

## ECOTONE SOILS IN NORTHEASTERN BRAZIL

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### ABSTRACT

Texture, base saturation, organic carbon content, and water storage availability of soil are drivers of plant physiognomy and composition of communities. Soil properties in ecotone areas are still poorly studied, and the transition between dry, moist, and semideciduous forests is defined only by climate parameters. The objective of this study was to describe the soil properties of a moist-dry forest ecotone in Northeastern Brazil. Seven soil profiles were dug in a pristine semideciduous forest known as “Agreste”. Four more pedons were described to represent soils of dry forests. Morphology, reactivity, texture, organic matter content, and water storage capacity of the soil horizons were determined. The soils of the study area are derived from granites and granitoids, rocks highly resistant to weathering. Soils of dry forests are loam, neutral to alkaline, and hypereutrophic. Soils of semideciduous forest are sandy, acidic, dystrophic, and have up to 65% higher C content. The rocks act as impermeable layers to water, and consequently, most soils develop stagic properties in semideciduous forests. Soils are dystrophy and have low CEC and loam texture. These properties are attributed to ferrollysis. Umbrisols and Stagnosols with higher water storage capacity than dry forests soils sustain semideciduous forests in Northeastern Brazil.

**Keywords:** Caatinga. Semideciduous forest. Dry forest. Water storage.

## SOLOS ECOTONAIIS NO NORDESTE DO BRASIL

### RESUMO

Textura, saturação de base, conteúdo de carbono orgânico e disponibilidade de armazenamento de água do solo são fatores determinantes da fisionomia das plantas e composição das comunidades. As propriedades do solo em áreas de ecótonos ainda são pouco estudadas e a transição entre florestas secas, úmidas e semidecíduas é definida apenas por parâmetros climáticos. O objetivo deste estudo foi descrever as propriedades do solo de um ecótono de floresta úmida e seca no Nordeste do Brasil. Sete perfis de solo foram descritos em uma floresta semidecídua intocada conhecida como “Agreste”. Mais quatro perfis foram descritos para representar solos de florestas secas. A morfologia, reatividade, textura, conteúdo de matéria orgânica e capacidade de armazenamento de água dos horizontes do solo foram determinadas. Os solos das florestas secas são de textura média, neutros a alcalinos e eutróficos. Os solos da floresta semidecidual são arenosos, ácidos, distróficos e têm até 65% maior teor de C. As rochas atuam como camadas impermeáveis à água e, conseqüentemente, a maioria dos solos desenvolve

cores gleizadas em florestas semidecíduais. Os solos são distróficos e possuem baixa CTC e textura média. Essas propriedades são atribuídas à ferrúlise. Neossolos e Gleissolos com maior capacidade de armazenamento de água em comparação com solos de florestas secas sustentam florestas semidecíduais no Nordeste do Brasil.

**Palavras-chave:** Caatinga. Floresta estacional semidecidual. Floresta seca. Armazenamento de água.

## INTRODUCTION

The classification of vegetation types, or biomes, is an issue that is currently debated (ARRUDA et al., 2017; PENNINGTON; LEHMANN; ROWLAND, 2018; MUCINA, 2019). In tropical zones, the occurrence of moist and dry forests is associated with the climate (PENNINGTON; LEHMANN; ROWLAND, 2018), edaphic factor, and vegetable composition (MIRANDA et al., 2018). The transition between moist and dry forest in Northeastern Brazil is called ‘Agreste’. This zone is a zonal forest that comprises six states in Brazil and covers more than 100,343 km<sup>2</sup> (IBGE, 2010). Semideciduous forests cover this land and are mostly used for agriculture, prevailing fruits. Like the Caatinga, the Agreste is frequently affected by drought, though generally with less severe effects.

The definition of semideciduous forests is still uncertain. Some studies have grouped semideciduous forests with the dry forest biome (PENNINGTON et al., 2000) and others with the moist forest biome (BANDA et al., 2016). Nowadays, semideciduous forests are described as transition zones between dry and moist forests in the Neotropics (DEXTER et al., 2018). Vegetable composition and abiotic factors, such as climate and soil properties, define their occurrence (PENNINGTON et al., 2018). Although semideciduous forests are expected to cover approximately 1 million km<sup>2</sup> in South America (DEXTER et al., 2018), its occurrence is still poorly defined (PENNINGTON et al., 2000; MIRANDA et al., 2018).

The average annual precipitation, potential evapotranspiration, and seasonality are important factors responsible for delimiting moist forests, dry forests, and savannas (PENNINGTON et al., 2018). Besides, water availability and fertility of the soils also play critical roles (ARRUDA et al., 2015; de MENDONÇA et al., 2017; RODRIGUES et al., 2018) in the selection of vegetation composition. The soil influences plant physiognomies in the Brazilian Savanna (Cerrado) (NERI et al., 2013), Restinga forest (MAGNAGO et al., 2012), Amazonia rainforest (SOUZA et al., 2018; HOORN et al., 2010), Tundra (POELKING et al., 2015) and other biomes around the world (ALLIÉ et al., 2015; JONES et al., 2016). Although soil properties are essential for vegetation, they have received limited attention in studies regarding biome transitions.

The occurrence of semideciduous forests is still blurry once its delimitation depends on climate conditions, relief, and soil properties (PENNINGTON et al., 2018). Thus, we have hypothesized that specific soil properties are related to the occurrence of semideciduous forests. This study aimed to characterize the soil properties in a gradient slope at a preserved hill in semideciduous forests in Northeastern Brazil.

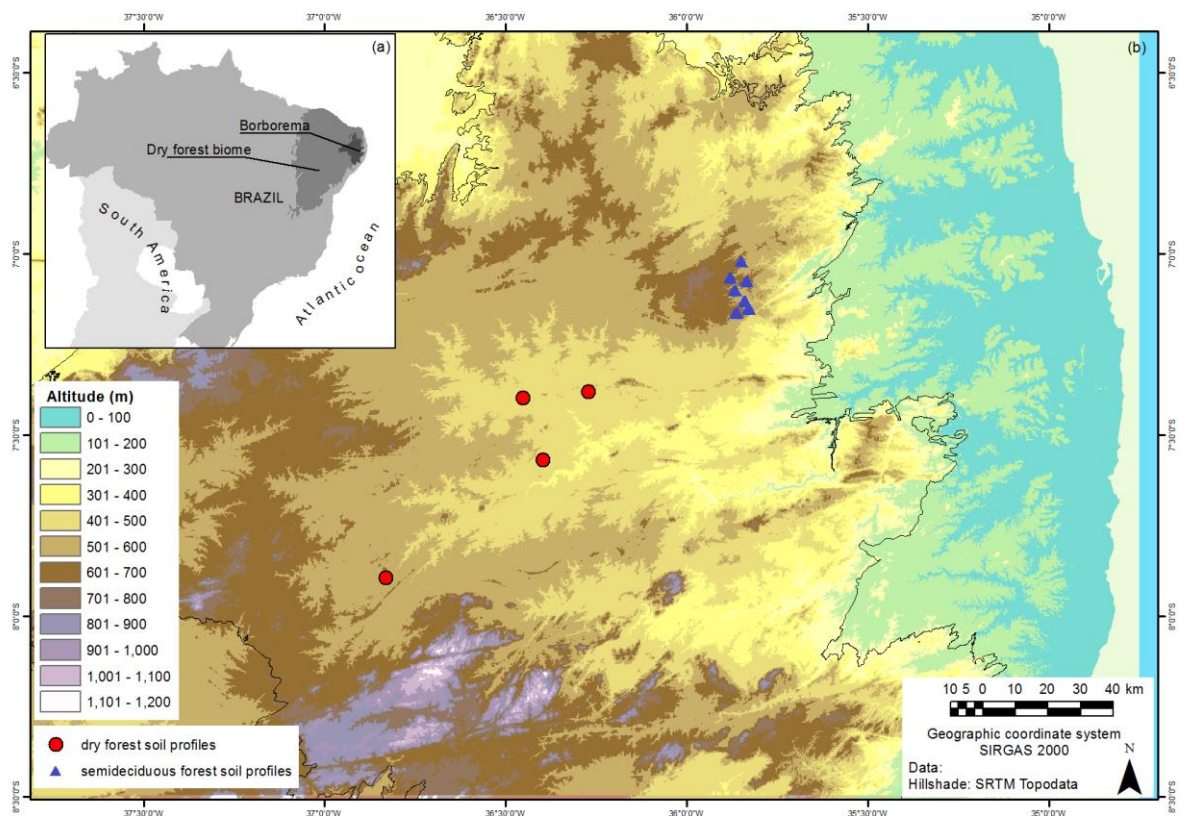
## METHODOLOGY

### *Study area*

The study area encompasses the Borborema province in the State of Paraíba (Figure 1). The Borborema province has a total area of approximately 25.984 km<sup>2</sup> and specific landscape diversity. Altitudes vary between 200 and 1,200 m in cliffs associated with resistant rocks and horst-graben systems. The Borborema province can be divided into two climatic regions (KAYANO and ANDREOLI,

2009): i) the Eastern slope, characterized by the occurrence of high orographic rainfalls (950–1,350 mm per year), caused by the range of cliffs with medium altitudes (600–1,200 m) acting as orogenic barriers to moist fronts of air from the Atlantic Ocean where plant physiognomy is described as a semideciduous forest, which has few endemic tree species and, instead, it contains species of trees associated to dry and moist forests (DEXTER et al., 2018), and; ii) an extensive flat surface, developed on Meso- and Neoproterozoic gneiss and schist, with an average temperature of 23 °C and precipitation below 700 mm per year.

Figure 1 - Borborema province: sampling sites according to altitude.



The plant physiognomy is described as a dry forest, composed by Bromeliaceae Juss., Cactaceae Juss. And Fabaceae Lindl. and members of the families Poaceae Barnhart and Cyperaceae Juss. (BANDA et al., 2016). Pollen records and radiocarbon analysis indicate a similar vegetation composition at ~8,500 cal yr B.P. in the extensive flat surface of Borborema province due to semiarid climate establishment and moist forest retraction (de Medeiros et al., 2018). Previous studies indicated the dominance of shallow and incipient weathered soils, with Leptosols (Neossolos Litólicos according to Brazilian Soil Classification System) and Luvisols (Luvisolos Crômicos) representing 43% of the study area (SANTOS et al., 2011).

### Sampling and analysis

Eleven pedons were taken, described, and classified according to the World Reference Base for Soil Resources (IUSS WORKING GROUP WRB, 2015) and the Brazilian Soil Classification System (SANTOS et al., 2018) to represent soil diversity in the Borborema province. Soil samples were collected from the surface, down to the lithic contact at each pedon. For deeper soils, a 150-cm control

section was used. Four soil profiles were selected from an open-source database to represent the soil diversity of the Atlantic rainforest (EMBRAPA, 2017).

