SPATIALIZATION OF PHYSICAL, MECHANICAL AND CHEMICAL CHARACTERISTICS OF SOILS IN DIFFERENT MODELS OF SLOPES IN PORTO VELHO – BRAZILIAN AMAZON

ESPACIALIZAÇÃO DAS CARACTERÍSTICAS FÍSICAS, MECÂNICAS E QUÍMICAS DE SOLOS EM DIFERENTES MODELADOS DE VERTENTES EM PORTO VELHO – AMAZÔNIA BRASILEIRA

ESPACIALIZACIÓN DE CARACTERÍSTICAS FÍSICAS, MECÁNICAS Y QUÍMICAS DE SUELOS EN DIFERENTES MODELOS DE TALUDES EN PORTO VELHO - AMAZÓNIA BRASILEÑA

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ABSTRACT

In this study, it sought to spatialize the mechanical, physical and chemical soil parameters in 3 different slope models (Convex, Rectilinear and Concave) in Oxisols under the Tabular relief of the Belmont basin stream in Porto Velho city, Rondônia state - Brazil. For analysis of the slopes, topographic plots of the soil in the top, middle and bottom up to 1.5 m in depth were used in auger and trenches, spatialized by interpolation. It was observed that the Convex slopes followed by the Rectilinear slopes presented higher clay content in the soils, with an increase in sand to the foothills. The organic matter in the slopes indicated that the Concave format presents the greatest amount of these, followed by Rectilinear and Convex. The infiltration revealed that the Convex and Rectilinear are similar, with greater infiltration at the top, however, the Concave slope showed the least infiltration at the top. The middle of the slopes stands out, which registered the lowest pH values. The justification would be that in the middle of the slopes there is a greater slope and greater water flow, which contributes to a greater circulation of organic acids from organic matter in the superficial layers and upstream.

Keywords: Toposequence; Belmont; cohesion; infiltration.

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RESUMO
Neste estudo, procurou-se espacializar os parâmetros mecânicos, físicos e químicos de solo em 3 modelados diferentes de vertentes (Convexo, Retilíneo e Côncavo) em Latossolos sob o relevo Denudacional Estrutural Tabular da Bacia do Igarapé Belmont em Porto Velho, Rondônia. Para análise das vertentes foram utilizadas parcelas topográficas do solo em topo, meio e sopé em até 1,5 m de profundidade em trincheiras e tradagens, espacializadas por interpolação. Observou-se que as vertentes Convexas seguida da Retilínea apresentaram maior teor de argila nos solos, com aumento de areias para o sopé. A matéria orgânica nas vertentes indicou que o formato Côncavo apresenta a maior quantidade das vertentes, seguido da Retilínea e Convexa. A Coesão Aparente dos solos foi maior na vertente Convexa e menor na Côncava. A infiltração revelou que as vertentes Convexa e Retilínea são semelhantes, com maior infiltração no topo, contudo, a vertente Côncava apresentou menor infiltração no topo. Destaca-se o meio das vertentes, que registraram os menores valores de pH. A justificativa seria que no meio das vertentes encontram-se a maior declividade e maior fluxo hídrico, que contribui para uma maior circulação de ácidos orgânicos proveniente da matéria orgânica das camadas superficiais e a montante.

Palavras-chave: Toposequência; Belmont; coesão; infiltração.

1. Introdction
Sloped surfaces are the most revealing areas of the relief, as a large part of the dynamics that the terrain undergoes can be seen in them, whether of natural or anthropic origin.

To analyzing the dynamics of variation in soil attributes on slopes, Souza et al. (2004) and Camargo et al. (2008 and 2013) state that small relief variations
influence soil attributes, especially convex surfaces, which are more dependent on the stability of soil attributes for its shape.

This concept is also accepted by Bigarella (2003) and Werlang et al. (2016), who state that the convex at the top and concave at the base profiles are the ones that present the greatest energy to change the physical characteristics of the slopes, which are concentrated in the central portion of the profile.

From the middle of the concave surfaces, according to Montanari et al. (2005), Campos et al. (2007) and Sanchez et al. (2009), there are the highest values of variation in textures, organic matter and erosion rate when compared to inclined surfaces with a convex and rectilinear shape. An indication of these variations in physical attributes is mentioned by QueirozNeto (2011), who defends the transformation of the latosolic horizon, which starts at the base of the slope with this soil and advances to the top, with progressive losses of clay in the horizons, however, the middle of the slope has higher infiltration rates and greater clay flocculation, leaving thicker particles on the surface that are dragged downstream, causing changes, with the beginning of a concavity that advances towards the slope and increases its declivity in reference to the crest.

Regarding the percentage of organic matter in the soil, there is variation according to depth, according to Vicente et al. (2012) and Castro Filho et al. (1998), the percentage of organic matter reaches its peak at depth between 0-10 centimeters. After 10 centimeters in depth, the percentage of organic matter drops linearly to 20 centimeters in depth, where the presence of organic matter is practically non-existent. Following this principle Canellas et al. (2001) analyzed a slope toposequence on the UFRRJ campus and found that the distribution of organic matter fractions is influenced by the topography, since the water dynamics are different in each segment of the slope, influencing the percolation of free fluvic acids that they are transported by the lateral and vertical flows of water in the relief, however, there is always a decrease in organic matter as the depth increases in any section of the slope. The same conclusion reached Wang et al. (2015), who consider the dominant topography in the variations in the percentage of organic matter and depth.

Valente and Gomes (2005) emphasize that the spatial variation of water infiltration has a saturation limit, which is when precipitation exceeds the
infiltration capacity. After the end of the rain event, the water in the soil can be retained, turning into moisture or it can move by percolation towards the water table, depending on the permeability of the soil. Permeability is greater in the superficial layers of the soil, which produces a flow parallel at surface in slopes, called hypodermic or subsurface flow, according to Leli, Stevaux and Nóbrega (2011). This hypodermic flow corresponds to the horizontal water flow at the level of the root system of the plants and, as shown by Valente and Gomes (2005), at a depth that can reach 150 cm. Subsurface runoff is at the threshold between surface runoff and underground runoff, and at some points on the slope it may intercept the surface and emphasize the surface water flow causing a large variation in hydraulic conductivity along the course of the slope, according to Sousa (2019); Rosolen and Herpin (2008).

