiness began in the 1980s, but significant agricultural production effectively started only in the 1990s through medium entrepreneurs producing grains, especially soybeans, with aid of modern techniques and inputs (GONÇALVES; MONTEIRO, 2007). Then, mapping the steepness of these areas is crucial for planning and consequent streamlining of processes relating to agricultural mechanization such agro-ecosystem and enhancement of forestry investments and forestry activities in the region.

The forest sector in Piauí state still occupies a small portion of its territory when compared with other regions of the country, with small patches of planted forests, especially of small farmers. According to the Yearbook of ABRAF (2013), the state of Piauí presents along with Pará, Mato Grosso, Rio de Janeiro and Tocantins, about 36,223 ha of planted forests, coming from their own plantations. However, the Parnaíba Valley Forest Development Program in Piauí (BRAZIL, 2006) was launched with the aim to pursue the economic and social development of Piauí through the evaluation of the state's potential for development of a large-scale forestry program. For this, a Plan of Action was proposed and has served as guidance to the State Government for implementing the program.

Therefore, just as it is for agriculture, the relief of the region is extremely important for the investor in the forestry sector, once it beacons the costs of implementation, harvesting and transportation. *Soil surveys, remote sensing, use of satellite images and use of GIS (Geographic Information System) environment constitute appropriate tools for assessing the suitability of land (MENEZES et al., 2009)*. While assessing the suitability of the land to agriculture, forestry or specific suitability, aspects of the environment such as soil, climate, water resources, vegetation cover, planialtimetrics information, among others, must be taken into account. Thus, one of the great advantages of GIS is the possibility to obtain slope maps in a rapid manner. These maps are obtained by means of Digital Elevation Models (DEM), which are defined as any representation of the continuous variation of the relief in the space (SILVA et al., 2001). Geographic Information Systems assist studies that support the sustainability of the use of land, water and natural resources. It, thus, contributes to environmental analysis and geoecological studies. There are, for example, Digital Elevation Models (DEM), which are altimetric data of the terrestrial surface, based on the SRTM image (Shuttle Radar Topography Mission) (BISPO et al., 2010).

Thus, the present study aimed to map the land to agricultural and forestry mechanization in the Uruçuí-Preto River Hydrographic Basin, state of Piauí, aimed at planning and environmental management.

2. MATERIAL AND METHODS

The study area comprises the Uruçuí-Preto River Hydrographic Basin with a total drainage area of 15,777 Km², located between the geographic coordinates 07°18'16" to 09°33'06" S and 44°15'30" to 45°31'11" W of Greenwich (LEÃO; MONTEIRO, 2009) and it is important for 12 municipalities of the Southwest region of Piauí, as shown in Figure 1.The climate of the region studied in Piauí is, according to Koppen classification, Aw (tropical hot and humid with rainy

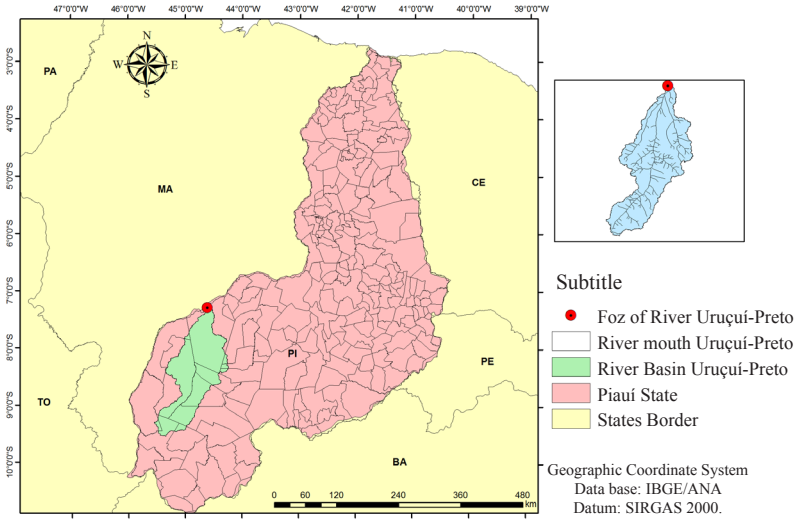

Figure 1. Location Map of Rio Uruçuí-Preto Hydrographic Basin, Piauí, Brazil (Authors, 2016).
Figura 1. Mapa de Localização da Bacia Hidrográfica do Rio Uruçuí-Preto, Piauí, Brasil. (Autores, 2016).

season in the summer).In this type of climate, the main limitation for commercial plantation forests is water stress, which happens in average during 6 months in the region. However, the same climate type is found in other regions of the country, such as Vale do Rio Jequitinhonha in Minas Gerais, and commercial forests of *Eucalyptus* have been successfully planted for decades (BRASIL, 2006).