Samples were air-dried and sieved through a 2-mm sieve before texture, reaction, and organic matter analysis. All procedures were executed according to well-established methods for tropical soils (DONAGEMA et al., 2011). Particle size composition was determined by the sieve-pipette method. The pH was measured in soil-water (1:2.5) and soil-KCl (1:2.5) solutions. Exchangeable Ca, Mg, and Al were extracted with a KCl mol L<sup>-1</sup> solution. K<sup>+</sup> and Na<sup>+</sup> were extracted with Mehlich-1 solution. The potential acidity (H + Al) was determined by the ammonium acetate method at pH 7. The sum of bases (SB= Ca<sup>2+</sup> + Mg<sup>2+</sup> + K<sup>+</sup> + Na<sup>+</sup>), equivalent cation exchange capacity (ECEC= SB + Al<sup>3+</sup>), total cation exchange capacity [CEC= SB+ (H+ Al)] base saturation (V= SB/CEC) and aluminum saturation (m= Al<sup>3+</sup> /ECEC) were calculated. A Mehlich-1 extraction solution determined the soil P status for plant growth (P<sub>M</sub>). Total organic carbon (C) was determined by Walkley and Black method (YEOMANS and BREMNER, 1988). Total nitrogen (N) was determined by the Kjeldahl method and titration (EMBRAPA, 1997). The carbon to nitrogen ratio (C/N) was calculated on a mass basis. The P adsorption capacity of the soil was determined after stirring it for 1 hour with 2.5 g of soil in 0.01 M CaCl<sub>2</sub> containing 60 mg of P L<sup>-1</sup>. The suspension was stirred for 5 min on a helical motion shaker and left to stand for 16 hours, and the remaining P in solution (P<sub>REM</sub>) was determined by photocolourimetry (ALVAREZ et al., 2000).

Bulk density, particle density and water retention curve (-6, -10, -30, -60, -100, -300, -1500 kPa tensions) were determined in undisturbed soil samples collected by volumetric rings. Total porosity and available water were calculated from these results. The tension of -1500 kPa was considered the wilting point.

## RESULTS

We have identified different soil groups in semideciduous and dry forests. Four of the seven collected soil profiles in the semideciduous forest were classified as Umbrisols according to WRB and as Neossolos Regolíticos in the Brazilian Soil Classification System. Three Stagnosols were described in a concave slope: a Pantoorthodystric Stagnosols with non-cemented iron and manganese masses (Gleissolo Háplico) in the upper slope; a Pantoorthodystric Anoumbic Stagnosols (Gleissolo Melânico) with non-cemented iron and manganese masses in the midslope; and a Pantoorthodystric Anoumbic Stagnosols (Gleissolo Melânico) in the base slope (Table 1). In general, soils are composed by a sequence of A and C horizons. Tree Luvisols (Luvisolos Crômicos) and one Regosol (Neossolo Regolítico) were described on a partially dissected pavement covered by dry forest.

The depth of the soils in semideciduous forest varied between 55 cm and 160 cm with a mean of 117 cm (Table 2). Soils are deep, and the transition between horizons was predominantly gradual, indicating high homogeneity between horizons. Soils in the dry forest are slightly shallower than the ones in the semideciduous forest.

The structure is low to moderately developed, with subangular blocky and granular types dominantly. Wormholes and sand-filled animal burrows were observed in all Regosols, indicating widespread bioturbation. Roots are denser in shallow horizons, and their growth is limited by lithic contact. Medium and coarse roots occur below 70 cm of depth. The soil color ranged from greenish-black in horizon C, with stagnic properties, to dark reddish gray in umbric epipedon. The umbric epipedon described in the soil profiles indicates melanization.

The texture of semideciduous and dry forest soils is similar. The soil profiles vary between loamy sand and clay. In general, a slight increase in clay content in deeper horizons is observed (Table 3). Coarse sand is the main fraction of soil, once its average content is approximately 40%. The clay content in subsurface horizons increases with the increase of altitude; the subsurface horizon of soils in the upper slope has an average clay content even nine times higher than the other ones. Quartz was identified in the field as the main component of coarse fraction in all soils.



Table 1 - Borborema province: sites description and classification of soils.

| Soil profile               | WRB                                                                           | SiBCS                                       | Altitude (m) | Area description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | Coordinates <sup>1</sup>  |
|----------------------------|-------------------------------------------------------------------------------|---------------------------------------------|--------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------|
| Semideciduous forest soils |                                                                               |                                             |              |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                           |
| 1                          | Leptic Umbrisol (Endoclayic, Hyperdystric)                                    | NEOSSOLO REGOLÍTICO Húmico léptico          | 650          | Soil developed on the shoulder of rock outcrop. Well-drained soils, with no apparent erosion and derived from granitoid colluvium. Soil is covered by litter and subperennial arboreal specimens. Fabaceae, Myrtaceae, Sapindaceae families, and <i>Allophylus puberulus</i> (Cambess.) Radlk., <i>Campomanesia aromatica</i> (Aubl.) Griseb., <i>Cupania impressinervia</i> Acev.-Rodr., <i>Guapira opposita</i> (Vell.) Reitz species dominate. Clay texture, umbric epipedon, and gentle slope surface. | -7.163081°<br>-35.860817° |
| 2                          | Haplic Umbrisol (Pantoloamic, Pantohyperdystric)                              | NEOSSOLO REGOLÍTICO Húmico típico           | 641          | Soil developed on footslope of rock outcrop. Well-drained soils, with no apparent erosion and derived from granitoid colluvium. Soil is covered by litter and subperennial arboreal specimens. Myrtaceae e Salicaceae families and <i>Aspidosperma parvifolium</i> A.DC., <i>Handroanthus serratifolius</i> (Vahl), <i>Zanthoxylum petiolare</i> A. St.-Hil. & Tul. Species dominate. Sandy clay loam texture, umbric epipedon and gentle slope surface.                                                   | -6.978878°<br>-35.751339° |
| 3                          | Pantoorthodystric Stagnosols (Amphiclayic, Katomanganiferic, Humic, Inclinic) | GLEISSOLO HÁPLICO Tb Distrófico argissólico | 657          | Soil developed on summit of rock outcrop. Poorly drained soils, with no apparent erosion and derived from granitoid colluvium. Soil is covered by litter and subperennial arboreal specimens. Fabaceae and Myrtaceae families and <i>Byrsonima vacciniifolia</i> A.Juss., <i>Guapira opposita</i> (Vell.) Reitz., <i>Myrcia splendens</i> (Sw.) DC. Species dominate. Sandy clay texture, umbric epipedon and gentle slope surface.                                                                        | -7.262193°<br>-35.583155° |
| 4                          | Pantoorthodystric Anoumbic Stagnosols (Pantoclayic, Humic, Inclinic)          | GLEISSOLO MELÂNICO Tb Distrófico típico     | 640          | Soil developed on footslope of rock outcrop. Poorly drained soils, with no apparent erosion and derived from granitoid colluvium. Soil is covered by litter and subperennial arboreal specimens. Fabaceae and Myrtaceae families and <i>Allophylus puberulus</i> (Cambess.) Radlk., <i>Casearia aculeata</i> Jacq., <i>Cynophalla flexuosa</i> (L.) J.Presl, <i>Zanthoxylum petiolare</i> A. St.-Hil. & Tul. Species dominate. Loamy sand texture, umbric epipedon and gentle slope surface.               | -7.054347°<br>-35.667504° |
| 5                          | Leptic Umbrisol (Endoclayic, Pantodystric)                                    | NEOSSOLO REGOLÍTICO Húmico léptico          | 643          | Soil developed on shoulder of rock outcrop. Well drained soils, with no apparent erosion and derived from granitoid colluvium. Soil is covered by litter and subperennial arboreal specimens. Bignoniaceae, Fabaceae, Myrtaceae, Cordiaceae families and <i>Allophylus puberulus</i> (Cambess.) Radlk., <i>Casearia aculeata</i> Jacq., <i>Manilkara salzmannii</i> (A. DC.) H. J. Lam. Species dominate. Sandy clay texture, umbric epipedon and gentle slope surface.                                    | -6.850142°<br>-5.867742°  |

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|   |                                                                                         |                                         |     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                           |
|---|-----------------------------------------------------------------------------------------|-----------------------------------------|-----|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------|
| 6 | Pantoorthodystric Anoumbic Stagnosols (Pantoclayic, Katomanganiferric, Humic, Inclinic) | GLEISSOLO MELÂNICO Tb Distrófico típico | 636 | Soil developed on footslope of rock outcrop. Poorly drained soils, with no apparent erosion and derived from granitoid colluvium. Soil is covered by litter and subperennial arboreal specimens. Euphorbiaceae e Myrtaceae families and <i>Allophylus puberulus</i> (Cambess.) Radlk., <i>Psidium oligospermum</i> Mart. ex DC., <i>Sebastiania jacobinensis</i> (Müll.Arg.) Müll.Arg. species dominate. Loamy sand texture, umbric epipedon and gentle slope surface. | -6.831324°<br>-35.614601° |
| 7 | Leptic Umbrisol (Pantoloamic, Hyperdystric)                                             | NEOSSOLO REGOLÍTICO Distrófico léptico  | 640 | Soil developed on backslope of rock outcrop. Well drained soils, with no apparent erosion and derived from granitoid colluvium. Soil is covered by litter and subperennial arboreal specimens. Fabaceae, Myrtaceae, Sapindaceae families and <i>Bowdichia virgilioides</i> Kunth, <i>Campomanesia dichotoma</i> (O. Berg) Mattos, <i>Cupania impressinervia</i> Acev.-Rodr. species dominate. Sandy loam texture, umbric epipedon and gentle slope surface.            | -6.648407°<br>-35.610948° |

Dry forest soils

|    |                                                         |                                       |     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                          |
|----|---------------------------------------------------------|---------------------------------------|-----|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------|
| 8  | Leptic Luvisols (Pantoloamic, Pantohypereutric, Ochric) | LUVISSOLO HÁPLICO Órtico léptico      | 439 | Soil developed on partially dissected pediment. Well drained soils, with apparent laminar erosion and derived from autochthonous gneiss. <i>Cenostygya pyramidale</i> and <i>Myracroduon urundeuva</i> dominate a dry forest fragment. Litter is absent due to sparse cover of herbaceous and deciduous arboreal specimens. Desert pavement covers the soil surface. Loam texture and ochric horizon.                                                              | -7.396507°<br>-36.45182° |
| 9  | Rhodic Luvisols (Pantoloamic, Pantohypereutric, Ochric) | LUVISSOLO CRÔMICO Órtico típico       | 538 | Soil developed on partially dissected pediment. Well drained soils, with apparent laminar erosion and derived from autochthonous gneiss. <i>Cenostygya pyramidale</i> , <i>Myracroduon urundeuva</i> , <i>Aspidosperma pyriformium</i> , <i>Jatropha mollissima</i> dominate a dry forest fragment. Litter is absent due to sparse cover of herbaceous and deciduous arboreal specimens. Desert pavement covers the soil surface. Loam texture and ochric horizon. | -7.567306°<br>-36.39647° |
| 10 | Pantohypereutric Leptic Regosols (Pantoarenic, Ochric)  | NEOSSOLO REGOLÍTICO Eutrófico léptico | 525 | Gently inclined pediment. Well drained soils, with apparent laminar erosion and derived from autochthonous granitoid. Litter is absent due to sparse cover of herbaceous and deciduous arboreal specimens. <i>Cenostygya pyramidale</i> , <i>Myracroduon urundeuva</i> , <i>Aspidosperma pyriformium</i> , <i>Jatropha mollissima</i> dominate a dry forest fragment. Gravelly sand texture and ochric horizon.                                                    | -7.378778°<br>-36.27122° |
| 11 | Leptic Luvisols (Pantoloamic, Pantohypereutric, Ochric) | LUVISSOLO CRÔMICO Órtico léptico      | 541 | Soil developed on partially dissected pediment. Poorly drained soils without evidence of erosion and derived from autochthonous schist. <i>Cenostygya pyramidale</i> , <i>Myracroduon urundeuva</i> , <i>Aspidosperma pyriformium</i> , <i>Jatropha mollissima</i> dominate a dry forest fragment. Litter is absent due to sparse cover of herbaceous and deciduous arboreal specimens. Loam texture and ochric horizon.                                           | -7.893028°<br>-36.83156° |

<sup>1</sup> Geographic coordinate system. SIRGAS 2000 datum.