Soil infiltration, according to Baird (1997), Carvalho (2002) and Streck et al. (2008) is more dependent on the structure than on its texture, considering that the structure interferes with the geometry of the porous space of the soils. In the superficial layers of the soil, generally, there is greater variation in the density of the soil due to the type of land management used, which favors the formation of pores with larger diameters in the soil, which allow for greater permeability. However, Mesquita and Moraes (2004) highlight that these pores cannot drastically influence the soil density. What distinguishes soil density is less influence on hydraulic conductivity than structure.

Soil consistency is related to the manifestations of physical forces of cohesion, which occur between soil particles and adhesion between these particles with other materials that change according to the variation in water content (BRANDÃO et al.; 2015). According to Reichert et al. (2010) when part of the water is lost, the soil particles start to slide over each other and the water works as a lubricant, which results in the plasticity of the soil.

Soil plasticity is an important parameter for its physical analysis. Özdemir and Gülser(2017) inform the study the limits fisical of soil may be used for a rapid and quantitative method to assessing soil structure, especially in fine textural class. Besides particle size distribution, using plasticity index value gives more details about soil structure and forms of slopes.
For spatial dependence, geostatistical modeling is a powerful tool that contributes to environmental research, allowing the identification of the existence or not of spatial dependence between observations, which can be applied in representative drawings. This can estimate the values of attributes in non-sampled locations, facilitating the management of natural resources, especially in the pedological context (LEMOS FILHO et al; 2017). This method is preferred over other simple interpolators, as it presents greater statistical rigor compared to methods that do not consider the spatial dependence structure of the samples (WEBSETER and OLIVER, 2009).

The aim of this study is to specialize in different slope formats the variation of physical, chemical and mechanical soil attributes, with emphasis on the analysis of the soil profile up to a depth of 150 centimeters.

2. Materials and Methods

2.1 Study Area

The samples slopes are located in the Belmont Basin Stream, basin this, has an extension of 126.5 km². The city of Porto Velho - RO is located to the south of the Basin, where most of the springs of the stream are located. The middle and lower course of the stream is located in a rural area, which is home to forms of agricultural and pastoral activities. It should be noted that in the middle course of the stream is located the area of the Municipal Natural Park OlavoPires (Ecological Park), a conservation unit that already suffers from the effects of environmental degradation in its surroundings, this conservation unit has as its main tributary. the Belmont Stream, according to Santos, Della-Justina and Ferreira (2012), (Figure 1).
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Figure 1 – Location of slopes in the Belmont Basin Stream.

The slopes analyzed, according to Santos, Della-Justina and Ferreira (2012), who classified the relief of the Belmont basin stream on a scale of 1:25,000, are in a Denudational Structural Tabular model, a structure caused by the Madeira 14 de Abril and Araras that transfixed the Belmont Basin fitting and orienting the relief between faults. These faults, which tipped and caused the rejuvenation of the relief in the Miocene period.

The Concave, Convex and Rectilinear shaped slopes are located in the Structural Tabular Denudation model with a low degree of carving of the valleys and small interfluvial dimension (DEt 24). The carving of the valleys covers a dimension between 10 to 30 meters in depth and the between fluviums dimension ranging from 400 to 730 meters. This model presents linear incisions in the form of erosive grooves and shallow ravines studied by Santos, Della-Justina and Ferreira (2012).

The choice of denudational relief modeled Tabular Structure with a low degree of carving of the valleys and small between fluviums dimension - DEt 24, falls under its greater slope in the Basin, according to Santos, Della-Justina and
Ferreira (2012) and on the class of soil: Red-yellow clayey oxisol, according to Rondônia (2000). This slope of the valley carvings, according to Rubira et al. (2019), serves as an area of analysis of pedological influences on morphogenesis and relief modification. This area corresponds, according to IBGE (2009) and Ross (1992) to the 5th Taxon of morphological analysis of the Relief, called Types of Slope, which according to Santos, Della-Justina and Ferreira (2012) and Guerra and Marçal (2006) is necessary an analysis scale of 1:25,000 or greater to observe the relief dynamics on these surfaces. Thus, the scale for analysis of soil layers on the slopes of this study was 1:1,000.

To better resemblance of samples slopes was considered criteria of homogeneity of the studied soil were considered, taking the following aspects as boundaries, Figure 2.

![Figure 2](image-url)

For topographic recognition of slopes, a pantometer based on Pitty (1968) with a 1-meter scale was used (Figure 3). The slope and distance values of the slopes were plotted in the AutoCAD Map program, with the objective of constructing the surface schematic profiles of the slopes. The preparation of the soil layer profiles of the slopes with the data obtained in the field, was used in the Qgis 2.18 software, applying the Inverse Distance Weighted – IDW interpolator, which is an exact method, therefore, it does not perform error prediction
evaluation. Just needing that the points are equally distributed over the area with
trends of increasing or decreasing variations of values (JAKOB and YOUNG, 2006)

Figure 3 – Pitty’s Pantometer.

The topographic recognition aims to classify the slopes in the formats:
Convex - CX, Rectilinear - RT and Concave - CV, according to Guasselli et al.
(2009) and Berndtsson and Carson (1987), as well as dividing each slope shape
into thirds: Top Third - T/T, Middle Third – M/T and Botton Third – B/T, according
to Martins et al. (2013); Grigorowitshs and Rodrigues (2009); Pachepsky et al.
(2001) (Figure 4).

Figure 4 - Shapes of slopes and division into topographic thirds according with Martins et al. (2013).

In each third of the slope, tracings were carried out, in compliance with the
precepts of the IBGE (2017) and Santos et al. (2015), with emphasis on the needs
of color and tactile texture, in particular to locate a more peculiar area of each third for the opening of the analysis trench, obeying the cohesion limit imposed by the soil, according to NBR 9603 (ABNT, 1986) and Vieira and Fernandes (2002).

