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Water infiltration in the Brazilian tropical savanna: the case of Cerrado típico

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ABSTRACT

The Brazilian savanna, regionally known as *Cerrado* is an important water source due to its spatial position in the highlands known as Planalto Central of Brazil. Yet, the hydrological functioning of such complex ecosystems and its many variations is poorly understood. In this paper, we characterized the topsoil permeability to water under in one of the most common vegetation types: the *Cerrado típico* which is a type of savanna. In doing so, we measured infiltration capacity using the Mini-Disk infiltrometer ($n = 15$) and soil resistance to penetration using the Stolf penetrometer ($n = 7$) in a Latossolo (oxisol) under Cerrado típico located in Brasília (Planaltina), Distrito Federal, Brazil. Our results indicated a high infiltration capacity under *Cerrado típico* which is potentially associated with a low penetration resistance. This fact might highlight the importance of the natural undisturbed ecosystems, in this case *Cerrado típico*, as a land-cover which favors hydrological processes which, in turn, promotes soil-groundwater recharge that are important to maintain water bodies and reservoirs in the region.

RESUMO

Infiltração de água na savana tropical brasileira: o caso do Cerrado típico

A savana brasileira, regionalmente conhecida como Cerrado é uma importante fonte de água devido à sua posição espacial na região de terras de alta altitude conhecida como Planalto Central do Brasil. No entanto, o funcionamento hidrológico desse complexo conjunto de ecossistemas e de suas inúmeras variações é pouco compreendido. O objetivo do presente estudo foi caracterizar a permeabilidade da superfície do solo à água em um dos mais comuns tipos de vegetação do Cerrado: o Cerrado típico que é um tipo de savana. Foram medidas a capacidade de infiltração usando o infiltrometro Mini-Disk ($n = 15$) e a resistência do solo à penetração usando o penetrômetro Stolf ($n = 7$) em um Latossolo sob Cerrado típico localizado em Brasília (Planaltina), Distrito Federal, Brasil. Os resultados indicaram uma alta capacidade de infiltração sob Cerrado típico que pode estar associada à uma baixa resistência do solo à penetração. Este fato destaca a importância dos ecossistemas naturais sem distúrbio, no presente caso o Cerrado típico, como uma cobertura da terra que favorece processos hidrológicos que promovem a recarga de água no solo e de água subterrânea que mantém a água nos corpos d'água e reservatórios da região.

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INTRODUCTION

The Brazilian savanna, regionally known as *Cerrado*, is composed by a variety of forests, grasslands and savannas (Castro e Kauffmann, 1998). However, as its name suggests, the main vegetation type is savanna. These savannas are not similar in terms of woody components density (Furley, 1999). For example, *Cerrado*, which is also the term used to describe the most abundant savanna type, comprises at least three variation with regards to woody components density (Ribeiro e Walter, 2008), that is, (i) *Cerrado ralo* (savanna with low density of woody components), (ii) *Cerrado denso* (savanna with high density of woody components) and (iii) *Cerrado típico* (savanna with moderate density of woody components).

Cerrado is widely distributed within Brazil. Though massive land-use change has been taken place within this biome (Strassburg et al., 2017), original area is estimated to be in the order 2 million km² (Ratter et al., 1997). This means that *Cerrado* covers a large extent of important river-basins. For example, Tocantins-Araguaia, São Francisco and Paraná have their springs within the *Cerrado* biome (Lima e Silva, 2005; Lima, 2011). Although, natural ecosystems are considered to play an important role in protecting the water of such basins, few precise basic information is available with respect to soil permeability of the *Cerrado*. From the available data, few have precisely described the exact type of vegetation under which measurements have been taken. As shown earlier,

this description is insufficient if the hydrological functioning of the different types of vegetation (frequently called “phytophysognomies”) is required to better understand the types of *Cerrado*. Furthermore, the few publications regarding soil permeability used a number of samples sufficient to properly describe hydraulic properties variability (Brito, 2019). Generally, a high number of samples ($n \geq 15$) is necessary to characterize such properties that vary in space (Bonell et al., 2010; Salemi et al., 2020).

Understanding soil permeability to water is crucial to comprehend the hydrological functioning of the *Cerrado* and, as a consequence, the ecosystem (hydrological) services they provide. In this respect, infiltration is one of the most relevant hydrological processes in order to allow soil-groundwater recharge which is necessary to maintain the dry season flow in rivers. The objective of the present paper was to characterize the soil surface permeability to water under a savanna type vegetation (*Cerrado típico*).