Table 2 - Borborema province: Morphological properties of soils.

| Horizon                                                                                                                    | Depth (cm)    | Boundary (distinctness, topography) | Moist color  | Structure (grade, size, type) | Consistence (dry, moist, wetter, cementation) | Redoximorphic features (kind, quantity, size, contrast, state, hardness, boundary) | Redoximorphic color (matrix, masses) | Roots (quantity, size) | Pores (quantity, size, shape) |
|----------------------------------------------------------------------------------------------------------------------------|---------------|-------------------------------------|--------------|-------------------------------|-----------------------------------------------|------------------------------------------------------------------------------------|--------------------------------------|------------------------|-------------------------------|
| Semideciduous forest soils                                                                                                 |               |                                     |              |                               |                                               |                                                                                    |                                      |                        |                               |
| Leptic Umbrisol (Endoclayic, Hyperdystric)/ NEOSSOLO REGOLÍTICO Húmico léptico                                             |               |                                     |              |                               |                                               |                                                                                    |                                      |                        |                               |
| A1                                                                                                                         | 0-20          | G-S                                 | 10YR 2/1     | 2, m, sbk                     | SH, FR, ss, ps, NC                            |                                                                                    |                                      | 2, co-m-f              | 2, co-m-f, DT                 |
| A2                                                                                                                         | 20-30         | G-S                                 | 10YR 2/1     | 2, m, sbk                     | SH, FR, ss, vp, NC                            |                                                                                    |                                      | 2, m-f-vf              | 2, f, DT                      |
| AC                                                                                                                         | 30-50         | G-S                                 | 7.5YR 2.6/1  | 2, m, sbk                     | SH, FR, ms, vp, NC                            |                                                                                    |                                      | 2, m-f                 | 2, f-vf, DT                   |
| Cr                                                                                                                         | 50-55         | C-S                                 | 2.5YR 2.5/4  | 0, -, m                       | SH, FR, ms, ps, NC                            |                                                                                    |                                      | absent                 | 1, f, IG                      |
| R                                                                                                                          | 55+           |                                     |              |                               |                                               |                                                                                    |                                      |                        |                               |
| Haplic Umbrisol (Pantoloamic, Pantohyperdystric)/ NEOSSOLO REGOLÍTICO Húmico típico                                        |               |                                     |              |                               |                                               |                                                                                    |                                      |                        |                               |
| A1                                                                                                                         | 0-40          | G-S                                 | 10YR 2/1     | 2, f, gr                      | SH, FR, ss, ps, NC                            |                                                                                    |                                      | 3, m-f-vf              | 2, m-f, DT                    |
| A2                                                                                                                         | 40-62         | G-S                                 | 7.5YR 2.5/1  | 1, f, gr                      | SH, FR, ss, ps, NC                            |                                                                                    |                                      | 2, m-f-vf              | 2, f-vf, DT                   |
| A3                                                                                                                         | 62-100        | C-S                                 | 2.5YR 2.5/1  | 2, m, sbk                     | SH, FR, ss, mp, NC                            |                                                                                    |                                      | 2, f-vf                | 2, f, DT                      |
| AC                                                                                                                         | 100-140       | A-S                                 | 5YR 3/3      | 1, f, sbk                     | SH, FR, ss, ps, NC                            |                                                                                    |                                      | 1, f-vf                | 2, f, DT                      |
| R                                                                                                                          | 140+          |                                     |              |                               |                                               |                                                                                    |                                      |                        |                               |
| Pantoorthodystric Stagnosols (Amphiclayic, Katomanganiferic, Humic, Inclinic)/ GLEISSOLO HÁPLICO Tb Distrófico argissólico |               |                                     |              |                               |                                               |                                                                                    |                                      |                        |                               |
| A                                                                                                                          | 0-25          | G-S                                 | 2.5YR 3/1    | 1, m, sbk                     | SH, FR, so, po, NC                            |                                                                                    |                                      | 2, m-co-f-vf           | 2, m, TU                      |
| AB                                                                                                                         | 25-60         | G-S                                 | 5YR 3/1      | 2, m, sbk                     | SH, FR, ss, ps, NC                            |                                                                                    |                                      | 1, m, f                | 2, m, TU                      |
| Btg                                                                                                                        | 70-90(60-100) | C-W                                 | GLEY1 4/10Y  | 2, m, sbk                     | SH, FR, vs, vp, NC                            | FMM, f, 1, D, M, VW, C                                                             | GLEY1 4/10Y, 5YR 3/2                 | 1, v-vf                | 2, m-f, TU                    |
| Cgr                                                                                                                        | 90-150+       |                                     | GLEY1 2.5/N  | 1, m, sbk                     | SH, FR, vs, vp, NC                            | FMM, m, 1, D, M, VW, C                                                             | GLEY1 2.5/N, 10R 4/8                 | absent                 | 1, f, TU                      |
| Pantoorthodystric Anoumbic Stagnosols (Pantoclayic, Humic, Inclinic)/ GLEISSOLO MELÂNICO Tb Distrófico típico              |               |                                     |              |                               |                                               |                                                                                    |                                      |                        |                               |
| Ag                                                                                                                         | 0-70          | G-S                                 | GLEY1 2.5/5G | 2, m, gr                      | SH, FR, ss, po, NC                            |                                                                                    |                                      | 3, co-m-f              | 2, m, TU                      |

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| Y                                                                                                                              |              |     |                 |                   |                          |                              |                               |  |                  |                   |
|--------------------------------------------------------------------------------------------------------------------------------|--------------|-----|-----------------|-------------------|--------------------------|------------------------------|-------------------------------|--|------------------|-------------------|
| Cg                                                                                                                             | 70-122       | C-S | GLE Y1<br>3/5GY | 1, m,<br>sbk      | SH, FR,<br>so, po, NC    |                              |                               |  | 1, f             | 2, f, VE          |
| Cg                                                                                                                             | 122-160<br>+ |     | GLE Y1<br>4/10Y | 0, -, m           | SH, FR,<br>so, po, NC    | FMM, f, 1,<br>D, M, VW,<br>C | GLE Y1<br>4/10Y,<br>7.5YR 5/6 |  | 1, f             | 1, f, VE          |
| Leptic Umbrisol (Endoclayic, Pantodystric)/ NEOSSOLO REGOLÍTICO Húmico léptico                                                 |              |     |                 |                   |                          |                              |                               |  |                  |                   |
| A1                                                                                                                             | 0-27         | G-S | 2.5Y<br>3/1     | 2, m,<br>gr       | SH, FR,<br>ss, ps, NC    |                              |                               |  | 2, m-<br>co-f    | 2, m,<br>TU       |
| A2                                                                                                                             | 27-47        | C-S | 7.5YR<br>3/2    | 2, m/f,<br>sbk/gr | SH, FR,<br>ms, mp,<br>NC |                              |                               |  | 1, vc-<br>co-m-f | 1, m,<br>TU       |
| Cr                                                                                                                             | 47-67        |     | variegat<br>ed  | 0, -, m           | SH, FR,<br>so, po, NC    |                              |                               |  | 1, f             | 1, f, IG          |
| R                                                                                                                              | 67+          |     |                 |                   |                          |                              |                               |  |                  |                   |
| Pantoorthystric Anoumbic Stagnosols (Pantoclayic, Katomanganiferri c, Humic, Inclinic)/GLEISSOLO MELÂNICO Tb Distrófico típico |              |     |                 |                   |                          |                              |                               |  |                  |                   |
| A                                                                                                                              | 0-58         | G-S | 5YR<br>2.5/1    | 2, m,<br>sbk      | SH, FR,<br>ss, po, NC    |                              |                               |  | 2, co-<br>m-f    | 2, m,<br>TU       |
| CA                                                                                                                             | 58-78        | G-S | 10YR<br>3/2     | 2, f,<br>sbk      | SH, FR,<br>so, po, NC    |                              |                               |  | 2, f-vf          | 1, f, IG          |
| Cg                                                                                                                             | 78-150<br>+  |     | GLE Y1<br>5/10Y | 2, m,<br>sbk      | SH, FR,<br>so, po, NC    | FMM, f, 1,<br>D, M, VW,<br>C | GLE Y1<br>5/10Y,<br>7.5YR 5/6 |  | 2, f-vf          | 1, f, IG          |
| Leptic Umbrisol (Pantoloamic, Hyperdystric)/ NEOSSOLO REGOLÍTICO Distrófico léptico                                            |              |     |                 |                   |                          |                              |                               |  |                  |                   |
| A                                                                                                                              | 0-45         | C-S | 7.5YR<br>3/1    | 1, m,<br>sbk      | SH, FR,<br>so, po, NC    |                              |                               |  | 3, co-<br>m-f    | 2, co-<br>m, TU   |
| AC                                                                                                                             | 45-100       | A-S | 5YR<br>3/2      | 2, m,<br>sbk      | SH, FR,<br>so, po, NC    |                              |                               |  | 3, m-f-<br>vf    | 2, f, TU          |
| R                                                                                                                              | 100<br>+     |     |                 |                   |                          |                              |                               |  |                  |                   |
| Dry forest soils                                                                                                               |              |     |                 |                   |                          |                              |                               |  |                  |                   |
| Leptic Luvisols (Pantoloamic, Pantohypereutric, Ochric)/ LUVISSOLO HÁPLICO Órtico léptico                                      |              |     |                 |                   |                          |                              |                               |  |                  |                   |
| A                                                                                                                              | 0-10         | C-S | 10R 3/4         | 2, f,<br>sbk      | SH, FR,<br>vs, p, NC     |                              |                               |  | 1, f-vf-<br>m    | 3, f-vf-<br>m, DT |
| Bt                                                                                                                             | 10-30        | C-S | 2.5 YR<br>3/2   | 2, m,<br>sbk      | H, FI, vs,<br>vp, NC     |                              |                               |  | 3, f-vf-<br>m    | 1, f-vf-<br>m, TU |
| CR                                                                                                                             | 30-50        | C-S | 7.5YR<br>4/4    | 0, -, m           | H, FI, ms,<br>mp, NC     |                              |                               |  | absent           | 2, vf,<br>VE      |
| R                                                                                                                              | 50+          |     |                 |                   |                          |                              |                               |  |                  |                   |
| Rhodic Luvisols (Pantoloamic, Pantohypereutric, Ochric)/ LUVISSOLO CRÔMICO Órtico típico                                       |              |     |                 |                   |                          |                              |                               |  |                  |                   |
| A                                                                                                                              | 0-3<br>(2-5) | C-W | 7.5YR<br>3/3    | 2, f,<br>sbk      | H, FR, so,<br>po, NC     |                              |                               |  | 1, vf            | 2, f, TU          |
| Bt1                                                                                                                            | 3-25         | G-S | 7.5YR<br>3/4    | 1, m,<br>sbk      | H, FI, vs,<br>mp, NC     |                              |                               |  | 2, f-vf          | 3, m,<br>TU       |
| Bt2                                                                                                                            | 25-50        | C-S | 7.5YR<br>3/6    | 3, m,<br>pr       | H, FI, vs,<br>vp, NC     |                              |                               |  | 1, f-vf          | 2, m,<br>IG       |
| Cr                                                                                                                             | 50-75        | G-S | 7.5YR<br>5/6    | 0, -, m           | H, FI, ms,<br>mp, NC     |                              |                               |  | absent           | 2, vf,<br>VE      |