For the trenches, the IBGE (2015) and Santos et al. (2015b) for opening these, for on-site tests and deformed and undisturbed soil chests according to EMBRAPA (2017) and IBGE (2017); Souza, et al. (2016); Marcatto et al. (2015); Costa and Nishiyama (2007); Celligoi et al. (2006); Vieira and Fernandes (2002) and Baird (1997) at a depth of 150cm.

The period of field trials and soil collection comprised the months of June, July, August, September and early October of 2018, where the annual water deficit is greater, according to Menezes (2015); Fabian and OttoniFilho, (2000); EMBRAPA (2017).

2.2 Parameters of Soil

The classification of layers, granulometric and textural soils was carried out following the EMBRAPA standard (2017), of visual classification of each soil layer through its coloration and classification, using the Munssel chart in an open trench.

To calculate the organic matter, the method of soil incineration in a muffle was used, as an option for the total determination of organic matter. According to EMBRAPA (2017), it is a satisfactory method for obtaining total organic compounds, however, it does not discriminate the amount of humus sub-decomposition in the soil.

The percentage of organic matter was obtained at depths 0-10 cm, 10-20cm, 20-40cm and between 100-140cm of each third of the slopes.

The degree of flocculation of the soils was obtained using the IBGE method (2017), which calculates flocculation by the difference of total clays from natural clays in each sampled soil layer.

Soil density was obtained from each soil layer by the ratio between the weight of an undisturbed soil sample by its volume, according to EMBRAPA (2017) and NBR 10838 (ABNT,1988).

The Atterberg Limit of each soil layer was followed according to NBR 6459
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(ABNT,1984) Liquidity Limit - LL and NBR 7180 (ABNT, 1984) Plasticity Limit - PL standards. The Plasticity Index is the product of subtracting LL from PL.

The apparent cohesion of the soil was obtained by using the Stolf Impact Penetrometer device (Figure 05) at a depth between 0-150cm. The data obtained on this device are applicable to the equation by Stolf et al. (2014) (Equation 01). The device has characteristics similar to the NBR 12069 (ABNT, 1991) standard for determining the soil resistance to continuous penetration of a standardized tip – cone in situ.

\[
N = g \cdot \frac{n^6}{dm} \quad C = 5.6 + 6.89 \cdot N
\]  

(01)

Where:

\[
N \text{ (impacts average) in blows/dm} \\
g \text{ (gravity) em } 9.8m/s^2 \\
dm \text{ (depth variation) em cm} \\
n^6 \text{ (blows numbers)} \\
C \text{ (cohesion) in kgf/cm}^2 \cdot (0.098) \text{ in MPa}
\]

For the analysis of hydraulic conductivity of the sample soils, the three segments of each slope were evaluated (top, middle and bottom third). For a concise evaluation of the soil water permeation process, holes were drilled with depths between 0-20 cm; 60-80 cm and 120-140 cm using trenches opened in each third.

To calculate the infiltration, the Guelph permeameter technique was used, which follows the precepts of Reynolds and Elrick (1985), to calculate the hydraulic conductivity in drained soils (Permeability Coefficient – K). The permeability model is based on the Richards equation (1931), for a unidirectional flow in a cylindrical hole, according to Fernandes et al. (2001).
To calculate the infiltration speed, Equation 02 was used:

\[ V_i = \frac{h_1 - h_2}{t_1 - t_2} \]  

(02)

Where:

\( V_i \) = infiltration speed (mm/h)
\( h_1 \) e \( h_2 \) = wather depth hights (cm)
\( t_1 \) e \( t_2 \) = time (min.)

The calculation of hydraulic conductivity is obtained from the following Richards Equations (05) e (06).

\[ Q = R \cdot A \]  

(03)

\[ K_{fs} = \frac{CQ}{2\pi \cdot H^2 + \pi a^2 \cdot C + \frac{2\pi h}{\alpha}} \]  

(04)
The determinations of chemical parameters were used to evaluate the acidity level of the layers of soil samples, which were based on the methods defined by EMBRAPA (2017), for determining the pH of the soil in water.

3. Results

The Belmont Basin, according to IBGE (1978, 2017) presents as predominant soil the Red Yellow Latosol, which classified it as alic, plinthic and low clay activity, identified as oxidickaolinitic soil, with a silt-clay texture. Rondônia (2000), carried out studies of this soil in the DEt 13 relief model (depressed relief in relation to the Basin, with concave and straight slopes), which was characterize as a well-developed soil, of autochthonous origin of metamorphic igneous rock, dystrophic with A horizon prominent without erosions, well drained, with a sandy-clay loam texture, subangular block structure with very high porosity and permeability, ranging from 60-125 mm/h. It presents color on the A horizon (0-12cm) bruno-dark yellow (10YR 3/4); on the Bw1 horizon (50-80cm) bruno yellow (10YR 5/8) and on the Bw2 horizon (80-120 cm) strong bruno (7.5YR 5/8) (Figure 6).

3.1 Morphometric and Two-Dimensional Description of the Soil of the Slopes

The Convex - CX slope presented the following morphometric
characteristics: large ramp dimension, 195 meters in length and small average slope of only 3.02°, the Top Third - T/T and Medium Third - M/T of this slope showed little slope between them, but the Botton Third – B/T presented more than triple the slope in relation to the upland thirds, which conditions the topography of the slope in a convex format starting from the M/T (Figure 7).

Figure 7 – Longitudinal morphometric profile and toposequence of the Convex Slope – CX.

This slope had a dimension of 65m per third. The T/T is located at an altitude of 80m with a flat surface, with an average slope of only 0.1°, which
contributes to the infiltration process being greater than the surface flow, according to Jorge and Guerra (2013), Carvalho et al. (2019). The M/T that presents a greater slope, of 1.9° and in the field, it was observed that the entire slope did not show superficial linear erosive characteristics, for the slope. The B/T, with a final altitude at the foot of the slope of 71m, showed the greatest slope of the sloping surface with 6.5°.

The average particle size of this slope showed a predominance of clayey texture along the entire slope, above 50%. However, there is a decrease in this clay content with the increase in the sand content in the downstream direction from the middle of the slope (Figure. 8).

The toposequence of this CX slope highlights the uniform distribution in the organization of the soil layers, demonstrating a balance in the pedological structure of the slope, which is organized in a concordant manner in relation to the surface.

