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Topsoil physical properties under a riparian forest in Central Brazil: infiltration and penetration resistance

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Título resumido: Topsoil physical properties under a riparian forest in Central Brazil

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ABSTRACT – (Topsoil physical properties under a riparian forest in Central Brazil: infiltration and penetration resistance). Plant composition, diversity and structure of riparian forests of Central Brazil are well known. However, little is known about soil physical properties under these forests. This knowledge is important as a baseline for biodiversity restoration and ecosystem services that occur in riparian zones. In order to bridge this gap, here we assessed the infiltration capacity and soil penetration resistance in a plinthic soil under gallery forest in Planaltina, Distrito Federal, Brazil. We measured infiltration capacity (Mini-Disk infiltrometer) and soil penetration resistance (Stof penetrometer) following linear transects. The plinthic soil had high infiltration capacity and low penetration resistance. Our infiltration estimate is in the middle range when compared to other permeability studies in tropical forests. Like their counterparts, high biological activity along with the lack of disturbance are the likely explanations for such high topsoil permeability to water.

Keywords: buffer zones, soil conservation, streamside áreas, tropical ecosystems, water management

RESUMO – (Propriedades físicas da camada superficial do solo em florestas ripária no Brasil central: resistência à infiltração e penetração). As florestas de galeria são bem descritas em termos de composição, diversidade e estrutura da vegetação. No entanto, pouco se sabe sobre as propriedades físicas do solo sob essas florestas que são importantes para a restauração de zonas ripárias. A fim de preencher essa lacuna, no presente trabalho, avaliou-se a capacidade de infiltração e a resistência do solo à penetração em um solo plíntico sob floresta ripária em Planaltina, Distrito Federal, Brasil. Mediu-se a capacidade de infiltração (infiltrômetro de Mini-Disk) e a resistência à penetração no solo (penetrômetro de Stolf) seguindo transectos lineares. O solo plíntico apresentou alta capacidade de infiltração e baixa resistência à penetração. Nossa estimativa de infiltração está na faixa intermediária em comparação com outros estudos de permeabilidade em florestas tropicais. Mesmo assim, a mediana da capacidade de infiltração foi superior à intensidade de chuva de alto período de retorno o que descarta a possibilidade de escoamento superficial Hortoniano. Como em outras florestas tropicais, a alta atividade biológica junto com a ausência de perturbação do solo são as razões prováveis para essa alta permeabilidade do solo à água.

Palavras-chave: zonas tampão, conservação do solo, áreas ribeirinhas, ecossistemas tropicais, manejo da água.

Introduction

Gallery forests, also known as riparian forests, occur along small streams in the Cerrado biome of Brazil (Ribeiro and Walter, 1998). These forests are well known in terms of plant species composition, diversity and structure (Felfili 1994, Felfili 1995, Nóbrega et al. 2001, Silva Júnior 2004, Silva Júnior 2005, Moretti et al. 2013, Cabacinha & Fontes 2014, Pio 2018). Generally, they present a high biological diversity. One of the possible explanations for such diversity might be attributed to heterogeneity of soil types over which these forests occur which include both well and poorly drained soils (Haridasan 1998). For example, they might occur on oxisols (latossolos) and histosols (organossolos) (Resck & Silva 1998). Since these soil types present a clearly distinct hydric behaviour, they not only affect plant community but are also expected to influence the ecosystem service of buffering zones that riparian forests play. For instance, riparian forests under histosols might not reduce surface runoff from uplands in the wet season since these soils would be water saturated during this period following the runoff generation (as described in Dunne & Black 1970a,b). So, it is important to understand hydrological functions of these forests under different soil types.

Like many riparian forests elsewhere, such ecosystems are expected to carry out important buffer functions including retaining sediment, nutrients and human-made chemicals such as pesticides. The assumption behind is that riparian soil under these forests present high topsoil permeability which, in turn, diminish or extinguish surface runoff from uplands (Salemi et al. 2011). To date, there is no documentation on basic topsoil permeability for these riparian forests. Understanding such properties under specific physical settings may allow to infer whether they carry out the expected functions they are expected to. Moreover, such information may serve as a baseline which, in turn, may help scientists and managers to predict the impacts of inappropriate riparian occupation and restoration (see Brito et al. 2019; Pereira et al. 2021).