|                                                                                               |           |     |              |              |                       |  |  |               |                 |
|-----------------------------------------------------------------------------------------------|-----------|-----|--------------|--------------|-----------------------|--|--|---------------|-----------------|
| R                                                                                             | 75+       |     |              |              |                       |  |  |               |                 |
| Pantohypereutric Leptic Regosols (Pantoarenic, Ochric)/ NEOSSOLO REGOLÍTICO Eutrófico léptico |           |     |              |              |                       |  |  |               |                 |
| A                                                                                             | 0-5       | C-S | 10YR<br>2/2  | 2, m,<br>sbk | L, FR, so,<br>po, NC  |  |  | 2, f-vf       | 3, m-f,<br>TU   |
| AC1                                                                                           | 5-15      | C-S | 7.5YR<br>3/3 | 2, m,<br>sbk | S, FR, so,<br>po, NC  |  |  | 2, f-vf       | 2, f, TU        |
| AC2                                                                                           | 15-<br>30 | C-S | 7.5YR<br>4/4 | 2, m,<br>sbk | SH, FR,<br>so, po, NC |  |  | 2, co-<br>m-f | 2, f-vf,<br>TU  |
| C                                                                                             | 30-<br>60 | A-S | 5YR<br>4/4   | 1, f,<br>sbk | S, L, so,<br>po, NC   |  |  | 1, vf         | 2, f-vf,<br>IG  |
| R                                                                                             | 60+       |     |              |              |                       |  |  |               |                 |
| Leptic Luvisols (Pantoloamic, Pantohypereutric, Ochric)/ LUVISSOLO CRÔMICO Órtico léptico     |           |     |              |              |                       |  |  |               |                 |
| A                                                                                             | 0-5       | C-S | 5YR<br>4/2   | 2, m,<br>sbk | SH, FR,<br>ss, ps, NC |  |  | 2, f          | 1, f, TU        |
| Bt                                                                                            | 5-25      | C-S | 5YR<br>3/4   | 2, m,<br>pr  | H, FR, s,<br>ps, NC   |  |  | 2, m          | 2, m, f,<br>TU  |
| C                                                                                             | 25-<br>55 | C-S | 7.5YR<br>4/4 | 2, f, pr     | VH, FI, vs,<br>vp, NC |  |  | 1, m          | 2, co-<br>m, VE |
| R                                                                                             | 55+       |     |              |              |                       |  |  |               |                 |

Distinctness: A=abrupt, C=clear, G=gradual. Topography: S=smooth, W=wavy. Structure: Grade: 0=structureless, 1=weak, 2=moderate. Size: f=fine, m=medium. Type: gr=granular, m=massive, sbk=subangular block, /=principal structure parting to secondary one. Consistence: Dry: L=loose, S=soft, SH=slightly hard. Moist: FI=firm, FR=friable, L=loose. Wetter: ms=moderately stick, vs=very stick, so=nonsticky, ss=slightly sticky, mp=moderately plastic, po=nonplastic, ps=slightly plastic, vp=very plastic. Cementation: NC=non-cemented. Redoximorphic features: Kind: FMM=non-cemented iron-manganese masses. Quantity: f=few, m=many. Size: 1=fine. Contrast: D=distinct. State: M=moist. Hardness: VW=very weakly cemented. Boundary: C=clear. Roots and pores: 1=few, 2=common, 3=many, co=coarse, f=fine, m=medium, vc=very coarse, vf=very fine, DT=dendritic tubular, IG=irregular, TU=tubular, VE=vesicular.

Table 3 - Borborema province: Physical soil data of soil profiles and comparison data.

| Horizon                                                                             | Depth<br>cm | Coarse sand<br>----- % ----- | Fine sand | Silt | Clay | Texture         |
|-------------------------------------------------------------------------------------|-------------|------------------------------|-----------|------|------|-----------------|
| Semideciduous forest soils                                                          |             |                              |           |      |      |                 |
| Leptic Umbrisol (Endoclayic, Hyperdystric)/ NEOSSOLO REGOLÍTICO Húmico léptico      |             |                              |           |      |      |                 |
| A1                                                                                  | 0-20        | 28.1                         | 20.9      | 14.1 | 36.8 | sandy clay      |
| A2                                                                                  | 20-30       | 32.4                         | 18.7      | 13.2 | 35.7 | sandy clay      |
| AC                                                                                  | 30-50       | 17.8                         | 11.2      | 10.5 | 60.5 | clay            |
| Cr                                                                                  | 50-55       | 14.3                         | 6.5       | 10.1 | 69.1 | clay            |
| R                                                                                   | 55+         |                              |           |      |      |                 |
| Haplic Umbrisol (Pantoloamic, Pantohyperdystric)/ NEOSSOLO REGOLÍTICO Húmico típico |             |                              |           |      |      |                 |
| A1                                                                                  | 0-40        | 37.6                         | 18.3      | 15.8 | 28.4 | sandy clay loam |
| A2                                                                                  | 40-62       | 36.0                         | 21.8      | 15.5 | 26.6 | sandy clay loam |
| A3                                                                                  | 62-100      | 31.9                         | 23.8      | 15.8 | 28.6 | sandy clay loam |
| AC                                                                                  | 100-140     | 33.1                         | 17.8      | 16.9 | 32.2 | sandy clay loam |

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|                                                                                                                                  |               |         |         |         |         |                 |
|----------------------------------------------------------------------------------------------------------------------------------|---------------|---------|---------|---------|---------|-----------------|
| R                                                                                                                                | 140+          |         |         |         |         |                 |
| Pantoorthodystric Stagnosols (Amphiclayic, Katomanganiferriç, Humic, Inclinic)/ GLEISSOLO HÁPLICO Tb Distrófico argissólico      |               |         |         |         |         |                 |
| A                                                                                                                                | 0-25          | 40.0    | 31.5    | 7.8     | 20.7    | sandy clay loam |
| AB                                                                                                                               | 25-60         | 38.2    | 27.8    | 11.1    | 22.9    | sandy clay loam |
| Btg                                                                                                                              | 70-90(60-100) | 25.3    | 22.0    | 11.3    | 41.4    | sandy clay      |
| Cgr                                                                                                                              | 90-150+       | 21.5    | 11.7    | 10.7    | 56.2    | clay            |
| Pantoorthodystric Anoumbriç Stagnosols (Pantoclayic, Humic, Inclinic)/ GLEISSOLO MELÂNICO Tb Distrófico típico                   |               |         |         |         |         |                 |
| Ag                                                                                                                               | 0-70          | 51.1    | 21.5    | 13.3    | 14.2    | sandy loam      |
| CAg                                                                                                                              | 70-122        | 60.0    | 22.9    | 11.6    | 5.5     | loamy sand      |
| Cg                                                                                                                               | 122-160+      | 59.1    | 24.4    | 10.9    | 5.5     | loamy sand      |
| Leptic Umbrisol (Endoclayic, Pantodystric)/ NEOSSOLO REGULÍTICO Húmico léptico                                                   |               |         |         |         |         |                 |
| A1                                                                                                                               | 0-27          | 51.8    | 13.1    | 6.3     | 28.8    | sandy clay loam |
| A2                                                                                                                               | 27-47         | 47.5    | 11.7    | 12.0    | 28.8    | sandy clay loam |
| Cr                                                                                                                               | 47-67         | 42.5    | 10.2    | 10.3    | 37.0    | sandy clay      |
| R                                                                                                                                | 67+           |         |         |         |         |                 |
| Pantoorthodystric Anoumbriç Stagnosols (Pantoclayic, Katomanganiferriç, Humic, Inclinic)/GLEISSOLO MELÂNICO Tb Distrófico típico |               |         |         |         |         |                 |
| A                                                                                                                                | 0-58          | 45.1    | 26.1    | 14.0    | 14.9    | sandy loam      |
| CA                                                                                                                               | 58-78         | 51.0    | 23.7    | 17.4    | 8.0     | sandy loam      |
| Cg                                                                                                                               | 78-150+       | 52.5    | 25.6    | 14.3    | 7.6     | loamy sand      |
| Leptic Umbrisol (Pantoloamic, Hyperdystric)/ NEOSSOLO REGULÍTICO Distrófico léptico                                              |               |         |         |         |         |                 |
| A                                                                                                                                | 0-45          | 62.3    | 19.0    | 8.2     | 10.5    | loamy sand      |
| AC                                                                                                                               | 45-100        | 50.4    | 22.4    | 16.5    | 10.7    | sandy loam      |
| R                                                                                                                                | 100+          |         |         |         |         |                 |
| All (median-CV)                                                                                                                  |               | 40.0-34 | 21.5-32 | 12.0-24 | 28.4-64 |                 |
| Dry forest soils                                                                                                                 |               |         |         |         |         |                 |
| Leptic Luvisols (Pantoloamic, Pantohypereutric, Ochric)/ LUVISSOLO CRÔMICO Órtico léptico                                        |               |         |         |         |         |                 |
| A                                                                                                                                | 0-10          | 27.2    | 18.9    | 12.9    | 4.1     | sandy loam      |
| Bt                                                                                                                               | 10-30         | 26.9    | 22.7    | 18.6    | 31.8    | sandy clay loam |
| CR                                                                                                                               | 30-50         | 24.0    | 24.0    | 31.4    | 21.6    | loam            |
| R                                                                                                                                | 50+           |         |         |         |         |                 |
| Rhodic Luvisols (Pantoloamic, Pantohypereutric, Ochric)/ LUVISSOLO CRÔMICO Órtico típico                                         |               |         |         |         |         |                 |
| A                                                                                                                                | 0-3 (2-5)     | 30.9    | 19.4    | 24.5    | 25.3    | sandy clay loam |
| Bt1                                                                                                                              | 3-25          | 26.3    | 12.8    | 26.8    | 34.0    | sandy clay loam |
| Bt2                                                                                                                              | 25-50         | 27.7    | 15.5    | 27.2    | 29.6    | sandy clay loam |
| Cr                                                                                                                               | 50-75         | 35.7    | 29.9    | 28.9    | 5.5     | sandy loam      |
| R                                                                                                                                | 75+           |         |         |         |         |                 |
| Pantohypereutric Leptic Regosols (Pantoarenic, Ochric)/ NEOSSOLO REGULÍTICO Eutrófico léptico                                    |               |         |         |         |         |                 |
| A                                                                                                                                | 0-5           | 59.5    | 19.6    | 14.0    | 6.9     | loamy sand      |
| AC1                                                                                                                              | 5-15          | 63.9    | 19.1    | 12.6    | 4.4     | loamy sand      |