The area is located in an economically active region of Piauí, with high concentration of investments in agricultural projects and large scale production, especially in soybean cultivation. The current use and vegetation are represented by forest formations of ecotone type (Cerrado-Caatinga). For the assessment of the suitability for agricultural and forestry mechanization in the region, interpretation of parameters and classification was carried out according to the degrees of slope: Flat Relief, Slightly Undulating, Undulating, Strongly Undulating, Mountainous and Strongly Mountainous. This classification is recommended by EMBRAPA. These characteristics were corroborated with the Soil Class Map, interpreting soils based on the underlying criteria of diagnostic attributes of soils, and after that, a final map of suitability for mechanization was prepared for these areas.

The parameters used to define the suitability for mechanization of the soil were classified into classes, considering the methodological description indicated by Francisco (2014), shown in Table 1.

For the preparation of the slope map, the database SRTM/DEM (Digital Elevation Model) was used. The mosaic of cells of the interferometric radar (SRTM) was generated, with a spatial resolution of 90 x 90 m, with subsequent preparation and classification of the slope map of the basin by means of the Spatial Analyst Surface extension followed by the tool *slope*. The steps for preparing the slope map and consequent association to suitability for mechanization are shown in Figure 2.

Soil maps were obtained (scale 1: 5,000,000) on the website of IBGE (Brazilian Institute of Geography and Statistics). |The final map of suitability for agricultural and forestry mechanization was obtained through visual interpretation of maps generated from the analysis of relief and soil classes. All procedures were performed in the Software *ArcGIS* 10.0.

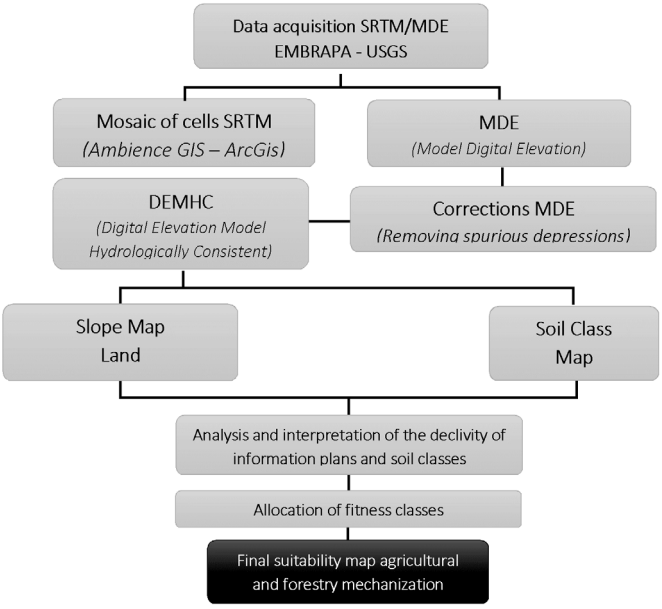

Figure 2. Stages of the development of the map of suitability for agricultural and forestry mechanization.
Figura 2. Etapas de elaboração do mapa de aptidão a mecanização agrícola e florestal.

3. RESULTS AND DISCUSSION

The development of the soil class map shows that Yellow Latosol is the predominant soil in the basin, corresponding to the main areas of agricultural crops today in the study region, followed by Red-Yellow Argisoles and Litholic Neosols and a small portion of Quartzipsamments Neosols, as shown in Figure 2. Latosols predominate in the Brazilian Cerrado, and, according to Santos et al. (2012), they are present in 46% of this biome. They are characterized by low fertility and high acidity and are old and deep soils with good drainage and are based on flat reliefs or slightly wavy reliefs.