In this context, the objective of the present paper was to characterize a plinthic soil under a riparian forest in terms of infiltration capacity and soil penetration resistance. We expected that, like other tropical rainforests, these riparian forests would present high permeability to water.

Methods

Study área - We selected a riparian forest located in Planaltina, Distrito Federal, Brazil. The Köppen-Geiger climatic classification is Aw, with two markedly defined seasons (dry and wet) (Alvares et al. 2013). Annual rainfall is 1,393 mm with nearly 100% of it falling in the wet season (October to April)

(Malaquias et al., 2010). Average temperature is 20.7°C. The soil type is a clay Plintossolo (Plinthosols), according to the Brazilian Soil Classification System (Embrapa, 2018).

Riparian forests in the study area usually have high plant species diversity. Trees density and basal area are around, respectively, 1.300-1.900 individuals ha^{-1} and 32-38 m^2 ha^{-1} (Nóbrega et al. 2001, Silva Júnior 2004, Silva Júnior 2005). Common species found in these forests are *Protium spruceanum* (Benth.) Engl. (Burseraceae), *Copaifera langsdorffii* Desf. (Fabaceae), *Tapirira guianensis* Aubl. (Anacardiaceae), *Inga alba* (Sw.) Willd. (Fabaceae), *Cheiloclinium cognatum* (Miers) A.C.Sm. (Celastraceae), *Pseudolmedia guaranitica* Hasler (Moraceae), *Euterpe edulis* Mart. (Arecaceae) and *Talauma ovata* A. St.-Hill. (Magnoliaceae) (Nóbrega et al. 2001, Silva Júnior, 2004, Silva Júnior, 2005).

Variables and sampling design - We measure both infiltration capacity and soil resistance to penetration using, respectively, Mini-Disk infiltrometer (Decagon) and Stof Impact Penetrometer (Kamaq) during the dry season of 2018.

The Mini-disk infiltrometer is a two-chamber device in which the Mariotte principle is applied to control soil suction. Such equipment uses the analytical solution proposed by Zhang (1997). Similar to Ghimire et al. (2013), to increase the contact area between the infiltrometer and the soil, we carried out two steps: (i) we carefully removed the litter layer and (ii) we used a thin (< 1 mm) of fine sand. These procedures ensure optimum contact between the infiltrometer and the soil. To capture the highest range of pores, we set a suction pressure of 0 cm which corresponds to Ko, that is, the saturated hydraulic conductivity (Reichardt & Timm 2019). The rates of water discharge through the Mini-Disk, as inferred from changes in the water levels in the storage chamber, were recorded until steady-state flow was reached. Infiltration was measured using three linear transects randomly distributed within the riparian forest (figure 2). To randomize linear transects, we used a randomizer software (randomizer.org) which selected 3 out of 50 grid transects. Ten infiltration samples were taken from each of these transects. Transects were established in parallel to stream channel. When measuring infiltration, it is important to minimize the effect of soil moisture on infiltration measurements since substantial variation can occur from one month to the next (see Pereira et al. 2021). Thus, we carried out two steps: (i) measurements were made in August (dry season) when soil moisture in the region is minimal (Oliveira et al. 2005), and (ii) we set 0 cm of suction pressure in the Mariotte bottle.

In order to predict the effectiveness of the riparian forest in accommodating storms of the region, we compared our median of infiltration capacity with 5-minutes rainfall intensities of different return periods (100, 50 and 25-years) available in Souza (2014).

Soil penetration resistance was measured for ten times following the linear transects described above (figure 2). We arbitrarily selected four impacts to determine soil penetration resistance. This include the first impact which is the inherent weight of the equipment followed by the other three impacts which resulted from the impact of a standard 2 kg weight into the soil. To minimize the effect of soil moisture on our penetration measurements, we carried out the measurements in the dry season (August) when soil moisture is minimal (Oliveira et al. 2005).