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|                                                                                                                    |          |         |         |         |         |                 |
|--------------------------------------------------------------------------------------------------------------------|----------|---------|---------|---------|---------|-----------------|
| AC2                                                                                                                | 15-30    | 65.3    | 15.3    | 15.1    | 4.3     | loamy sand      |
| C                                                                                                                  | 30-60    | 59.5    | 15.5    | 15.1    | 9.9     | sandy loam      |
| R                                                                                                                  | 60+      |         |         |         |         |                 |
| Leptic Luvisols (Pantoloamic, Pantohypereutric, Ochric)/ LUVISSOLO CRÔMICO Órtico léptico                          |          |         |         |         |         |                 |
| A                                                                                                                  | 0-5      | 42.7    | 25.8    | 17.2    | 14.3    | sandy loam      |
| Bt                                                                                                                 | 5-25     | 29.3    | 11.7    | 19.1    | 39.9    | clay loam       |
| C                                                                                                                  | 25-55    | 43.4    | 20.0    | 13.3    | 23.4    | sandy clay loam |
| R                                                                                                                  | 55+      |         |         |         |         |                 |
| All (median-CV)                                                                                                    |          | 33.3-39 | 19.3-26 | 17.9-34 | 18.0-70 |                 |
| Moist forest soils*                                                                                                |          |         |         |         |         |                 |
| Xanthic Ferralsols (Loamic, Pantohyperdystric, Ochric)/ LATOSSOLO AMARELO Distrófico psamítico                     |          |         |         |         |         |                 |
| A1                                                                                                                 | 0-15     | 11.0    | 78.0    | 2.0     | 9.0     | loamy sand      |
| A2                                                                                                                 | 15-30    | 11.0    | 77.0    | 2.0     | 10.0    | loamy sand      |
| Bw1                                                                                                                | 30-90    | 13.0    | 68.0    | 3.0     | 16.0    | sandy loam      |
| Bw2                                                                                                                | 90-145   | 13.0    | 68.0    | 2.0     | 17.0    | sandy loam      |
| Bw3                                                                                                                | 145-175+ | 14.0    | 66.0    | 2.0     | 18.0    | sandy loam      |
| Xanthic Pisoplinthic Ferralsols (Loamic, Orthodystric, Ferric, Ochric)/ LATOSSOLO AMARELO Distrófico plintossólico |          |         |         |         |         |                 |
| A1                                                                                                                 | 0-20     | 20.0    | 60.0    | 6.0     | 14.0    | sandy loam      |
| A2                                                                                                                 | 20-40    | 18.0    | 60.0    | 5.0     | 17.0    | sandy loam      |
| Bw1                                                                                                                | 40-75    | 16.0    | 56.0    | 6.0     | 22.0    | sandy clay loam |
| Bw2                                                                                                                | 75-120   | 18.0    | 54.0    | 6.0     | 22.0    | sandy clay loam |
| Bw3                                                                                                                | 120-165+ | 17.0    | 45.0    | 8.0     | 30.0    | sandy clay loam |
| Xanthic Pisoplinthic Ferralsols (Loamic, Orthodystric, Ferric, Ochric)/ LATOSSOLO AMARELO Distrófico plintossólico |          |         |         |         |         |                 |
| A1                                                                                                                 | 0-20     | 19.0    | 55.0    | 7.0     | 19.0    | sandy loam      |
| A2                                                                                                                 | 20-40    | 16.0    | 53.0    | 4.0     | 27.0    | sandy clay loam |
| Bw1                                                                                                                | 40-70    | 15.0    | 50.0    | 4.0     | 31.0    | sandy clay loam |
| Bw2                                                                                                                | 70-150+  | 15.0    | 52.0    | 5.0     | 28.0    | sandy clay loam |
| Xanthic Ferric Ferralic Pisoplinthic Acrisols (Loamic, Ochric)/ ARGISSOLO AMARELO Distrófico plintossólico         |          |         |         |         |         |                 |
| A1                                                                                                                 | 0-20     | 19.0    | 68.0    | 4.0     | 9.0     | loamy sand      |
| A2                                                                                                                 | 20-40    | 20.0    | 60.0    | 3.0     | 17.0    | sandy loam      |
| Bw1                                                                                                                | 40-65    | 19.0    | 53.0    | 4.0     | 24.0    | sandy clay loam |
| Bw2                                                                                                                | 65-140+  | 18.0    | 53.0    | 4.0     | 25.0    | sandy clay loam |
| All (median-CV)                                                                                                    |          | 16.5-18 | 58-19   | 4-44    | 18.5-40 |                 |

\* (EMBRAPA, 2017).

The reactivity of soils in the semideciduous and dry forest is different. The first one is between extremely and strongly acid, dystrophic, and hyperdystrophic, having aluminum saturation (m) dominantly above 50% (Table 4). The soils in the dry forest vary from strongly acid to slightly alkaline, hypereutrophic, and  $Al^{3+}$  is virtually absent. KCl pH in semideciduous and dry forests soils is equal or below 5.0, and delta pH is negative in all horizons, indicating the dominance of negative charges.  $Ca^{2+} > Mg^{2+} > K^{+} > Na^{+}$  is the base dominance in the exchange complex. In general, BS, ECEC, CEC,

PM, C, and N content in semideciduous forest soils decreases with the increase of depth, suggesting that chemical soil properties are directly correlated to the input of organic residues. In opposite, the increase of natural fertility of dry forest soils with an increase of depth suggests that these soils are directly related to the parent material.

The C content in the upper horizon of semideciduous forest soils ranged between 0.70 and 2.92%. In the 20–50 cm depth, the median C concentration is 1.39%, and the coefficient of variation is 46%. The mean C content in dry forest soils is slightly lower than in semideciduous forest soils. The C/N ratio decreases with the increase of depth. In the uppermost horizons, C/N ratio ranged between 10 and 17. In the 10–100-cm depth, the C/N ratio values ranged between 2 and 10 (Table 4). The soil profile presented particle and bulk densities values close to the density of quartz (Table 5). The available water and wilting point represent, respectively, 3 and 2% of total porosity in semideciduous and dry forest soils.

## DISCUSSION

Although semideciduous and dry forest soils are derived from similar parent material, the morphology, texture, and chemical properties suggest that the semideciduous forest soils exhibit common traits with soils in moist and dry forests. The absence of weatherable minerals in the coarse fraction, acidic pH, low CEC, and low base saturation reflects a deeply weathered scenario under moist and tropical climate (Marques et al., 2004; de Souza et al., 2015, 2018), as well as in moist forests (Table 4). On the other hand, coarse sand dominance and low grade structure indicate similarity to incipient soils developed in the Brazilian dry forests (PINHEIRO; COSTA; ARAÚJO, 2013; ARAÚJO FILHO et al., 2017).

The high organic carbon content in the semideciduous forest soils is attributed to the high C/N ratio. A decrease in C/N ratio, simultaneous to the proportion of stabilized organic carbon compounds, has been shown in several studies (GIONGO et al., 2011; GRÜNEBERG; ZICHE; WELLBROCK, 2014; PIRES et al., 2017). A strong positive correlation between C/N and C indicates that the organic carbon is stocked in less favorable microbial activity conditions (GRAND and LAVKULICH, 2012). A decrease of potential acidity, ECEC, and CEC with an increase of depth indicates that the soil's fertility from semideciduous forests is not associated with parent material, possibly related to organic carbon. This result indicates that organic carbon influences geochemical processes in semideciduous forests and moist forests (CARTER, 2000; SOUZA et al., 2015).

Low clay content is attributed to gleization, ferrollysis, and elutriation. Elutriation is a common soil process in semiarid areas of selective transport of lighter particles in the surface horizon by rainwater. The low to moderate grades in this study area suggest high erosivity of rains in these soils, so the clay can be preferentially eroded to lower altitudes. Kaolinite and Fe (hydr)oxides are the main components of the clay fraction in acidic Brazilian soils (FONTES and WEED, 1991). However, poor drainage and waterlogged conditions in Stagnosols are associated with reductive dissolution of Fe (hydr)oxides. Values of  $P_{REM}$  above  $20 \text{ mg L}^{-1}$  indicate a low P adsorption capacity and it suggests a virtual absence of Fe oxides in these soils. Besides, seasonally alternating cycles of reduction and oxidation lead to clay destruction by ferrollysis and CEC reduction (BRINKMAN, 1970; FERREIRA et al., 2016). During the anaerobic phase, iron is reduced by microorganisms with the oxidation of organic matter and the formation of hydroxyl ions. The  $\text{Fe}^{2+}$  displaces exchangeable cations, which are leached. During the following aerobic phase,  $\text{Fe}(\text{OH})_3$  and  $\text{H}^+$  are produced by oxidation of  $\text{Fe}^{2+}$ . Consequently, the  $\text{H}^+$  displaces the exchangeable ferrous iron, and it corrodes the octahedral layers of the clay minerals at their edges. Simultaneously, there is an equivalent diffusion of hydrogen against bases released from the octahedral lattice edges. With continued fluctuation between anaerobic and aerobic phases, the seasonally eutrophic soil develops to a grey, unstable sandy soil with low clay content and very low cation exchange capacity. Widespread redoximorphic colors are attributed to stagnation of rainwater in deep horizons due to low permeable layers on subsurface. This process is different from the rise of the water table and it changes the soil morphology. Furthermore, we suggest the inclusion of the suborder 'Estágnicos' for Gleissolos in the Brazilian Soil Classification System, once soils with stagnic properties have a larger spatial distribution than expected.