MATERIAL AND METHODS

Study area

We used an area of *Cerrado típico* (savanna with moderate density of woody components) located within the *campus* Planaltina of the University of Brasília (Figure 1). The site is located in Brasília (Planaltina region), Distrito Federal, Brazil in the following coordinates: 15°35'59.48”S and 47°39'28.90”O.

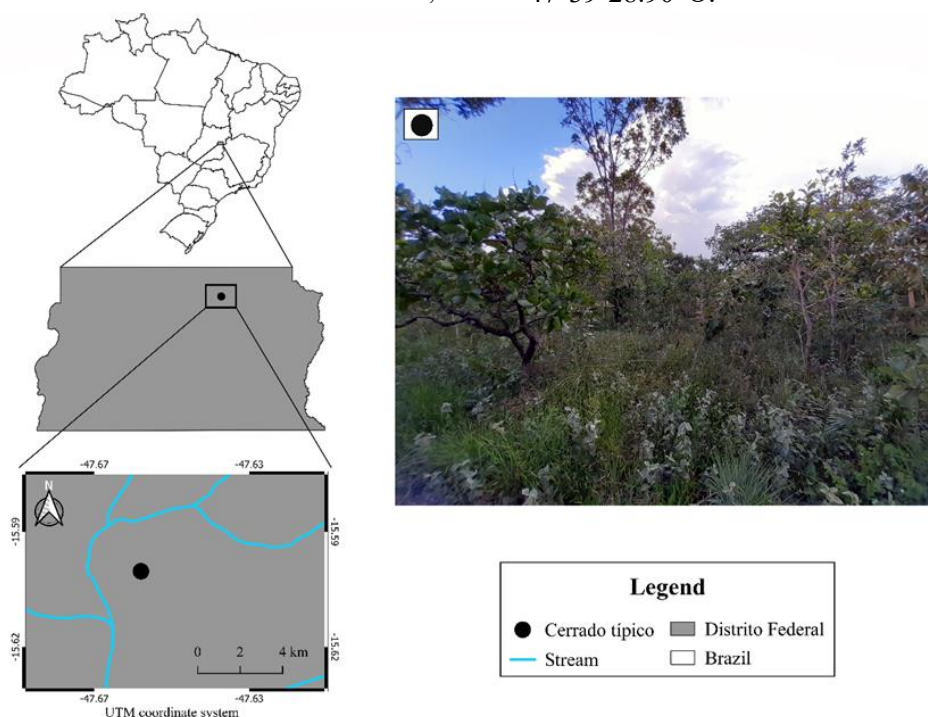


Figure 1 - Location of the study area.

Regarding pedology, the soil type is a Latossolo Vermelho-Amarelo (Brazilian classification system) or Oxisol (US Soil taxonomy) or Ferralsol (FAO). Texture is classified as clayey (J.V. Bernardi, personal communication).

The climate of the region is markedly seasonal. Annual rainfall is around 1393 mm (Malaquias et al., 2010). Wet season (October to April) generally presents nearly 100% of rainfall (Malaquias et al., 2010).

The vegetation is described as *Cerrado típico* which, as shown earlier, is a type of savanna where trees and shrubs are present at moderate density when compared to other forms of *Cerrado* (Ribeiro e Walter, 2008). *Cerrado típico* (in english “Typical Cerrado”) means that it is the most abundant type of savanna of the *Cerrado* biome.

Variables and sampling design

Infiltration capacity have been measured using *Mini disk infiltrometer* (Decagon Devices). Such device is a type of tension-infiltrometer which operates from 0 to - 7 cm suction rate and uses the

mathematical solution proposed by Zhang (1997) to calculate the hydraulic conductivity. In the present paper, aiming to estimate infiltration capacity, 0 cm suction rate has been adopted. In order to improve the contact of the infiltrometer with the soil, we used a thin layer of sand. Measurements have been taken at constant time intervals until a steady infiltration rate had been found for at least 3 times consecutively. We sampled 15 points in two linear transects following contour lines (Figure 2). The mean distance between each sampling point was 2 m.

In order to clarify indirectly soil porosity and bulk density, soil penetration resistance was measured using the Stolf impact penetrometer (*Kamaq*). Such device operates using 2 kg weight which drives a metal tap into to the soil (Stolf et al., 2012). We arbitrarily selected four impacts to measure soil resistance. Seven sampling units have been chosen randomly within the area of infiltration linear transects (Figure 2). Aiming to avoid interference of soil moisture content on soil penetration resistance, measurements have been performed during the dry season.