Data análisis - Sample sufficency was verified for infiltration capacity using a simple plot of mean and standard deviation versus number of samples. An adequate sample size was considered met when central tendency statistics stabilized for at least three times consecutively (Salemi et al. 2020).

Residuals of soil penetration resistance were subjected to Shapiro-Wilk test which indicated a lack of gaussian distribution. Therefore, we used Kruskal-Wallis test followed by the post hoc Dunn test to check significant differences between impacts. Statistical analyses were carried out in PAST software at $\alpha < 0.05$.

Results and Discussion

The number of samples used for infiltration was considered appropriate given the relative stabilization of the median statistics (figure 3). The median infiltration capacity was 893 mm hr^{-1}(figure 4). Mean (± standard deviation) of soil penetration resistance for all four impacts were, respectively, as follows: 0.63 ± 0.21 MPa, 0.66 ± 0.32 MPa, 0.74 ± 0.22 MPa and 0.76 ± 0.22 MPa (figure 5). There was a significant increase in soil penetration resistance with depth. Such increase has previously been documented for a forest within the Brazilian savanna (see Pereira et al. 2021). Our resistance to penetration was lower compared to a nearby savana (regionally known as “Cerrado típico”) in the same area (Murta et al. 2021). Such difference of soil penetration resistance in the riparian forest compared to a savanna might be attributed to the higher and more continuous addition of litter year-round in the forest compared to the savanna (Costa et al. 2020). For example, Aquino et al. (2016) measured an average of 6 ton ha^{-1} $year^{-1}$ in a riparian forest whereas Valenti et al. (2008) found 0.6 ton ha^{-1} $year^{-1}$ in a savana.

We found infiltration capacity of the plinthic soil under riparian forest to be in the middle range compared to estimates carried out in other tropical forests such as the Amazon and Atlantic Forest (table 1). Generally, high soil biological activity (e.g. continuous litter production, root growth and decay and soil fauna) along with the lack of disturbance (e.g. human and animal trampling, use of heavy machinery) leads to high infiltration in forest soils (Bruijnzeel 1990, Salemi et al. 2011).

Our median infiltration capacity estimate was higher compared to the rain intensity of various storms in the region (figure 4). Thus, we rule out the occurrence of infiltration excess overland-flow in this forest. However, our penetration resistance indicated a likely reduction of these permeability with depth which was, to some extent, expected due the presence of the plinthic horizon. A previous study on plinthic soils showed the formation of a perched water table above such layer (Moraes et al. 2006). Furthermore, riparian forests, like the one studied here, generally might occur in shallow water table zones (Ribeiro & Walter 2008). In case the water table (perched or not) intersects the soil surface, both return-flow and overland-flow are triggered (Dunne & Black 1970a, b, Elsenbeer & Vertessy 2000). Thus, saturation overland-flow can occur. In this case, unlike the generally expected role of surface runoff sinks, these zones might act as surface runoff sources instead. More studies are needed to clarify percolation capacities of these soil and their implications for runoff processes.

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Author Contributions

Johnny Rodrigues de Melo Murta: sampling design, sampling, data analyses, manuscript preparation.

Gleicon Queiroz de Brito: sampling, manuscript preparation.

Sergio Fernandes Mendonça Filho: sampling, manuscript preparation.

Luiz Felippe Salemi: sampling design, sampling, data analyses, manuscript preparation.

Conflict of interest

The authors declare no conflict of interest.