Table 4 - Borborema province: Chemical soil properties of soils in the study area and comparison data.

| Horizon                                                                                                                    | Depth<br>cm   | H <sub>2</sub> O<br>pH | KCl<br>pH | P <sub>M</sub> | K <sup>+</sup>              | Na <sup>+</sup> | Ca <sup>2+</sup> | Mg <sup>2+</sup>                   | Al <sup>3+</sup> | H+Al | SB   | ECEC | CEC           | V  | m  | C     | N     | C/N | P <sub>REM</sub><br>mg<br>L <sup>-1</sup> |
|----------------------------------------------------------------------------------------------------------------------------|---------------|------------------------|-----------|----------------|-----------------------------|-----------------|------------------|------------------------------------|------------------|------|------|------|---------------|----|----|-------|-------|-----|-------------------------------------------|
|                                                                                                                            |               |                        |           |                | --- mg kg <sup>-1</sup> --- |                 |                  | ----- cmolc kg <sup>-1</sup> ----- |                  |      |      |      | ----- % ----- |    |    |       |       |     |                                           |
| Semideciduous forest soils                                                                                                 |               |                        |           |                |                             |                 |                  |                                    |                  |      |      |      |               |    |    |       |       |     |                                           |
| Leptic Umbrisol (Endoclayic, Hyperdystric)/ NEOSSOLO REGOLÍTICO Húmico léptico                                             |               |                        |           |                |                             |                 |                  |                                    |                  |      |      |      |               |    |    |       |       |     |                                           |
| A <sub>1</sub>                                                                                                             | 0-20          | 4.4                    | 3.67      | 3.3            | 90                          | 7.8             | 1.82             | 1.00                               | 1.8              | 12.7 | 3.08 | 4.83 | 15.78         | 20 | 36 | 2.92  | 0.224 | 13  | 26.6                                      |
| A <sub>2</sub>                                                                                                             | 20-30         | 4.38                   | 3.69      | 1.8            | 47                          | 4.9             | 0.65             | 0.80                               | 2.2              | 11.6 | 1.59 | 3.83 | 13.19         | 12 | 59 | 2.55  | 0.153 | 17  | 24.2                                      |
| AC                                                                                                                         | 30-50         | 4.69                   | 3.79      | <1             | 71                          | 9.8             | 0.29             | 1.49                               | 1.9              | 8.7  | 2.00 | 3.85 | 10.7          | 19 | 48 | 1.39  | 0.102 | 14  | 22.2                                      |
| Cr                                                                                                                         | 50-55         | 4.75                   | 3.85      | <1             | 76                          | 11.8            | 0.22             | 1.51                               | 1.5              | 5.6  | 1.98 | 3.44 | 7.58          | 26 | 42 | 0.70  | 0.067 | 10  | 22.7                                      |
| R                                                                                                                          | 55+           |                        |           |                |                             |                 |                  |                                    |                  |      |      |      |               |    |    |       |       |     |                                           |
| Haplic Umbrisol (Pantoloamic, Pantohyperdystric)/ NEOSSOLO REGOLÍTICO Húmico típico                                        |               |                        |           |                |                             |                 |                  |                                    |                  |      |      |      |               |    |    |       |       |     |                                           |
| A <sub>1</sub>                                                                                                             | 0-40          | 4.35                   | 3.69      | 2.4            | 76                          | <1              | 0.85             | 0.46                               | 2.7              | 12   | 1.51 | 4.23 | 13.51         | 11 | 64 | 2.39  | 0.142 | 17  | 24.7                                      |
| A <sub>2</sub>                                                                                                             | 40-62         | 4.42                   | 3.70      | 1.2            | 20                          | 3.9             | 0.39             | 0.38                               | 3.1              | 11.4 | 0.84 | 3.95 | 12.24         | 7  | 79 | 1.39  | 0.085 | 16  | 21.8                                      |
| A <sub>3</sub>                                                                                                             | 62-100        | 4.73                   | 3.70      | 1.0            | 16                          | 12.8            | 0.51             | 0.54                               | 2.8              | 9.2  | 1.15 | 3.97 | 10.35         | 11 | 71 | 0.93  | 0.057 | 16  | 23.1                                      |
| AC                                                                                                                         | 100-140       | 5.15                   | 3.75      | 1.0            | 24                          | 37.5            | 0.49             | 0.95                               | 2.2              | 6.9  | 1.66 | 3.90 | 8.56          | 19 | 57 | 0.54  | 0.042 | 13  | 27                                        |
| R                                                                                                                          | 140+          |                        |           |                |                             |                 |                  |                                    |                  |      |      |      |               |    |    |       |       |     |                                           |
| Pantoorthydystric Stagnosols (Amphiclayic, Katomanganiferic, Humic, Inclinic)/ GLEISSOLO HÁPLICO Tb Distrófico argissólico |               |                        |           |                |                             |                 |                  |                                    |                  |      |      |      |               |    |    |       |       |     |                                           |
| A                                                                                                                          | 0-25          | 4.6                    | 3.82      | 3.9            | 73                          | <1              | 1.3              | 0.76                               | 0.7              | 8    | 2.25 | 2.93 | 10.25         | 22 | 23 | 2.55  | 0.165 | 16  | 39                                        |
| AB                                                                                                                         | 25-60         | 4.44                   | 3.87      | 1.2            | 27                          | <1              | 0.27             | 0.16                               | 1.7              | 6.9  | 0.50 | 2.15 | 7.4           | 7  | 77 | 1.00  | 0.062 | 16  | 28.3                                      |
| Btg                                                                                                                        | 70-90(60-100) | 4.69                   | 3.88      | <1             | 32                          | <1              | 0.28             | 0.44                               | 1.9              | 6.4  | 0.81 | 2.66 | 7.21          | 11 | 70 | 0.62  | 0.050 | 12  | 24.2                                      |
| Cgr                                                                                                                        | 90-150+       | 4.85                   | 3.94      | <1             | 32                          | 4.9             | 0.21             | 1.00                               | 1.5              | 5.1  | 1.31 | 2.77 | 6.41          | 20 | 53 | 0.62  | 0.043 | 14  | 23.1                                      |
| Pantoorthydystric Anoumbic Stagnosols (Pantoclayic, Humic, Inclinic)/ GLEISSOLO MELÂNICO Tb Distrófico típico              |               |                        |           |                |                             |                 |                  |                                    |                  |      |      |      |               |    |    |       |       |     |                                           |
| Ag                                                                                                                         | 0-70          | 4.92                   | 3.79      | 1.6            | 32                          | 9.8             | 0.5              | 0.52                               | 1.4              | 5.5  | 1.14 | 2.50 | 6.64          | 17 | 54 | 0.85  | 0.053 | 16  | 33.2                                      |
| CAg                                                                                                                        | 70-122        | 5.3                    | 4.02      | <1             | 18                          | 7.8             | 0.32             | 0.27                               | 0.4              | 1.9  | 0.67 | 1.06 | 2.57          | 26 | 37 | 0.08  | 0.009 | 9   | 52.6                                      |
| Cg                                                                                                                         | 122-160+      | 5.23                   | 4.00      | <1             | 20                          | 10.8            | 0.29             | 0.33                               | 0.6              | 1.8  | 0.72 | 1.30 | 2.52          | 29 | 45 | <0.01 | 0.005 | 2   | 51.6                                      |
| Leptic Umbrisol (Endoclayic, Pantodystric)/ NEOSSOLO REGOLÍTICO Húmico léptico                                             |               |                        |           |                |                             |                 |                  |                                    |                  |      |      |      |               |    |    |       |       |     |                                           |
| A <sub>1</sub>                                                                                                             | 0-27          | 4.94                   | 3.92      | 3.7            | 154                         | 15.7            | 1.99             | 1.12                               | 0.8              | 6.9  | 3.57 | 4.35 | 10.47         | 34 | 18 | 2.39  | 0.187 | 13  | 38.7                                      |
| A <sub>2</sub>                                                                                                             | 27-47         | 4.85                   | 3.80      | 1.6            | 114                         | 20.7            | 0.61             | 1.05                               | 1.9              | 6.9  | 2.04 | 3.89 | 8.94          | 23 | 48 | 1.39  | 0.093 | 15  | 27.6                                      |
| Cr                                                                                                                         | 47-67         | 5.00                   | 3.75      | <1             | 78                          | 35.5            | 0.39             | 1.52                               | 2.5              | 5.5  | 2.26 | 4.79 | 7.76          | 29 | 53 | 0.31  | 0.039 | 8   | 27.8                                      |



Ecotone soils in northeastern Brazil

|                                                                                                                                 |           |            |            |           |       |             |              |             |            |            |             |             |             |             |             |             |              |           |             |
|---------------------------------------------------------------------------------------------------------------------------------|-----------|------------|------------|-----------|-------|-------------|--------------|-------------|------------|------------|-------------|-------------|-------------|-------------|-------------|-------------|--------------|-----------|-------------|
| R                                                                                                                               | 67+       |            |            |           |       |             |              |             |            |            |             |             |             |             |             |             |              |           |             |
| Pantorthodystric Anoumbic Stagnosols (Pantoclayic, Katomanganiferriic, Humic, Inclinic)/GLEISSOLO MELÂNICO Tb Distrófico típico |           |            |            |           |       |             |              |             |            |            |             |             |             |             |             |             |              |           |             |
| A                                                                                                                               | 0-58      | 4.56       | 3.66       | 1.8       | 101   | 1.9         | 0.49         | 0.22        | 1.7        | 6.6        | 0.98        | 2.63        | 7.58        | 13          | 63          | 0.70        | 0.071        | 10        | 34.9        |
| CA                                                                                                                              | 58-78     | 4.57       | 3.75       | <1        | 27    | <1          | 0.27         | 0.08        | 1.3        | 3.9        | 0.42        | 1.69        | 4.32        | 10          | 75          | 0.23        | 0.021        | 11        | 42.8        |
| Cg                                                                                                                              | 78-150+   | 5.16       | 3.67       | <1        | 32    | 1.9         | 0.36         | 0.22        | 0.7        | 2.1        | 0.67        | 1.35        | 2.77        | 24          | 50          | 0.08        | 0.008        | 10        | 51.2        |
| Leptic Umbrisol (Pantoloamic, Hyperdystric)/ NEOSSOLO REGOLÍTICO Distrófico léptico                                             |           |            |            |           |       |             |              |             |            |            |             |             |             |             |             |             |              |           |             |
| A                                                                                                                               | 0-45      | 4.62       | 3.70       | 4.1       | 61    | 2.9         | 1.32         | 0.64        | 0.8        | 6.6        | 2.13        | 2.91        | 8.73        | 24          | 27          | 1.16        | 0.085        | 14        | 45.5        |
| AC                                                                                                                              | 45-100    | 4.79       | 3.89       | <1        | 39    | 3.9         | 0.28         | 0.26        | 1.0        | 3.5        | 0.66        | 1.63        | 4.16        | 16          | 60          | 0.16        | 0.018        | 9         | 42.9        |
| R                                                                                                                               | 100+      |            |            |           |       |             |              |             |            |            |             |             |             |             |             |             |              |           |             |
| All (median-CV)                                                                                                                 |           | 4.73-<br>6 | 3.79-<br>3 | 1-<br>129 | 39-93 | 4.9-<br>209 | 0.39-<br>130 | 0.54-<br>83 | 1.7-<br>47 | 6.6-<br>47 | 1.31-<br>64 | 2.93-<br>39 | 7.76-<br>46 | 19.4-<br>39 | 52.8-<br>31 | 0.85-<br>83 | 0.077-<br>78 | 13-<br>29 | 27.8-<br>38 |
| Dry forest soils                                                                                                                |           |            |            |           |       |             |              |             |            |            |             |             |             |             |             |             |              |           |             |
| Leptic Luvisols (Pantoloamic, Pantohypereutric, Ochric)/ LUVISSOLO CRÔMICO Órtico léptico                                       |           |            |            |           |       |             |              |             |            |            |             |             |             |             |             |             |              |           |             |
| A                                                                                                                               | 0-10      | 7.26       | 5.07       | 1.5       | 34    | 97.9        | 16.88        | 8.68        | 0.0        | 0.8        | 26.07       | 26.07       | 26.87       | 97          | 0           | 0.31        | 0.004        | 81        | 40.9        |
| Bt                                                                                                                              | 10-30     | 7.57       | 5.47       | 13.8      | 19    | 149.3       | 16.41        | 7.32        | 0.0        | 0.6        | 24.43       | 24.43       | 25.03       | 98          | 0           | 0.31        | 0.003        | 123       | 48          |
| CR                                                                                                                              | 30-50     | 8.12       | 5.31       | 107.<br>7 | 11    | 239.2       | 21.38        | 8.87        | 0.0        | 0.3        | 31.32       | 31.32       | 31.62       | 99          | 0           | 0.08        | 0.008        | 9         | 51.2        |
| R                                                                                                                               | 50+       |            |            |           |       |             |              |             |            |            |             |             |             |             |             |             |              |           |             |
| Rhodic Luvisols (Pantoloamic, Pantohypereutric, Ochric)/ LUVISSOLO CRÔMICO Órtico típico                                        |           |            |            |           |       |             |              |             |            |            |             |             |             |             |             |             |              |           |             |
| A                                                                                                                               | 0-3 (2-5) | 7.19       | 6.33       | 183.<br>2 | 329   | 19.6        | 14.25        | 4.75        | 0.0        | 1.1        | 19.93       | 19.93       | 21.03       | 95          | 0           | 1.57        | 0.089        | 18        | 36.5        |
| Bt <sub>1</sub>                                                                                                                 | 3-25      | 6.64       | 4.85       | 7.6       | 85    | 49.4        | 22.57        | 9.25        | 0.0        | 1.5        | 32.25       | 32.25       | 33.75       | 96          | 0           | 0.39        | 0.029        | 13        | 32.8        |
| Bt <sub>2</sub>                                                                                                                 | 25-50     | 6.90       | 4.27       | 15.7      | 70    | 85.1        | 27.12        | 9.86        | 0.0        | 1.5        | 37.53       | 37.53       | 39.03       | 96          | 0           | 0.20        | 0.012        | 17        | 35.1        |
| Cr                                                                                                                              | 50-75     | 6.90       | 4.02       | 52.6      | 52    | 71.2        | 22.67        | 7.23        | 0.0        | 1.0        | 30.34       | 30.34       | 31.34       | 97          | 0           | 0.20        | 0.012        | 17        | 43.9        |
| R                                                                                                                               | 75+       |            |            |           |       |             |              |             |            |            |             |             |             |             |             |             |              |           |             |
| Pantohypereutric Leptic Regosols (Pantoarenic, Ochric)/ NEOSSOLO REGOLÍTICO Eutrófico léptico                                   |           |            |            |           |       |             |              |             |            |            |             |             |             |             |             |             |              |           |             |
| A                                                                                                                               | 0-5       | 7.16       | 6.53       | 10.7      | 115   | 7.7         | 8.07         | 1.69        | 0.3        | 0.6        | 10.09       | 10.38       | 10.69       | 94          | 3           | 0.20        | 0.02         | 10        | 44.9        |
| AC <sub>1</sub>                                                                                                                 | 5-15      | 6.71       | 5.58       | 3.2       | 74    | 3.7         | 3.42         | 0.96        | 0.0        | 1.0        | 4.59        | 4.59        | 5.59        | 82          | 0           | 0.47        | 0.053        | 9         | 45.7        |
| AC <sub>2</sub>                                                                                                                 | 15-30     | 6.70       | 5.30       | 2.7       | 48    | 7.7         | 3.00         | 1.40        | 0.0        | 0.8        | 4.56        | 4.56        | 5.36        | 85          | 0           | 0.24        | 0.041        | 6         | 47.4        |
| C                                                                                                                               | 30-60     | 6.10       | 4.41       | 2.6       | 38    | 29.5        | 2.73         | 1.67        | 0.00       | 1.3        | 4.63        | 4.63        | 5.93        | 78          | 0           | 0.16        | 0.003        | 53        | 42.7        |
| R                                                                                                                               | 60+       |            |            |           |       |             |              |             |            |            |             |             |             |             |             |             |              |           |             |
| Leptic Luvisols (Pantoloamic, Pantohypereutric, Ochric)/ LUVISSOLO CRÔMICO Órtico léptico                                       |           |            |            |           |       |             |              |             |            |            |             |             |             |             |             |             |              |           |             |