Figure 8 – Soil profiles in the slope trenches in CX Slope: a- Top Third, b-Middle Third and c-Bottom Third.

There is a darker coloration on the soil surface of the slope, which tends to increase in intensity towards the foothills, indicating by the color tone, a strong influence of organic matter in the surface layer, with a pinkish to grayish brown coloration, according to EMBRAPA (2017). With increasing depth, there is a more
yellowish and/or reddish hue of the soil with thicker layers downstream of the slope. This slope showed soil colors, predominantly pink (5YR 7/4 and 7.5YR 7/4) at the top to reddish yellow (7.5 6/6 and 5YR 6/8) at the bottom (Fig. 08a).

Along the entire course of the slope, it was observed that the structure of the surface soil is granular without cracks, however, from 50 cm onwards, there is a change in structure to blocks with cracks (Fig. 08 b, c), a difference, it is the lowest layer of the T/T, which presented a laminar structure without cracks (Fig. 08a).

The RectilinearSlope - RT presented as topographic characteristics, an average ramp dimension of 127.50 meters and a small average slope of 4.32°. It is observed that the slope between the thirds of this slope are shown in multiples of 2, obtained by field measurements with the Pantometer, indicating linearity of the increase in slope along the slope surface. This slope value configures the slope in a descending straight line, characterizing it as straight, both mathematically and by field observations (Fig. 09).

This slope had a dimension of 42.50m per third. The T/T is located at an altitude of 99m with a flat surface, with a slope of 2.1°. The M/T presented a 4.21° slope without revealing linear erosive characteristics. The B/T, with a final altitude at the foot of the slope of 89m, demonstrated the greatest declivity of this 6.56° inclined surface (Figure 9).

The average soil granulometry showed a predominance of clay content of approximately ≥50%, however, there is a decrease in this content from the upper third to the foot of the slope and an increase in the sand content.

By analyzing the soil of the RT Slope, more complex layers were distinguished, requiring 18 augers for morphological recognition of the layers. It was observed that there is a variation in the color of the soil on the slope surface (0-10cm), which highlights the uniformity of the Reddish Yellow color (7.5YR 6/6), starting from the lower layer in the T/T, showing as an intermediate layer in the M/T and as a surface layer in the B/T. This slope had lower chroma values than the soil colors of the CX slope, presenting a darker tone of the soils (Fig. 10).

Along the entire slope, the existence of 3 layers is distinguishable. Starting from a lighter diffuse color on the surface of the top of the slope (Redish Yellow – 5YR 6/8) to darker at a depth of 1m (Redish Yellow 7.5YR 6/6), however, in the
middle of the slope there is an inversion colors, where the surface is lighter and the bottom layer is darker (M/T). In the foothills, the intermediate layer (10-40cm) has a lighter color (5YR 6/8 Reddish Yellow) than the layers parallel to it.

Figure 9 – Morphometric and longitudinal toposequence profile of the Rectilinear Slope - RT.

The existence of cracks that cross the entire profile of the trench can be observed at the top of the slope (Figure 10 T/T), but in the middle third and at the foot there is an absence of cracks along the profiles. The massive structure
stands out along the surface of the slope up to a depth of 20cm. All lower layers of the profiles presented a massive structure.

The presence of retraction cracks from 10 cm to the greatest depth (150 cm) can be observed in the soil profiles in middle third (Figure 11), indicating high clay concentration in shrinkage due to dehydration.

Figure 10 – Soil profiles in the trenches in Rectilinear Slope – RT: Top Third, Middle Third, Bottom Third.

Source: Authors.

Figure 11 – Retraction cracks from 10 cm in depth on M/T the RT Slope.

Source: Authors.

The Concave Slope – CV presented as topographical characteristics of small dimension of the ramp, of 90m in length and the biggest average declivity
of the slopes, of 7.45°. It is observed that the topography of the B/T is the flattest, with only a steep slope of this third. The M/T, on the other hand, is the one that presented the highest slope of the slope and also where it shows the inflection point of the slope angle, preparing the upland surface for a flatter topography. The T/T revealed the same slope as the B/T of 5.5°. The M/T showed twice the declivity, with 11.1°, conditioning the slope to an inflection point in the Middle Third (Figure 12).

The topography of this slope had a dimension of 30m per third. The T/T located at an altitude of 139m and reveals a flat surface at the top and which increases the slope downstream, to 5.5° of this third. The M/T had a slope of 11.1°, (Figure 13). The B/T with a final altitude at the foot of the slope of 69m showed the same average slope as the Top Third (5.5°), exposing only erosive potential due to the slope in the upstream part of this third. The remainder of the B/T revealed a flat surface between 0° and 1° to the watercourse gutter. It was found in the upstream part of this third the presence of small depressions, which reduce the slope within the depressed area.

The soil average granulometry of this slope showed to be the least clayey of the analyzed slopes, with a clay predominance only in the top and middle third, the slope foot presented a franker texture. A peculiarity is the increase in clay content from the top to the middle of the slope and the decrease from the middle to the bottom of the slope. The fine sand content, on the other hand, increases continuously up to the base, differing from the heaping texture.
In CV slope, it presented the most complex layers of soil in the sample areas, requiring 19 augers to delimit the layers. It was found that there is a predominance of the tan color tone (7.5YR) in the surface soil. However, in T/I there is a change from the soil color matrix to a darker tan (10YR) hue (Figure 13).

This darker color is indicative of a higher content of organic matter in the soil. It is observed in the images (Figure 13) that the T/T and M/T presented the reddish color in greater depth (reddish yellow - 7.5YR 6/6), whereas in the B/T this reddish color is more to the surface.
The T/T of the slope, presented in a trench that there are 2 distinguishable layers: 0-40 cm and more than 40 cm. It is noticed in the entire soil profile the absence of cracks and ferruginous nodules (see Figure 13 - T/T), the soil layers of this slope (surface and subsurface) presented a granular structure.

For the M/T (Figure 13 M/T), it is noteworthy that there are 3 distinguishable layers, 0-25 cm, 25-60 cm and 60-100 cm. The B/T was also diagnosed as having 3 layers (Figure 13 B/T): 0-10 cm, 10-40 cm and more than 40 cm. It is observed that the hue is yellowish on the surface and as the depth increases, it tends to emphasize the darker hue at the foot of the slope.