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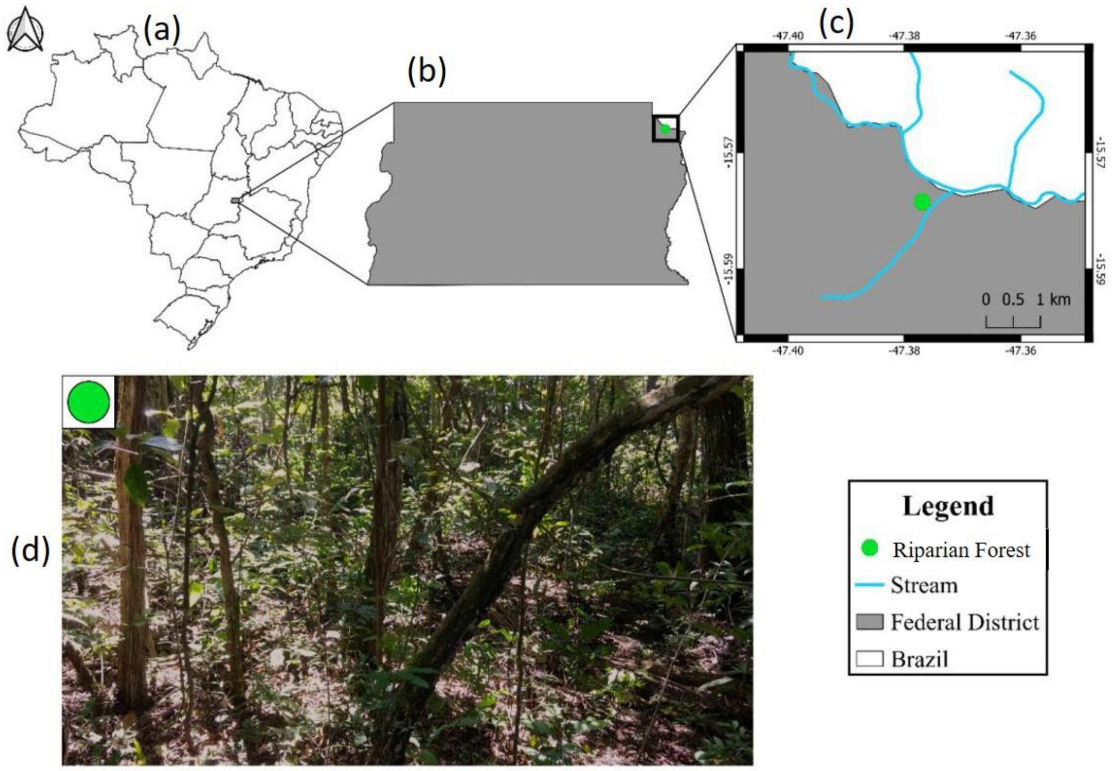

Figure 1. Study area located in Brazil (a), Distrito Federal State (b), Planaltina (c). Photograph shows the forest structure near the floor (d).