Ecotone soils in northeastern Brazil

|                                                                                                                    |          |        |         |         |          |          |          |         |        |         |          |          |          |         |        |          |          |        |         |
|--------------------------------------------------------------------------------------------------------------------|----------|--------|---------|---------|----------|----------|----------|---------|--------|---------|----------|----------|----------|---------|--------|----------|----------|--------|---------|
| A                                                                                                                  | 0-5      | 6.30   | 5.15    | 6.0     | 165      | 13.6     | 6.58     | 2.82    | 0.0    | 1.6     | 9.88     | 9.88     | 11.48    | 86      | 0      | 0.79     | 0.069    | 11     | 41.4    |
| Bt                                                                                                                 | 5-25     | 5.74   | 3.48    | 2.3     | 52       | 505.0    | 21.80    | 2       | 0.5    | 2.3     | 41.65    | 42.14    | 43.95    | 95      | 1      | 0.31     | 0.02     | 16     | 37.0    |
| C                                                                                                                  | 25-55    | 5.22   | 3.86    | 3.1     | 56       | 69.2     | 7.60     | 5.15    | 0.2    | 2.7     | 13.19    | 13.39    | 15.89    | 83      | 2      | 0.31     | 0.02     | 16     | 34.7    |
| R                                                                                                                  | 55+      |        |         |         |          |          |          |         |        |         |          |          |          |         |        |          |          |        |         |
| All (median-CV)                                                                                                    |          | 6.8-11 | 5.11-18 | 6.8-179 | 54-99    | 59.3-140 | 15.33-61 | 6.19-74 | <1-215 | 1.1-54  | 22.18-62 | 22.18-62 | 23.03-59 | 95-7    | <1-218 | 0.31-112 | 0.02-134 | 16-120 | 42.1-14 |
| Moist forests soils*                                                                                               |          |        |         |         |          |          |          |         |        |         |          |          |          |         |        |          |          |        |         |
| Xanthic Ferralsols (Loamic, Pantohyperdystric, Ochric)/ LATOSSOLO AMARELO Distrófico psamítico                     |          |        |         |         |          |          |          |         |        |         |          |          |          |         |        |          |          |        |         |
| A <sub>1</sub>                                                                                                     | 0-15     | 5.2    | 4.4     | 1.0     | 1.17     | 0.23     | <1       | <1      | 0.2    | 0.6     | 2.4      | 0.8      | 3.2      | 19      | 22     | 5.3      | 0.5      | 11     | -       |
| A <sub>2</sub>                                                                                                     | 15-300   | 5.2    | 4.6     | 1.0     | 1.17     | 0.23     | <1       | <1      | 0.2    | 0.4     | 2        | 0.6      | 2.6      | 15      | 29     | 4        | 0.5      | 8      | -       |
| Bw <sub>1</sub>                                                                                                    | 30-90    | 5.2    | 4.6     | 1.0     | 0.78     | 0.23     | <1       | <1      | 0.3    | 0.2     | 2.1      | 0.5      | 2.6      | 8       | 60     | 4.8      | 0.5      | 10     | -       |
| Bw <sub>2</sub>                                                                                                    | 90-145   | 5.1    | 4.6     | 1.0     | 1.17     | 0.46     | <1       | <1      | 0.2    | 0.3     | 1.8      | 0.5      | 2.3      | 13      | 40     | 3.4      | 0.4      | 9      | -       |
| Bw <sub>3</sub>                                                                                                    | 145-175+ | 5.2    | 4.5     | 1.0     | 1.17     | 0.46     | <1       | <1      | 0.3    | 0.3     | 1.5      | 0.6      | 2.1      | 14      | 50     | 1.8      | 0.3      | 6      | -       |
| Xanthic Pisoplinthic Ferralsols (Loamic, Orthodystric, Ferric, Ochric)/ LATOSSOLO AMARELO Distrófico plintossólico |          |        |         |         |          |          |          |         |        |         |          |          |          |         |        |          |          |        |         |
| A <sub>1</sub>                                                                                                     | 0-20     | 6.8    | 6.2     | 4.0     | 3.9      | 1.15     | 3.1      | 1.2     | 0      | 4.5     | 0.4      | 4.5      | 4.9      | 92      | 0      | 10.5     | 1.1      | 10     | -       |
| A <sub>2</sub>                                                                                                     | 20-40    | 5.3    | 3.9     | 1.0     | 5.07     | 0.92     | <1       | <1      | 0.4    | 0.9     | 1.3      | 1.3      | 2.6      | 41      | 31     | 4.1      | 0.4      | 10     | -       |
| Bw <sub>1</sub>                                                                                                    | 40-75    | 5.1    | 4.0     | 1.0     | 10.92    | 0.92     | <1       | <1      | 0.3    | 1.2     | 1.8      | 1.5      | 3.3      | 36      | 20     | 3.4      | 0.4      | 9      | -       |
| Bw <sub>2</sub>                                                                                                    | 75-120   | 5.0    | 3.9     | 1.0     | 2.73     | 1.15     | <1       | <1      | 0.3    | 1       | 1.1      | 1.3      | 2.4      | 42      | 21     | 3.3      | 0.3      | 11     | -       |
| Bw <sub>3</sub>                                                                                                    | 120-165+ | 5.0    | 3.9     | >1      | 1.56     | 2.76     | 1.1      | 0.3     | 0.4    | 1.6     | 1.5      | 2        | 3.5      | 46      | 20     | 3.4      | 0.3      | 11     | -       |
| Xanthic Pisoplinthic Ferralsols (Loamic, Orthodystric, Ferric, Ochric)/LATOSSOLO AMARELO Distrófico plintossólico  |          |        |         |         |          |          |          |         |        |         |          |          |          |         |        |          |          |        |         |
| A <sub>1</sub>                                                                                                     | 0-20     | 5.0    | 3.8     | 2.0     | 1.56     | 1.15     | 1.9      | 0.5     | 0.5    | 2.5     | 7.3      | 3        | 10.3     | 24      | 17     | 18.9     | 1.6      | 12     | -       |
| A <sub>2</sub>                                                                                                     | 20-40    | 5.1    | 3.9     | 2.0     | 1.56     | 1.15     | 1.9      | 0.5     | 0.7    | 2.5     | 5.6      | 3.2      | 7.7      | 18      | 33     | 18.9     | 1.6      | 12     | -       |
| Bw <sub>1</sub>                                                                                                    | 40-70    | 5.2    | 3.9     | >1      | 2.73     | 0.92     | 1        | <1      | 0.6    | 1.1     | 3.5      | 1.7      | 5.2      | 21      | 35     | 7.1      | 0.5      | 14     | -       |
| Bw <sub>2</sub>                                                                                                    | 70-150+  | 5.1    | 4       | <1      | 0.39     | 0.69     | 0.6      | <1      | 0.7    | 0.6     | 2.7      | 1.3      | 4        | 15      | 54     | 4.9      | 0.3      | 16     | -       |
| Xanthic Ferric Ferralic Pisoplinthic Acrisols (Loamic, Ochric)/ARGISSOLO AMARELO Distrófico plintossólico          |          |        |         |         |          |          |          |         |        |         |          |          |          |         |        |          |          |        |         |
| A <sub>1</sub>                                                                                                     | 0-20     | 5.1    | 4.1     | 1.0     | 0.78     | 0.46     | <1       | <1      | 0.2    | 0.4     | 1.4      | 0.6      | 2        | 20      | 33     | 2.7      | 0.4      | 7      | -       |
| A <sub>2</sub>                                                                                                     | 20-40    | 5.0    | 4.2     | 1.0     | 0.39     | 0.46     | <1       | <1      | 0.2    | 0.2     | 1.6      | 0.4      | 2        | 10      | 50     | 2.4      | 0.4      | 6      | -       |
| Bw <sub>1</sub>                                                                                                    | 40-65    | 5.1    | 4.4     | 1.0     | 0.39     | 0.46     | <1       | <1      | 0.2    | 0.3     | 1.8      | 0.5      | 2.3      | 13      | 40     | 2.2      | 0.3      | 7      | -       |
| Bw <sub>2</sub>                                                                                                    | 65-140+  | 4.9    | 4.3     | 1.0     | 0.39     | 0.46     | <1       | <1      | 0.2    | 0.3     | 1.7      | 0.5      | 2.2      | 14      | 40     | 2        | 0.3      | 7      | -       |
| All (median-CV)                                                                                                    |          | 5.1-8  | 4.15-13 | 1.0-61  | 1.17-121 | 0.58-75  | 1.5-56   | 0.5-63  | 0.3-58 | 0.6-106 | 1.8-72   | 1.1-83   | 2.6-61   | 18.5-79 | 33-46  | 3.7-91   | 0.4-75   | 10-27  | -       |

\* (EMBRAPA, 2017).