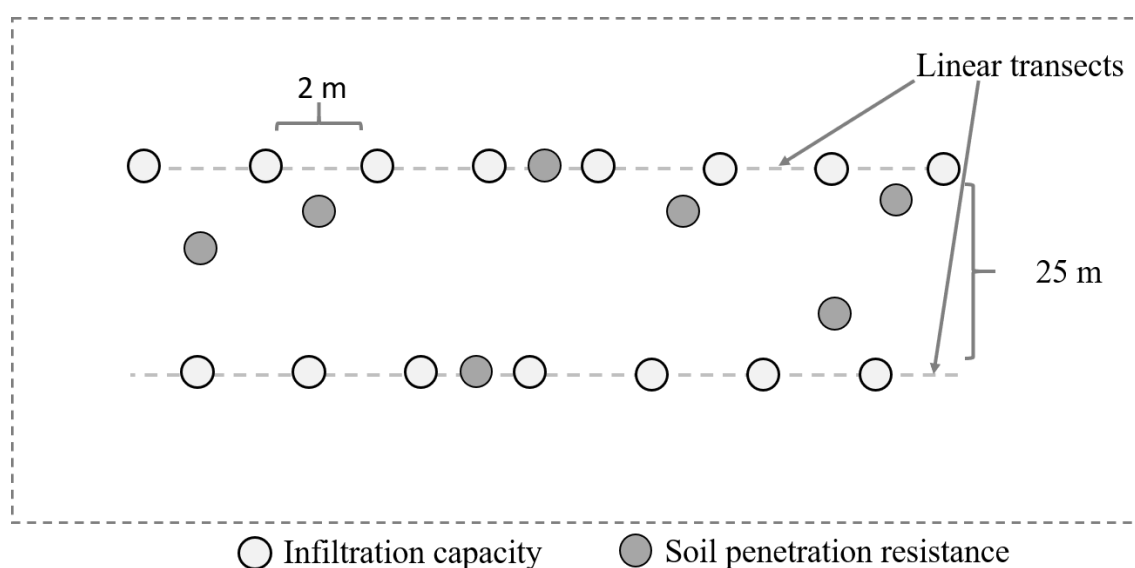


Figure 2 - Sampling design used to sample infiltration capacity (white circles) and soil resistance to penetration (gray circles). Not scaled for simplicity.

Analysis

Descriptive statistics have been used to present the observations. In order to evaluate if the number of samples were sufficient to properly characterize soil infiltration capacity variability, we carried out the sufficiency analysis provided by Salemi et al. (2020) in which a sufficient number of samples is considered met when variability statistics reached a relatively stable (i.e. $\leq 5\%$) value for, at least, three times consecutively. As our infiltration data

followed the normal distribution, we used standard deviation as the variability statistics. Our data was tested for normality using PAST software at $\alpha < 0.05$ (Hammer et al., 2001).

RESULTS AND DISCUSSION

Infiltration capacity was estimated as 716 ± 222 mm.hr⁻¹ (mean \pm standard deviation). A high variability could be detected (Figure 3). The number of samples collected suffice following the

criterion established by Salemi et al. (2020). That is, variability statistics stabilised as the number of samples increased (Figure 4). Soil presented a low resistance to penetration along all impacts (Figure 5).

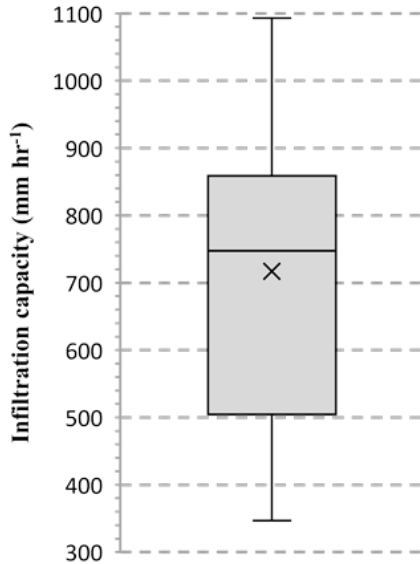


Figure 3 - Box-plot of infiltration capacity in soil under Brazilian tropical savanna (*Cerrado típico*). The length of the box represents the sample interquartile range; the bar in the box is the median whereas the x represents the mean. The extremes of the vertical lines outside the box represents the minimum and maximum observed values.