Figure 13–Soil profiles in the trenches of the CV Slope: Topo Third, Meddle Third and Bottom Third.

Source: Authors.

3.2 Physical Description of the Soil of Slopes CX, RT and CV

In the granulometric analysis, it is observed that the entire Convex - CX slope is clayey, with emphasis on the very clayey texture for the M/T layers. The other thirds showed texture variations of clayey and very clayey layers (Table 1).

Throughout the slope, there is a regressive variation in the percentage of fine sand and silt on the surface (except for B/T in which the silt increases with depth), coinciding with the change in the structure of the soil profile, which is granular on the surface in blocks from 40cm in depth.
The flocculation of clays on the surface was below 35%, indicating high infiltration of these in soil. In the lower layer, the high flocculation content of 97% can be seen.

At the top of this slope, the granulometric analysis showed a very clayey texture in all layers, with values above 64%.

The high percentage of clay in all layers is remarkable, however there is an increase in the fine sand content downstream of this slope, differentiating it from slope CX. According to Guerra (2014) and Araújo, Almeida and Guerra (2010), soils with a high content of fine sand are very likely to erode, because, like silt, fine sand does not have the necessary density and size to cause interlocking between grains, causing its drag by the water flow as well as, it does not have natural cohesion, like clays, which is easily detachable by the force of water. These characteristics make fine sand and silt the most erodible soil particles.

Table 1 – Physical Data of Toposequence of the Convex Slope– CX

<table>
<thead>
<tr>
<th>LAYERS (depth cm)</th>
<th>GRANULOMETRY (%)</th>
<th>SILT/CLAY</th>
<th>TEXTURE</th>
<th>STRUCTURE F.D. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coarse sand</td>
<td>Fine sand</td>
<td>Silt</td>
<td>Clay</td>
</tr>
<tr>
<td>PROFILE 1 – TOP THIRD (T/T)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-10</td>
<td>1.80</td>
<td>24.00</td>
<td>17.50</td>
<td>56.70</td>
</tr>
<tr>
<td>10-40</td>
<td>2.30</td>
<td>1.40</td>
<td>16.20</td>
<td>63.80</td>
</tr>
<tr>
<td>40-150</td>
<td>7.70</td>
<td>1.40</td>
<td>16.50</td>
<td>65.50</td>
</tr>
<tr>
<td>PROFILE 2 – MIDDLE THIRD (M/T)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-10</td>
<td>6.30</td>
<td>13.90</td>
<td>18.80</td>
<td>61.00</td>
</tr>
<tr>
<td>10-30</td>
<td>7.00</td>
<td>14.00</td>
<td>16.20</td>
<td>63.80</td>
</tr>
<tr>
<td>30-55</td>
<td>7.90</td>
<td>12.20</td>
<td>16.50</td>
<td>64.50</td>
</tr>
<tr>
<td>55-150</td>
<td>8.70</td>
<td>10.80</td>
<td>16.50</td>
<td>65.00</td>
</tr>
<tr>
<td>PROFILE 3 – BOTTOM THIRD (B/T)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-10</td>
<td>27.75</td>
<td>18.25</td>
<td>11.00</td>
<td>43.00</td>
</tr>
<tr>
<td>10-40</td>
<td>19.50</td>
<td>17.20</td>
<td>13.20</td>
<td>51.30</td>
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<tr>
<td>40-150</td>
<td>15.70</td>
<td>16.10</td>
<td>16.50</td>
<td>65.50</td>
</tr>
</tbody>
</table>
The flocculation of the surface soil was 40%, indicating a greater dissolution of clays on the surface, whereas in the lower layer, there is a variation of flocculation between thirds, with the lowest floculable value for the M/T with 62% and the higher in B/T with 96%.

In the B/T, it is observed that there was a decrease in the clay content of all layers, with a percentage below 60%, classifying them as clayey texture, a level similar to the CX Slope, in which the B/T was what recorded lower clay values.

In RT Slope, it is highlighted that there is an increase in the percentage of fine sand from the top to the base, contrasting with the percentage of clay that is higher at the top and lower at the bottom of the slope (Table 2).

Note that there is an increase in the sandy texture downstream of the slope, both on the surface and subsurface, to the detriment of the clayey texture. This type of texture arrangement according to Nóbrega and Cunha (2011); Espindola (2010); Moreau et al. (2006); Vidal-Torado et al. (1999); Abrahão et al. (1998) and Lucas et al. (1984) is caused by the dissolution of fine materials (clay), impoverishing the soil.

<table>
<thead>
<tr>
<th>LAYERS (Depth cm)</th>
<th>GRANULOMETRY (%)</th>
<th>SILT/CLAY</th>
<th>TEXTURE</th>
<th>STRUCTURE</th>
<th>F.D. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PROFILE 1 – TOP THIRD (T/T)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-10</td>
<td>1.10</td>
<td>16.50</td>
<td>16.70</td>
<td>66.70</td>
<td>0.25</td>
</tr>
<tr>
<td>10-20</td>
<td>1.70</td>
<td>18.10</td>
<td>16.20</td>
<td>65.00</td>
<td>0.24</td>
</tr>
<tr>
<td>20-150</td>
<td>1.30</td>
<td>19.80</td>
<td>16.00</td>
<td>64.00</td>
<td>0.25</td>
</tr>
<tr>
<td>PROFILE 2 – MIDDLE THIRD (M/T)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-20</td>
<td>1.70</td>
<td>28.60</td>
<td>14.30</td>
<td>56.40</td>
<td>0.25</td>
</tr>
<tr>
<td>20-55</td>
<td>1.70</td>
<td>28.50</td>
<td>14.30</td>
<td>56.50</td>
<td>0.25</td>
</tr>
<tr>
<td>55-150</td>
<td>1.60</td>
<td>23.80</td>
<td>15.30</td>
<td>60.30</td>
<td>0.25</td>
</tr>
</tbody>
</table>
In RT Slope, it is highlighted that there is an increase in the percentage of fine sand from the top to the base, contrasting with the percentage of clay that is higher at the top and lower at the bottom of the slope (Table 2).