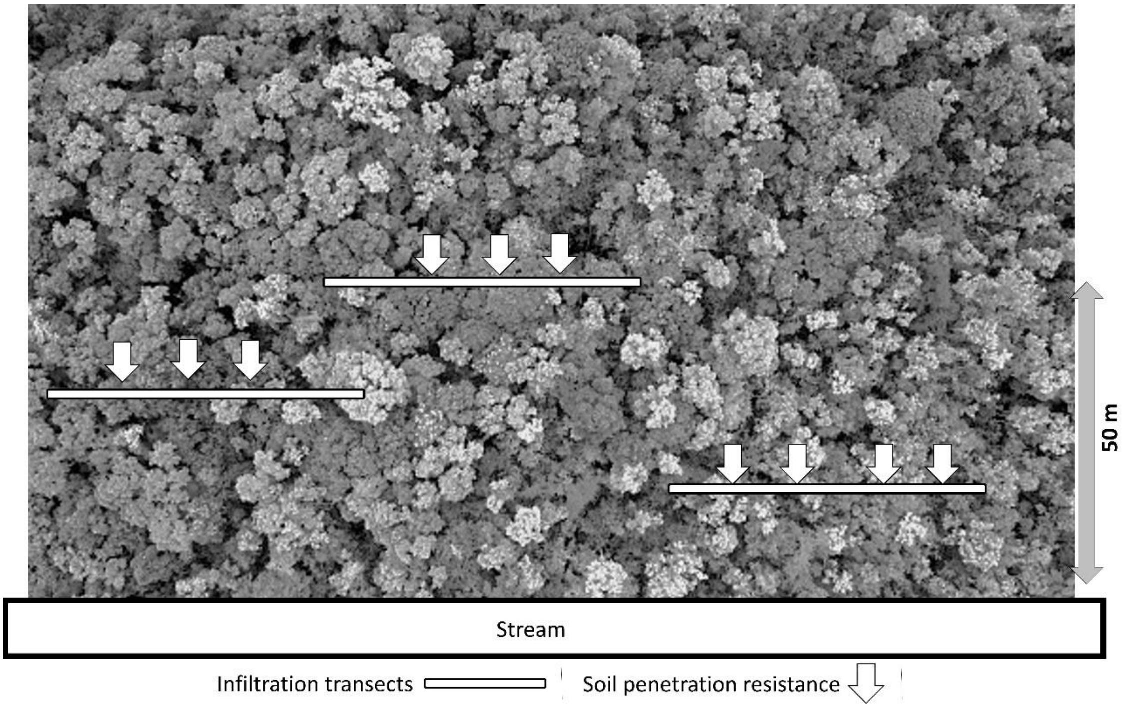

Figure 2. Design used for soil sampling in the riparian forest in Planaltina, Brasília, Distrito Federal State, Brazil. White lines represent infiltration transects. White arrows represent soil penetration resistance sampling points.

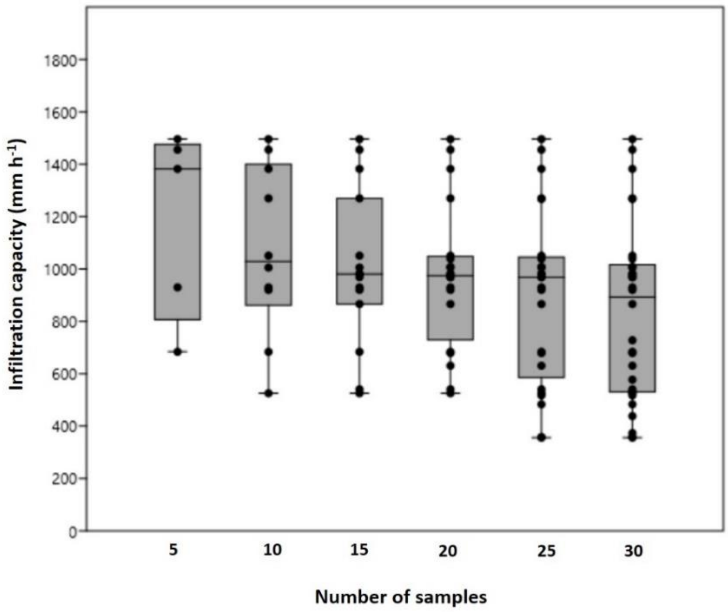

Figure 3. Box-Jitter plot showing infiltration capacity as function of the number of samples. Horizontal lines within the box represent the median. x represent the mean. Horizontal boundaries of the boxes represent the first and third quatiles. Tips of the vertical lines represent maximum (upper) and minimum (lower) values.