The map of predominant soil classes in the basin studied showed the predominance of occurrence of Yellow Latosol, coinciding with the flat and low slope areas suitable for agricultural and forestry crops, as well as for integration of machinery in the productive system in the region. After the

Table 1. Classes of suitability for agricultural and forestry mechanization and their respective characteristics (Adapted from Francisco, 2014).
Tabela 1. Classes de Aptidão à mecanização agrícola e florestal e suas respectivas características (Adaptado de Francisco, 2014).

Suitability classes	Characteristics
Very high (I)	Area with favorable conditions for agricultural mechanization, which do not have any restriction on mechanical preparation, with zero degree of limitation to receive agricultural or forestry machinery. They are generally areas free of rocks and rocky soils, with sandy texture, with satisfactory effective depth and extremely favorable land use conditions .
High (II)	Area with favorable conditions for mechanization with a slight degree of restraint, having at least one feature which prevents the embodiment in the preceding class, few areas with rocky characteristics, medium/silty texture of soil, etc..
Moderate (III)	Area with restrictions, mainly related to relief, drainage and effective soil depth. It has many areas with stony surface and clayey texture.
Low (IV)	Area with marked restrictive features, not recommended to mechanization. Quite rocky surface, low effective soil depth, very clayey or clayey surface.
Restricted (V)	Area assessed as unfit to agricultural mechanization. L ands that have very strong degree of limitation Areas of intense slope, with lots of rocks on the surface, low effective soil depth and very clayey texture.
Inapt (VI)	Area assessed as unfit to agricultural mechanization, the slope being the most limiting factor. It has all possible limiting factors for any type of motorized mechanical activity, whether agricultural or forestry.

map of soil types, the terrain slope map was generated. After analysis and interpretation, the final map of suitability for agricultural and forestry mechanization was produced, showing areas with the following classifications: Very High (Slope 0° to 1.9° or 0 to 3%); High (Slope 1.9° to 5.0° or 3 to 8%); Moderate (Slope 5.0° to 9.0° or 8 to 20%); Low (Slope 9.0° to 13.9° or 20 to 45%; Restricted (Slope 13.9° to 20.1° or 20 to 45%) and unsuitable areas (Slope 20.1° to 35.6° or above 75%), as shown in Figure 3.

As shown in the final map of suitability for agricultural and forestry mechanization, areas very unsuitable and with greater restrictions are represented by the classes Low (IV), Restricted (V) and unsuitable (VI) totaling 1,315.28 km^2, corresponding to 8.32% of the total area of the basin (Figure 4). These classes occur in greater proportion in regions known as 'baixões' which are areas close to waterways, rock formations, and are usually located between plateaus that divide the river basins in the region. In these areas are concentrated the soil classes of the type Neosols, characterized by being shallow and usually stony, what make them unsuitable to the use of agricultural and forestry machinery. Areas with the highest suitability were represented by the classes Very High (I), High (II) and moderate (VI), totaling 14,461.72 km^2 (Figure 4) and covering 91.64% of the basin. The largest proportion of areas exclusively classified as Cerrado occur in these classes. These are areas mainly characterized by Yellow Latosol soils, which are chemically poor soils despite the excellent physical structure, which enables mechanization in virtually all production processes, namely, land treatment, planting, maintenance and harvesting.

The final map of suitability for agricultural and forestry mechanization characterizes the region by high agricultural potential, which is already active in the region, and gives further support for the forestry potential of the region, particularly for investments in production forests on a large scale.

Very highly and highly suitable areas correspond to the major part of the Basin. Together they represent 83.60% of the total area, showing that most of the Basin has favorable conditions for mechanization and offer optimum conditions to the expansion of these sectors in the region. In fact, this area has been explored extensively by agribusiness with soy crops on commercial scale, precisely due to the relief and soils conditions that are highly favorable.

With regard to forestry, the potential for the development of this sector in the state stands out. The region has favorable climatic and soil conditions and potentially satisfactory slope to mechanization of forestry operations. It is observed that only 0.32% of the Basin has strongly mountainous relief with slopes between 20.1° to 35.6°. For Forest Harvesting activities, the use of machines in areas with slope up to 35° is recommended.