In the Concave Slope, there is a predominance of the clayey texture in the T/T and especially in the M/T. In the B/T, a transition from clayey to medium texture is noted with increasing depth, in which fine sand increases (Table 3).

There is a high amount of coarse sand (28%) at the top of the slope, as well as at the bottom, with 23.40%, which according to Guerra (2014), soils with a percentage of coarse sand are more drainable, however, less cohesion due to the low overlapping of the grains that do not fit together, which just make them more permeable. The fine sand also presented a percentage above 20% along the entire slope, reaching more than 42% at the foothills.

The soil flocculation showed an inversion of values depending on the position of the slope. Because on the surface (0-40cm), the top of the slope registered the lowest flocculation value with 39%. In the lower layer (40-100cm) it was the bottom of the slope that registered the lowest flocculation value, with 28%. It is noteworthy that the middle of the slope obtained the highest flocculation values along the entire depth of analysis of the layers.

The Silt/Clay ratio of all soil layers on the slopes (CX, RT and CV) presented a ratio below 0.6 which, according to EMBRAPA (2018), is indicative of developed advanced weathered in soils. It is noteworthy that the Silt/Clay values were well below 0.6; on average 0.2 along the profile of the layers of all slopes, indicating greater weathering and consistent with the soils of the Oxisol class (EMBRAPA, 2017).
Table 3 - Physical Data of the Toposequence of the Concave Slope — CV.

<table>
<thead>
<tr>
<th>LAYERS (depth. cm)</th>
<th>GRANULOMETRY (%)</th>
<th>SILT/CLAY</th>
<th>TEXTURE</th>
<th>STRUCTURE</th>
<th>F.D. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coarse sand</td>
<td>Fine sand</td>
<td>Silt</td>
<td>Clay</td>
<td></td>
</tr>
<tr>
<td>PROFILE 1 – TOP THIRD (T/T)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-40</td>
<td>28.00</td>
<td>20.50</td>
<td>10.50</td>
<td>41.00</td>
<td>0.25</td>
</tr>
<tr>
<td>40-100</td>
<td>13.80</td>
<td>23.60</td>
<td>12.80</td>
<td>53.00</td>
<td>0.24</td>
</tr>
<tr>
<td>PROFILE 2 – MIDDLE THIRD (M/T)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-25</td>
<td>8.00</td>
<td>24.00</td>
<td>13.00</td>
<td>55.00</td>
<td>0.23</td>
</tr>
<tr>
<td>25-60</td>
<td>7.00</td>
<td>25.00</td>
<td>13.50</td>
<td>54.50</td>
<td>0.24</td>
</tr>
<tr>
<td>60-100</td>
<td>7.00</td>
<td>26.00</td>
<td>13.50</td>
<td>53.50</td>
<td>0.25</td>
</tr>
<tr>
<td>PROFILE 3 – BOTTOM THIRD (B/T)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-10</td>
<td>17.10</td>
<td>32.90</td>
<td>10.00</td>
<td>41.00</td>
<td>0.24</td>
</tr>
<tr>
<td>10-40</td>
<td>9.00</td>
<td>39.30</td>
<td>10.20</td>
<td>41.50</td>
<td>0.24</td>
</tr>
<tr>
<td>40-100</td>
<td>23.40</td>
<td>42.50</td>
<td>5.60</td>
<td>28.50</td>
<td>0.19</td>
</tr>
</tbody>
</table>

F.D. (Floculation Degree)

Source: Authors.

The Silt/Clay ratio of all soil layers on the slopes (CX, RT and CV) presented a ratio below 0.6 which, according to EMBRAPA (2018), is indicative of developed advanced weathered in soils. It is noteworthy that the Silt/Clay values were well below 0.6; on average 0.2 along the profile of the layers of all slopes, indicating greater weathering and consistent with the soils of the Oxisol class (EMBRAPA, 2017).

3.3 Organic Matter (OM) of Slopes Soils

The organic matter of the studied slopes was shown to be high on the surface, consistent with the precepts of Rondônia (2002), which informs that the soil in the areas under study has a prominent surface (Figure 14).

It is highlighted in Figure 14 that the soil of the CX slope had the lowest percentage of organic matter in the slopes, with maximum values of 6.64%, followed by RT and finally, the CV slope, which showed the highest percentage of O.M. with more than 12%. In the RT slope, there is a greater variation of organic matter along its course, with higher values at the top (similar to the CV slope) and lower values at the bottom (similar to the CX slope).
It is observed that the inverse distance interpolation method (IDW) applied in this study presented spatial restrictions when the highest values of sample points are concentrated only on the edge of the sample cut, in this case, on the surface of the slopes, given that the highest values of organic matter are precisely in the first 20 centimeters of soil (SOUSA, 2019), which caused the isolation of values in an abrupt nodular spatial form, given the absence of values of closest neighbors, in this case, above the surface of the soil (NOGUEIRA and AMARAL, 2009).

Figure 14 – Spatial distribution of the percentage of Organic Matter in Slopes CX, RT and CV.
3.4 Apparent Cohesion (C) of the Slopes Soils

At evaluating the apparent cohesion of the soils on the slopes, we observed that the CX slope was the one with the most cohesive soils, followed by RT and CV. Note that the CV slope is the one that obtained the smallest variation in soil cohesion along the depth of the thirds (Figure 15), indicating greater homogeneity in the resistance of the soil structure on this slope.

It can be seen in Figure 15 that the T/T of the CX slope, cohesion reaches the value of 9.14 MPa on the surface. This level of apparent cohesion is quite high for soils, as when comparing the minimum level of compaction of a cast-in-place concrete sidewalk, the minimum level of compaction (FPK) is 15MPa (NBR 6118 – ABNT, 2014).

When observing the granulometry of the surface layer of this T/T, it is highlighted that there is a high value of fine sand (24%), (Table 1), which points out to be the cause of the high level of cohesion, as we observed that the arrangement of sand grains, mainly small grains, in the soil surface layer, causes a greater densification of these particles among themselves, increasing their apparent cohesion, which is consistent with the conclusions of Prado (2016), Throeh and Thompson (2007), Silva (2005) and Abrahão et al. (1998).
Figure 15 – Spatial Distribution of the apparent level of cohesion of the Slopes soil CX, RT and CV.