The infiltration capacity of the soil under *Cerrado típico* was considered rapid ($\geq 254 \text{ mm.hr}^{-1}$

¹) based on Soil Survey Staff (1993) standard. When comparing among natural ecosystems, it is within the order of magnitude of those observations carried out in the Brazilian tropical savanna documented by Souza and Alves (2003) and an order of magnitude lower compared to those by Hunke et al. (2015) (Table 1). Compared to forest ecosystems such as those of the Amazon, our infiltration estimate is also one order of magnitude lower (Zimmermann et al., 2006; Scheffler et al., 2011) (Table 1).

We hypothesize that differences in woody components density between forests and savannas and even within the savanna group (*Cerrado denso* vs. *cerrado típico*) may explain such differences. Thus, though no information on the type of “natural *Cerrado*” is available in Hunke et al. (2015), we suggest it was probably a *Cerrado denso*. In ecosystems with higher woody density, a higher biomass below and aboveground (Castro e Kauffmann, 1998) would promote higher biological activity (root growth and decay, higher litterfall, decomposition). These process may contribute to a high porosity already documented in Latossolos (Araújo et al., 2004) and observed here through our penetrometer assays. In addition, a less marked dry season in the Amazon forest would also enhance such differences through the promotion of the continuity of those biological processes since under marked dry season, as the one under our *Cerrado típico* region (Malaquias et al., 2010), those process may diminish with water limitation (Nardoto e Bustamante, 2003; Valenti et al., 2008).

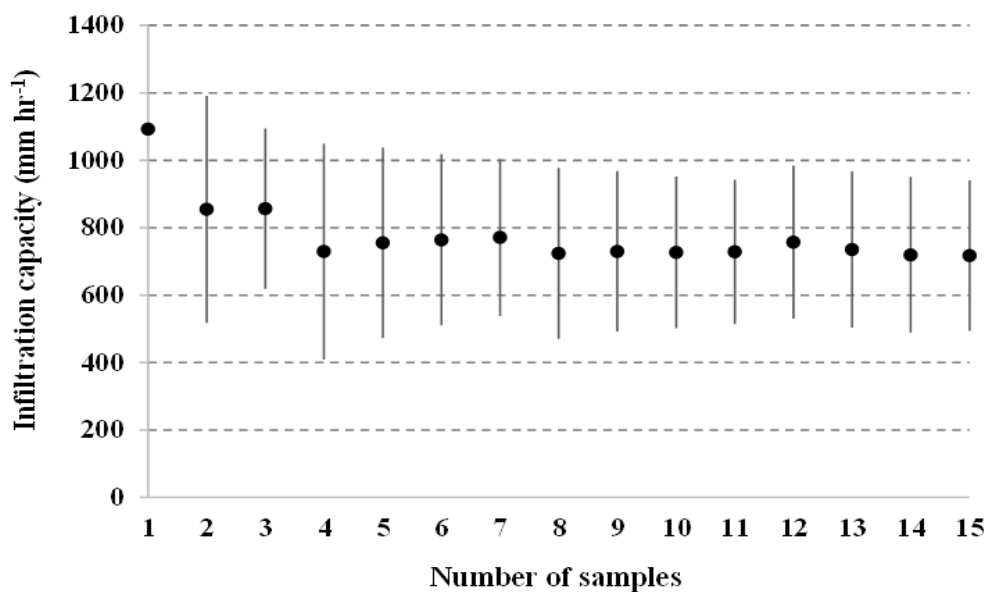


Figure 4 - Mean (circles) and standard deviation (bars) as a function of the number of samples.