With favorable soil conditions for agricultural and forestry cultivation, the relief characteristics (slope) are important factors for interventions and management of investments in Hydrographical Basins.

Silva et al. (2001) points to the success of the use of GIS for the classification of suitability of areas formechanization of coffee crops, starting from the slope class map, indicating that the region of Ponte Nova in Minas Gerais has 71.43% of the area very highly suitable for mechanization of coffee, with slopes lower than 10%, characterizing them as favorable.

For forests, the works of Lima et al. (2004) note that the main machines used in timber harvesting have restrictions on their use on land with slopes and Pereira et al. (2012) concluded that the depth of these terrains decreases with increasing steepness, suggesting a limit equal to 22°. Thus, a machine can only reach

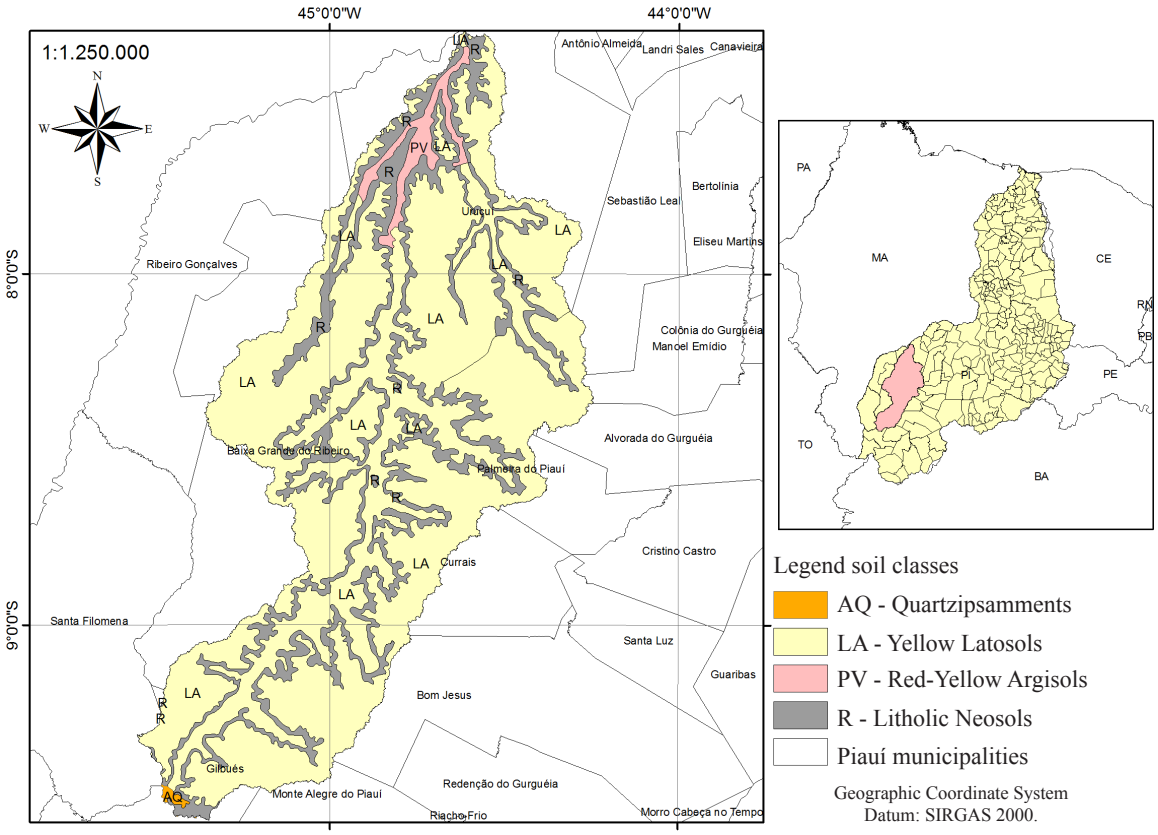

Figure 3. Soil Class Map prevalent in the Uruçuí-Preto River Hydrographic Basin, Piauí, Brazil (Authors, 2016).
Figura 3. Mapa de Classes de Solo predominantes na Bacia do Rio Uruçuí-Preto, Piauí, Brasil (Autores, 2016).

a slope where it can remain static without the use of traction force. In a forest industry of Minas Gerais, Brazil, areas with slopes of up to 35° are recommended for forest harvesting. Francis et al. (2014) confirms that the use of Geotechnology provide fast mapping of the land, allowing the decision-making for planning and environmental management in the semiarid region.