The same is observed in slope RT, that there is an increase in the cohesion of the lower layers, with approximate values of 6MPa, which also coincides with the increase in the percentage of fine sand at this depth, mainly in the middle of the slope. It is observed in the CV slope that cohesion was the lowest of all the soils on the analyzed slopes, with the value of cohesion not exceeding 3MPa along its entire course. The granular structure of the soil on this slope stands out, which contributes to a reduction in apparent cohesion, given its low-resistance arrangement between grains.

3.5 Hydraulic Conductivity – ($K_{sat}$) of Slopes Soil

The saturated hydraulic conductivity of the soils of the slopes presented a similarity between the CX and RT slopes, however the soil of the CV slope
showed an infiltration pattern different from the other slopes. (Figure 16).

Note that in both slopes (CX and RT) there is less infiltration in the T/T in relation to the other thirds, with values below 40 mm/h, however, the CV slope presented the opposite, with the highest infiltration values in this Top third, with an infiltration rate of more than 60 mm/h in the lower layer (120-140 cm). In the M/T, it is verifiable in Figure 16 that there is a large increase in the conductivity of the superficial layers (0-20cm) of the CX and RT slopes, exceeding 60 mm/h, indicating that they are layers of rapid conductivity, as they present values above of 25 mm/h, according to Thoeh and Thompson (2007).
One of the factors that contributes to the high infiltration of this M/T layer (0-20cm) of the CX and RT slopes is the granular structure on the surface and in subsurface blocks with cracks that contribute to greater conductivity, even with a clayed texture or too clayed soil. According to Morais (2012), Mesquita and Moraes (2004) and Carvalho (2002), clayed or very clayed soils can be as permeable as sandy soils, given their high structuring, with large pores that offer many structural voids, even when the soil is in a saturated stage, contributing to a greater subsurface water flow. In the middle of the CV slope, as shown in Figure 16, the intermediate layer (60-80cm) was the most conductive, with a rate greater than 60 mm/h, opposite to this, the surface layer and the lower layer presented a low infiltration rate, less than 20 mm/h. This high difference in hydraulic conductivity between layers tends to facilitate the saturation of the intermediate layer of this Middle Third (60-80cm) (Figure 17).

In B/T, there is a large increase in infiltration on the CX and RT slopes, with infiltration rates above 75 mm/h. Note that there is a reduction in cohesion in this third, between 0-80cm in depth to 4.3MPa in the CX slope and 1.5MPa in the RT slope (Figure 15), in addition, there was a change in the soil structure to subangular blocks with slits below the surface (Figure 8 and 10).

This permeable characteristic of the upper layers of the foothills of the slopes is also justified by the high percentage of sand for clayed textured soils, with a surface average of 46% for the CX slope and 41% for the RT (Table 1 and 2). In addition, the presence of plinthite and petroplinthite nodules in the intermediate layer of the RT slope is observed, indicating restriction of water percolation from this intermediate layer, pointing to be a soil temporarily saturated throughout the hydrological cycle of the Belmont basin (Figure 18 A). Precepts according to EMBRAPA (2017) and Gomes et al. (2007) who indicate that plinthite is formed by the oscillation of the water, causing the reduction (dissolution) of iron and its precipitation this to lower soil layers.
Figure 17 – Guelph Infiltrometer in the Middle Third of the Convex Slope – CX, between 60-80 cm deep.

Soil profile of the Bottom Third of the Convex Slope – CX, and use of the infiltrometer in depth 60-80 cm.

Source: Authors.

An indication that the lower layer (+40 cm) of the B/T of the RT slope is more hydraulically conductive than the underlay, as one of the characteristics for the development of plinthitic nodules is that they need soils with restrictions to temporary percolation and excess of moisture for its genesis, according to EMBRAPA (2018). Which is consistent with the infiltration values in this Bottom Third of this RT slope.

The CV slope, according to the hydraulic conductivity (Figure 16), presented in the B/T only the superficial layer (0-20 cm), as conductive, with a value of 43 mm/h. However, in the subsurface layers (60-140 cm), there is a water saturation of the soil, which prevents the percolation of water from the Guelph equipment, obtaining values of 0.00 mm/h. It is noteworthy that the field trials were carried out in September, when there is the greatest water deficit in the soil in the Belmont basin area, according to Rondônia (2004), Figure 18 (B).
3.6 Apparently Density – ($\gamma'$) of Slopes Soil

The apparent densities of the soil layers of the slopes ranged from 1.15 to 1.81 g/cm³, it is clear that the weights are beyond the clay soil standards advocated by Reinert and Reichert (2006) and IBGE (2017), in that the apparent density varies between 1.40 – 163 g/cm³. Such variations may be the influence of a greater presence of organic matter, which reduces the density of the soil, especially if it has a chernozemic horizon, which is the case for all slopes under analysis, according to Rondônia (2000) or greater compaction, either by the coarser texture of the soil (sands).

Note that the average density of soils analyzed on slopes tends to increase from slope CX to RT to CV, (Figure 19).

In Slope CX, the smallest variation in apparent density can be observed between the studied slopes. However, this slope had the lowest mean density, of 1.4 g/cm³, with the increase only in the subsurface of the foothills. This increase in density according to depth is due to the increase in sand content by more than 31% (Table 1), which is in line with the increase in density from 60 cm in depth, which according to IBGE (2017) and Rocha et al. (2002) soils with higher sand contents tend to be denser than clayey soils.

The RT slope showed a greater density variation along the thirds, presenting a greater density on the T/T surface (1.81 g/cm³) which coincides with
the greater cohesion of this slope of 5.49 MPa (Figure 15). This higher density is contributed by its very clayey texture and its block structure. According to IBGE (2017) and Reinert and Reichert (2006), very clayey soils when they present density values above 1.70 g/cm³ already denote a high compaction that compromises the physical structure of the soil, with no granular structure at this level of compaction, which coincides with this surface layer.