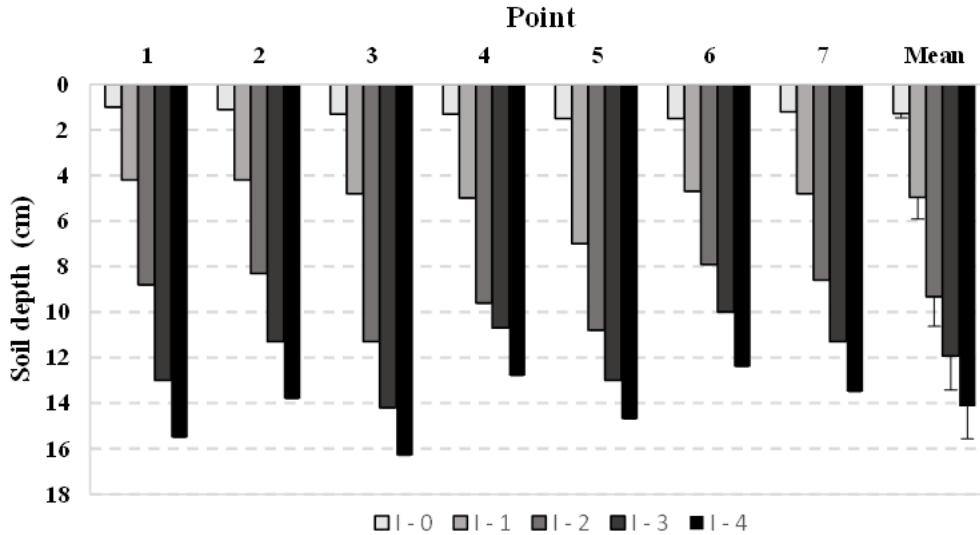


Figure 5 - Soil resistance to penetration in each of the seven points samples during impacts 0 to 4. On the right, the mean and standard deviation (bars) of all sampling points.

Finally, the infiltration capacity observed here is likely to exceed the maximum rainfall intensities of the region. For example, the highest 60-minute rainfall intensity recorded at Estação Ecológica das Águas Emendas Meteorological Station in 2019 (located 5 km distant from our *Cerrado típico* site) was 56 mm.hr⁻¹. Though there was no finer resolution record to estimate higher rainfall intensities, assuming the heaviest convective events available in Salemi et al. (2013) and Moraes et al. (2006) which were 105 mm.hr⁻¹ and 80 mm.hr⁻¹ respectively, even our lowest infiltration capacity observation (340 mm.hr⁻¹ see Figure 1)

was clearly higher than those rainfall intensities. This fact might highlight the importance of the natural undisturbed ecosystems, in this case *Cerrado típico*, as a land-cover which favors hydrological processes which, in turn, promotes soil-groundwater recharge that are important to maintain water bodies and reservoirs in the region. That is not the case of other land-uses such as soy and pasture which, demonstrably decrease infiltration capacity (Araújo et al., 2007; Bono et al., 2012; Hunke et al., 2015) favoring erosion and, as a consequence, land degradation (Montgomery, 2007).

Table 1 - Median of infiltration capacity from various studies that measured it in conditions similar to the present study

Reference	Method	Soil type	City/Region	Vegetation	Central tendency (mm.hr ⁻¹)
Present study	Mini-Disk infiltrometer	Latossolo Vermelho-Amarelo	Brasília (Planaltina), Distrito Federal, Brazil	Savanna (Cerrado típico)	716
Brito (2019)	Mini-Disk infiltrometer	Latossolo Vermelho-Amarelo	Brasília (Lago Sul), Distrito Federal, Brazil	Savanna (Cerrado típico)	697
Hunke et al. (2015)	Single ring infiltrometer	Latossolo Vermelho	Jaciara, Mato Grosso State, Brazil	Savanna (Cerrado)	1,200
Souza and Alves (2003)	Double ring infiltrometer	Latossolo Vermelho	Selvíria, Mato Grosso do Sul, Brazil	Savanna (Cerrado)	300
Scheffler et al. (2011)	Hood infiltrometer	Latossolo Vermelho-Amarelo	Canarana, Mato Grosso State, Brazil	Transition Tropical Forest	1,200
Zimmermann et al. (2006)	Hood infiltrometer	Argissolo	Rondônia State, Brazil	Tropical Forest	1,690

In order to predict the flowpath of the water that infiltrates the soil, observations of percolation are needed at higher soil depth. The only study which reported percolation capacity was by Hunke et al. (2015) who measured such property at 0.14, 0.2 and 0.4 m. Given that Latossolos (Oxisols) are deep soils ($\gg 2$ m), there is a clear gap to be bridged in future research. Likewise, though Latossolos are the most abundant soil type within the Cerrado biome (Reatto et al., 2003; Reatto e Martins, 2005), the savannas like *Cerrado típico* also occur in other different types of soils such as Entisols, Inceptisols, and Plinthic soils (Ribeiro e Walter, 2008). This may provide interesting opportunity to understand differences in near-surface hydrological processes in the same type of savannas under different soils.

CONCLUSION

The present study carried out an assessment of topsoil permeability under *Cerrado típico*, the most abundant type of savanna of the Cerrado biome (Brazil). We showed a remarkably high infiltration which probably accomodates the highest rainfall intensities in the region. This finding demonstrates the hydrological importance of the *Cerrado típico* in terms of promoting ecosystem services related to soil, groundwater and also biological conservation.

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