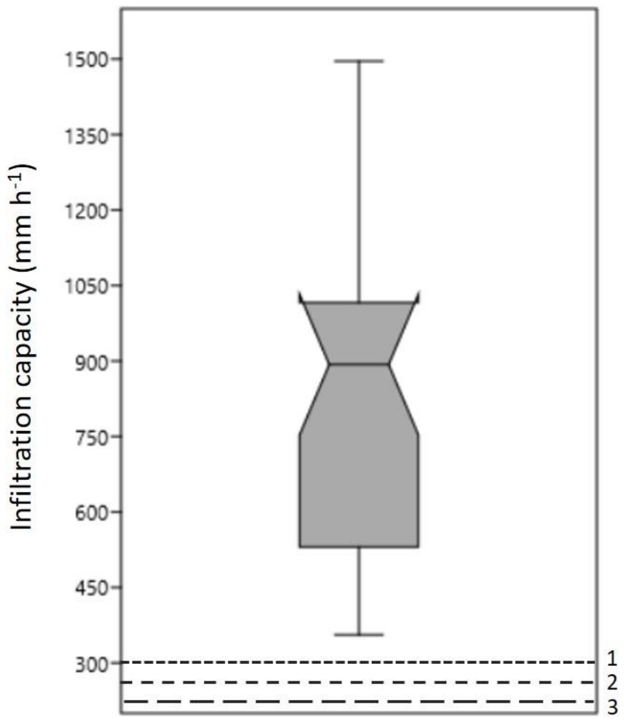

Figure 4. Box-plot of infiltration capacity of a plinthic soil under riparian forest. Horizontal line within the box represent the median. x represent the mean. Horizontal boundaries of the boxes represent the first and third quatiles. Tips of the vertical lines represent the maximum (upper) and minimum (lower) values. Notches indicate the 95% confidence interval of the median. Dotted lines 1, 2 and 3 indicate rainfall intensities with, respectively, 100 (300 mm hr^{-1}), 50 (260 mm hr^{-1}), and 25 (220 mm hr^{-1}) years return periods available in Souza (2014).

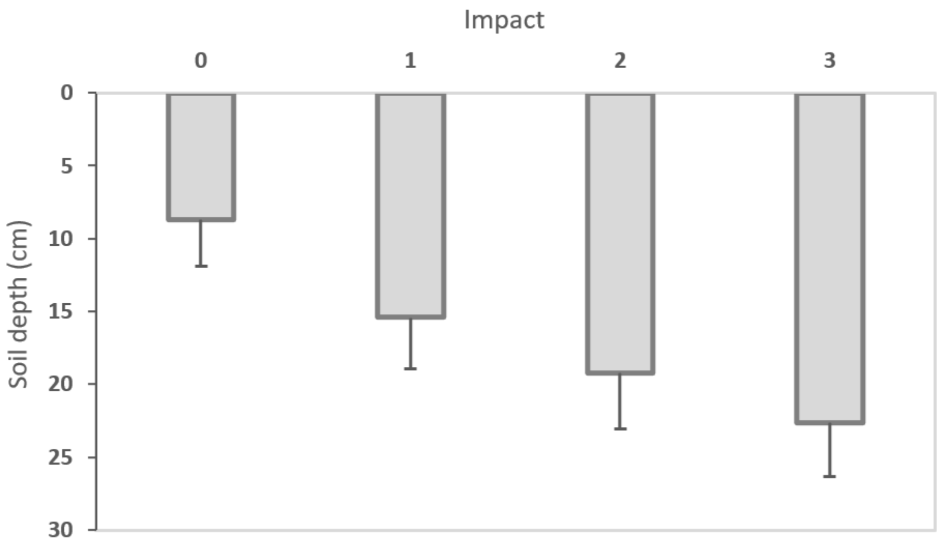

Figure 5. Soil penetration resistance (cm) in a plitnhic soil under riparian forest. Bars represent the mean. Error bars represent the standard deviation.

Table 1. Central tendency statistics of infiltration capacity found in different studies under tropical forests.

Infiltration capacity (mm h^{-1})	Method	Soil type	Number of samples	Vegetation type	Location	Reference
550*	Guelph permeameter	Plinthic soil	21	Tropical rain forest	Pará, Brazil	Moraes et al. (2006)
1533	Hood infiltrometer	Ultisol	25	Open tropical rain forest	Rondônia, Brazil	Zimmermann et al. (2006)
1200	Hood infiltrometer	Oxisol	75	Tropical rain forest	Mato Grosso, Brazil	Schefller et al. (2011)
557	Mini-Disk	Gleysol	10	Tropical riparian forest	Mato Grosso, Brazil	Brito et al. (2019)
200	Single disk	Ultisol	42	Semideciduous tropical forest	São Paulo, Brazil	Lozano-Baez et al. (2020)
893	Mini-Disk	Plinthsol	30	Tropical riparian forest	Distrito Federal, Brazil	Present study

*saturated hydraulic conductivity at 0.15 m

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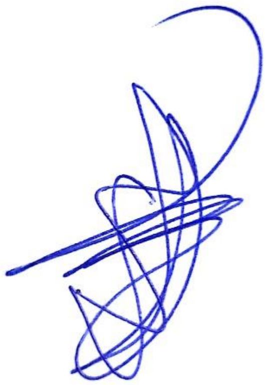

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