Figure 4 shows the results on the suitability for agricultural and forestry mechanization in the study area.

Table 2 shows the areas corresponding to each class of suitability and their percentages.

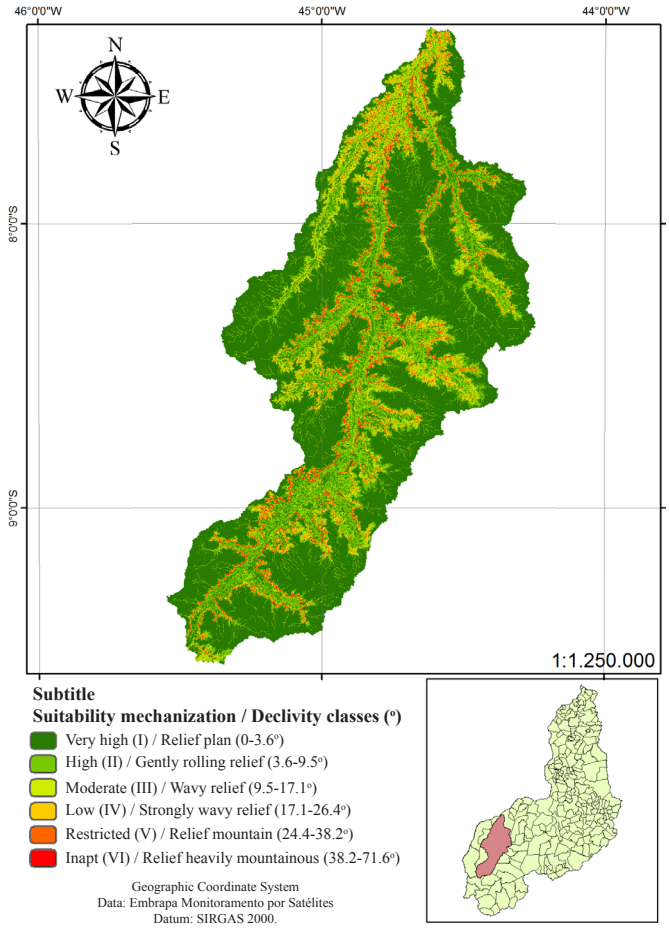

Figure 4. Map of suitability for agricultural and forestry mechanization in the Uruçuí-Preto River Hydrographic Basin, Piauí.

Figura 4. Mapa de Aptidão à mecanização agrícola e florestal na bacia do rio Uruçuí-Preto, Piauí.

Table 2. Areas occupied by soil classes according to suitability.
Tabela 2. Áreas ocupadas pelas classes de solo quanto à aptidão.

Soil classes (suitability)	Area (km²)	Percentage (%)
I – Very high	8,702.52	55.15
II – High	4,489.16	28.45
III – Moderate	1,270.04	8.04
IV – Low	907.17	5.74
V – Restricted	357.11	2.26
VI - Inapt	51	0.32
Total	15,777	100

4. CONCLUSIONS

The categories of suitability for mechanization of lands of the Uruçuí-Preto River Hydrographic Basin show that much of the region is very suitable for agricultural and forestry mechanization (very high suitability: 55.15% and high suitability: 28.45%). The potential of the region to agricultural and forestry use stands out. This makes it necessary to properly plan the use of the land through sustainable land management and environmental management aiming at the conservation of natural resources, from the correct planning of environmental licensing for vegetation removal and conversion of land into commercially productive areas, as well as the viability of less impactful techniques and activities, such as no-till agriculture. As for conservation aspects, the results provide means for better planning of delimitation of Permanent Preservation Areas (PPAs), Legal Reserves (LR), and others. It could be observed, through the parameters used, that restrictions on mechanization based on the steepness of the land and soil classes were effective through geo-technologic bases. Therefore, it is expected that this classification, according to the level of information of the mapping done, may provide technical support to planning the use of agricultural and forestry machinery for operations of soil preparation, planting, harvesting, and especially contributing to the rationality of soil management and conservation.

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