In the T/M of the RT slope there is a progressive increase in the apparent density as the depth increases. The most superficial layer had the lowest density of the entire Slope (1.15 g/cm³) and a granular structure on the surface, which, according to Guerra (2014), this structure and texture contribute to an increase in empty spaces in the soil, reducing its density.

The CV Slope presented the highest density of soils on the studied slopes, but with the lowest cohesion values (Figure 15), due to the type of soil texture, which is more sandy than the other slopes (Table 3). Well, there is an increase in apparent density when there is an increase in the fine sand content. Due to the ability of particles (grains) to arrange themselves more densely, increasing their weight compared to clays, according to IBGE (2017), Reinert and Reichert (2006) and Rocha et al. (2002).

Figure 19 – Spatial distribution Apparent Soil Density of Slopes CX, RT and CV.
The greatest variability of apparent density in the CV slope was in the M/T, which is precisely the most clayey. The lowest density is exactly in the lowest layer (120-140 cm) which is the most clayey, with a density of 1.42 g/cm³.

When observing the B/T of the CV Slope, an average density is higher than that of the upstream Thirds, due to the high percentage of fine sand in the foothills. However, this lower third registered the lowest cohesion of this slope (Fig 15), one of the causes for this, according to Therzaghi et al. (1997) and Prado (2016), it would be the smallest overlap that provides greater fit between sand particles, resulting in greater density, as well as promoting an attenuation in the internal friction in the soil, which consequently causes a reduction in cohesion between particles, facilitating the penetration into the ground.

3.7 Plasticity Index (PI) of Slopes Soils

The Plasticity Index of the soil of the CX slope, presented a unique spatialization, with the lowest plastic values on the surface, less than 5%, however, throughout the course of this slope there is an increase in plasticity as the depth increases, even at the foot of the slope, where the sand content increases (Figure 20). The value of less than 5% of PI can be explained by the percentage of sand above 20% of this surface layer (Table 1), which negatively induces the PI, given the lack of natural cohesion of the sand grains, which denote plasticity, which is according to the understanding of Fiori and Carmignani (2009), Guidicini and Nieble (1984).
On the other hand, the RT slope revealed low plasticity in the T/T by PI, with its increase in the downstream direction, revealing little variation in plasticity throughout the entire depth of analysis of this straight slope. One of the possible causes for the low PI values at the top would be the high percentage of the Plasticity Limit - PL, given that in very weathered soils there is a high potential for intraparticle water adsorption, which requires a greater amount of liquid to cause the change of state, mainly from solid to plastic, according to Prado (2016) and Caputo (1988). It is noteworthy that these soils, from the top of the slope, presented a silt/clay ratio below 0.25 (Table 2), which according to EMBRAPA (2017), soils with low values of silt/clay ratio is indicative of high weathering
chemistry in ourselves.

The CV slope had the opposite IP of the Rectilinear Slope, with the top more plastic and the foot less plastic. This IP characteristic is justified by the increase in the sandy texture (Table 3) in the downstream direction of this concave slope, which helps to reduce the soil plasticity.

3.8 Hydrogenic Potential (pH) of Slopes Soils

All soil layers on the slopes (CX, RT and CV) presented values of hydrogen potential - pH in water below 4.2 (Figure. 21). These low pH values are classified, according to EMBRAPA (2018) and IBGE (2017) as very acidic soils.
SPATIALIZATION OF PHYSICAL, MECHANICAL AND CHEMICAL CHARACTERISTICS OF SOILS IN DIFFERENT MODELS OF SLOPES IN PORTO VELHO – BRAZILIAN AMAZON

It is observed that all slopes have little variability in pH, with the lowest values in the middle of the slopes. One reason for this would be that in the middle of the slope is where the steepest slope is found and consequently there is a greater lateral flow that contributes to a greater circulation of organic acids from organic matter in the superficial layers and upstream of the slopes.

Second, Marcolin (2015); Ávila and Carvalho (2012); Moreau et al. (2006); Mafra et al. (2002), the dissolution of humic acids reaches its apex at a depth of 10 cm, which is consistent with the percentage peak of organic matter in the surface layer, with values above 6.5% for the slopes. Organic acid causes intense solubilization when present in water, which precipitates, causing soil acid rise along the slope.

4. Conclusion

In this study, was sought to specialize the mechanical, physical and chemical parameters of soil in observation of the shape of 3 different slope models in Oxisols under the Denudational Structural Tabular Relief (DEt 24) of the Belmont Stream Basin in Porto Velho City, Rondônia State - Brazil.

All slopes presented soil with texture varying from clayey to very clayed, the exception was only the lowest soil layer at the foot of the Concave slope, which presented a frank texture. It was observed that the slope in the Convex format, followed by the Rectilinear format had higher clay content in the soil than the slope in the Concave format. All slopes showed an increase in sand content in the downstream direction, in all layers of analysis.

The spatialization of organic matter in the slopes indicated that the Concave format prepared a higher percentage of O.M. throughout the course of the slope, with a substantial increase at the foot of this slope. Convex format presented the smallest amount of O.M. of the slopes, with the greatest accumulation in the Top third. The Straight slope behaved as a middle ground between the two already mentioned slopes.

Inversely to the spatialization of Organic Matter, the Apparent Cohesion of the soils was greater in the Convex slope and smaller in the Concave slope, with the Rectilinear being a middle ground of cohesive values. It is noteworthy that the
Concave slope showed less variability of cohesion values along the course of the slope.

The hydraulic conductivity revealed that the Convex and Rectilinear slopes are similar, with greater infiltration at the top and less infiltration at the foot.

The plasticity of the soil revealed a particularity, as in the Convex Slope there is an increase in plasticity as the depth increases along the entire course of the slope, caused by the low degree of clay flocculation in the more superficial layers. On the other hand, the Rectilinear Slope presented the Top Third as the least plasticity, opposite to what occurs in the Concave slope, where the Bottom Third is the least plastic.

The soils on the slopes presented a pH value below 4.2, indicating that they are very acidic soils. Highlight for the Middle Third of the slopes, which registered the lowest pH values. One reason for this would be that the middle of the slope is where the steepest slope is found and consequently there is greater lateral flow that contributes to a greater circulation of organic acids from organic matter in the superficial layers and upstream.

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