Table 5 - Borborema province: Physical soil properties determined in undisturbed samples.

| Horizon                                                                                                                           | Depth         | Particles density | Bulk density | Total porosity | Water retention curve (kPa) |      |      |      |      |       | Available water |
|-----------------------------------------------------------------------------------------------------------------------------------|---------------|-------------------|--------------|----------------|-----------------------------|------|------|------|------|-------|-----------------|
|                                                                                                                                   |               |                   |              |                | -6                          | -10  | -30  | -100 | -300 | -1500 |                 |
|                                                                                                                                   | cm            | kg/ kg            |              | %              |                             |      |      |      |      |       |                 |
| Leptic Umbrisol (Endoclayic, Hyperdystric)/ NEOSSOLO REGOLÍTICO Húmico léptico                                                    |               |                   |              |                |                             |      |      |      |      |       |                 |
| A <sub>1</sub>                                                                                                                    | 0-20          | 2.61              | 1.38         | 29.68          | 25.0                        | 19.6 | 16.5 | 13.8 | 10.3 | 7.5   | 12.1            |
| A <sub>2</sub>                                                                                                                    | 20-30         | 2.71              | 1.56         | 27.97          | 24.3                        | 20.9 | 17.5 | 15.5 | 13.4 | 9.0   | 11.9            |
| Haplic Umbrisol (Pantoloamic, Pantohyperdystric)/ NEOSSOLO REGOLÍTICO Húmico típico                                               |               |                   |              |                |                             |      |      |      |      |       |                 |
| A <sub>1</sub>                                                                                                                    | 0-40          | 2.74              | 1.60         | 33.93          | 28.7                        | 21.8 | 19.1 | 17.1 | 15.6 | 1.0   | 20.8            |
| A <sub>2</sub>                                                                                                                    | 40-62         | 2.74              | 1.65         | 37.00          | 30.2                        | 20.3 | 17.8 | 15.9 | 13.8 | 1.0   | 19.3            |
| Pantorthodystric Stagnosols (Amphiclayic, Katomanganiferriic, Humic, Inclinic)/ GLEISSOLO HÁPLICO Tb Distrófico argissólico       |               |                   |              |                |                             |      |      |      |      |       |                 |
| A                                                                                                                                 | 0-25          | 2.15              | 0.99         | 25.53          | 21.3                        | 15.1 | 13.5 | 11.8 | 9.7  | 5.7   | 9.4             |
| Btg                                                                                                                               | 70-90(60-100) | 2.79              | 1.63         | 38.26          | 31.7                        | 22.4 | 19.7 | 17.9 | 13.1 | 9.6   | 12.8            |
| Pantorthodystric Anoumbriic Stagnosols (Pantoclayic, Humic, Inclinic)/ GLEISSOLO MELÂNICO Tb Distrófico típico                    |               |                   |              |                |                             |      |      |      |      |       |                 |
| Ag                                                                                                                                | 0-70          | 2.78              | 1.71         | 20.97          | 17.4                        | 12.6 | 10.9 | 7.9  | 6.1  | 3.6   | 9.0             |
| Leptic Umbrisol (Endoclayic, Pantodystric)/ NEOSSOLO REGOLÍTICO Húmico léptico                                                    |               |                   |              |                |                             |      |      |      |      |       |                 |
| A <sub>1</sub>                                                                                                                    | 0-27          | 2.67              | 1.39         | 28.55          | 24.2                        | 18.5 | 16.2 | 14.8 | 12.7 | 9.8   | 8.7             |
| Pantorthodystric Anoumbriic Stagnosols (Pantoclayic, Katomanganiferriic, Humic, Inclinic)/GLEISSOLO MELÂNICO Tb Distrófico típico |               |                   |              |                |                             |      |      |      |      |       |                 |

Ecotone soils in northeastern Brazil

|                                                                                     |        |      |      |       |      |      |      |     |     |     |      |
|-------------------------------------------------------------------------------------|--------|------|------|-------|------|------|------|-----|-----|-----|------|
| A                                                                                   | 0-58   | 2.70 | 1.42 | 17.66 | 14.5 | 10.3 | 8.8  | 7.2 | 5.5 | 3.5 | 6.8  |
| CA                                                                                  | 58-78  | 2.75 | 1.68 | 16.45 | 12.7 | 8.6  | 6.3  | 5.8 | 4.9 | 2.3 | 6.3  |
| Leptic Umbrisol (Pantoloamic, Hyperdystric)/ NEOSSOLO REGOLÍTICO Distrófico léptico |        |      |      |       |      |      |      |     |     |     |      |
| A                                                                                   | 0-45   | 2.65 | 1.35 | 18.11 | 14.0 | 7.9  | 6.7  | 5.8 | 4.7 | 2.7 | 5.2  |
| AC                                                                                  | 45-100 | 2.73 | 1.6  | 22.17 | 18.4 | 13.8 | 11.6 | 8.8 | 6.1 | 3.3 | 10.5 |

Dry forest soils

Leptic Luvisols (Pantoloamic, Pantohypereutric, Ochric)/ LUVISSOLO CRÔMICO Órtico léptico

|    |       |      |      |       |      |      |      |      |      |      |      |
|----|-------|------|------|-------|------|------|------|------|------|------|------|
| A  | 0-10  | 2.71 | 1.42 | 35.97 | 31.8 | 25.8 | 23.9 | 20.8 | 18.1 | 13.5 | 12.3 |
| Bt | 10-30 | 2.72 | 1.66 | 30.38 | 27.6 | 24.4 | 22.3 | 19.7 | 16.1 | 12.6 | 11.8 |

Rhodic Luvisols (Pantoloamic, Pantohypereutric, Ochric)/ LUVISSOLO CRÔMICO Órtico típico

|                 |           |      |      |       |      |      |      |      |      |     |      |
|-----------------|-----------|------|------|-------|------|------|------|------|------|-----|------|
| A               | 0-3 (2-5) | 2.68 | 1.27 | 52.61 | 40.5 | 17.5 | 15.7 | 13.7 | 11.1 | 8.3 | 9.2  |
| Bt <sub>1</sub> | 3-25      | 2.65 | 1.21 | 54.33 | 36.9 | 19.0 | 16.6 | 14.1 | 12.7 | 8.7 | 10.3 |

Pantohypereutric Leptic Regosols (Pantoarenic, Ochric)/ NEOSSOLO REGOLÍTICO Eutrófico léptico

|                 |      |      |      |       |      |     |     |     |     |     |     |
|-----------------|------|------|------|-------|------|-----|-----|-----|-----|-----|-----|
| A               | 0-5  | 2.90 | 1.53 | 47.24 | 27.2 | 6.5 | 5.2 | 4.9 | 3.7 | 2.2 | 4.3 |
| AC <sub>1</sub> | 5-15 | 2.87 | 1.46 | 49.12 | 24.3 | 7.1 | 5.6 | 4.9 | 4.2 | 2.5 | 4.6 |

Leptic Luvisols (Pantoloamic, Pantohypereutric, Ochric)/ LUVISSOLO CRÔMICO Órtico léptico

|    |      |      |      |       |      |      |      |     |     |     |     |
|----|------|------|------|-------|------|------|------|-----|-----|-----|-----|
| A  | 0-5  | 2.71 | 1.34 | 50.55 | 30.3 | 13.6 | 11.7 | 8.8 | 7.5 | 4.0 | 9.6 |
| Bt | 5-25 | 2.71 | 1.27 | 53.14 | 30.9 | 11.2 | 9.1  | 7.5 | 6.9 | 4.4 | 6.8 |

The higher amount of available water and lower wilting point in semideciduous forest compared to dry forests could be used to explain the differences between these two ecosystems. Once differences in precipitation between these sites are low, the higher the available amount of water, the larger water volume could be consumed during the year. Simultaneously, a lower wilting point indicates that soil moisture can achieve a lower level without restricting water absorption by plants. The lower water availability in semiarid regions limits the nutrient absorption by plants, as N and P (SILVEIRA et al., 2006; MENEZES et al., 2012). Drought resistance species are less affected and persist while sensitive species have grown and reproduces compromised (BARROS et al., 2018; TERRA et al., 2018). Higher C, N, and  $P_M$  and contents guarantee the nutrition of several organisms and promote change in the composition of the vegetation community. Consequently, higher diversity and richness favor higher primary productivity, partially incorporated into the soil as organic residues. These organic residues became soil organic matter and contribute to soil fertility (MINICK; FISK; GROFFMAN, 2017; NOVOTNY et al., 2007) and water retention capacity (GAISER; GRAEF; CORDEIRO, 2000; VALARINI et al., 2003). This biogeochemical cycling of nutrients improves efficiency in a restrictive region. Previous studies indicated that where availability of nutrients is restricted to primary productivity a that higher efficiency in the use of natural resources decreases competition for nutrients and favors the occurrence of a higher number of species (PELLEGRINI, 2016; PEÑA-CLAROS et al., 2012; TILMAN et al., 2001).

## CONCLUSIONS

Our results emphasize that the semideciduous forest has characteristics found in humid and dry forests, reinforcing the results of other authors that these environments are essential to transition areas. The soils of dry and semideciduous forests are derived from similar parent materials, have similar textures with a coarse sand domain. However, soils in semideciduous forests have lower CEC and base saturation values than those in dry forest soils. This difference is attributed to the orographic rains captured by the eastern slope in the province of Borborema and, consequently, more significant weathering and leaching of bases, making the soils of semideciduous forest resemble those of humid forest. The higher amount of available water and the lower wilt point in the semideciduous forest than dry forests can be highlighted as one of the main diagnostic characteristics responsible for separating these two ecosystems. With greater water availability throughout the year, semideciduous forests can house species adapted to water stress as less adapted species, contributing to specific vegetation composition.

We emphasize that the study of semideciduous forest soils is essential to clarify doubts about the correct characterization and classification of these environments, in addition to serving as a basis for future management plans and study of forest restoration, since detailing of soil characteristics can determine which species best adapt to the environment of interest.

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