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# Infiltration rate in Argissolo Vermelho Amarelo cultivated with mombasa grass using a double-ring infiltrometer

## Taxa de infiltração em Argissolo Vermelho Amarelo cultivado com capim Mombaça utilizando um infiltrômetro de anel duplo

*Daniel Vítor Mesquita da Costa*[1], *Daiane de Cinque Mariano*[2], *Rafael Ferreira da Costa*[3], *Pedro Henrique Oliveira Simões*[2], *Cândido Ferreira de Oliveira Neto*[3], *Ricardo Shigueru Okumura*[3]

## ABSTRACT

This study aimed to determine the basic infiltration rate and physical properties of a Red-Yellow Ultisol (Argissolo Vermelho-Amarelo) cultivated with Panicum maximum cv. Mombaça. A completely randomized factorial design (3 × 2) was adopted, with three landscape positions (T1: pediment; T2: hillslope; T3: interfluve) and two soil depths (0–10 and 10–20 cm). T2 and T3 showed the lowest penetration resistance at 10–20 cm (2.56 and 2.20 MPa, respectively) and the highest basic infiltration rates (1.75 and 5.60 cm $h^{-1}$, respectively). T1 presented the lowest total porosity values (0.39 and 0.33 $m^3$ $m^{-3}$) at the 0–10 and 10–20 cm depths, as well as the lowest basic infiltration rate (0.90 cm $h^{-1}$). The cumulative infiltration $R^2$ values and basic infiltration rates across all treatments exceeded 0.94. Soil penetration resistance, bulk density, total porosity, and basic infiltration rate are interrelated; higher total porosity increases basic infiltration rate, which in turn enables crops to store and use water more efficiently.

**Keywords:** Soil bulk density; Physical attributes of the soil; Water in the soil.

## RESUMO

O objetivo do estudo foi determinar a taxa básica de infiltração e as características físicas do Argissolo Vermelho Amarelo cultivado com Panicum maximum cv. Mombaça. O delineamento experimental adotado foi o fatorial 3 x 2 inteiramente casualizado, com três posições na paisagem (T1: correspondente ao pedimento, T2: à encosta e T3: ao interflúvio) nas profundidades do solo, 0-10 e 10-20 cm. Os T2 e T3 apresentaram os menores valores de RP nas profundidades de 10 a 20 cm, 2,56 e 2,20 MPa, e as maiores TBI, 1,75 e 5,60 cm h-1. O T1 apresentou os menores valores de porosidade total (0,39 e 0,33 m3 m-3) nas profundidades de 0-10 e 10-20 cm, e o menor valor de TBI (0,90 cm h-1). A infiltração acumulada, $R^2$ e TBI dos tratamentos foram superiores a 0,94. A resistência do solo à penetração, a densidade do solo, a porosidade total e a TBI estão interligados, e um aumento na porosidade total resulta em um maior TBI, o que, por sua vez, permite que as culturas armazenem e utilizem água de forma mais eficiente.

**Palavras-chave:** Densidade aparente do solo; Atributos físicos do solo; Água no solo.

[1] Instituto Rede Terra;
[2] Universidade Federal do Mato Grosso;
[3] Universidade Federal Rural da Amazônia;
4 Ministério da Integração e do Desenvolvimento Regional.

Autor correspondente ricardo_okumura@hotmail.com

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## 1 INTRODUCTION

Understanding water infiltration from the soil surface into the subsurface is crucial, as this process directly impacts surface water runoff, a primary component of the hydrological cycle. Environmental conditions and climatic factors can influence erosion and flooding processes (Nery et al., 2017; Feki et al., 2018; Mahapatra et al., 2020).

Terrain slope, soil classification and texture, moisture content, precipitation effects, water application rates, compaction, vegetation cover, temperature variations, and infiltration capacity are the primary determinants that influence water infiltration into the soil.

Estimating infiltration rates is an essential analytical tool for understanding the distribution of water in soil, which in turn improves irrigation efficiency, optimizes water availability for plant growth, and increases crop yields (Adeniji et al., 2013; Rahman; Talaat; Zawe, 2016; Patle et al., 2019).

Numerous methodologies are available to determine the basic infiltration rate, such as the tension infiltrometer, rain simulator, and sprinkler infiltrometer. However, the double-ring infiltrometer was chosen for this investigation due to its cost-effectiveness, portability, and practicality. This instrument quantifies the water infiltration rate by positioning two concentric rings on the soil surface.

Mathematical models classified as theoretical and empirical are required to estimate the basic infiltration rate. These models are critical tools for the management of irrigation systems and the utilization of water resources (Sihag; Tiwari; Ranjan, 2017). Theoretical models are more complex due to the necessity of incorporating additional input parameters based on physical concepts. Conversely, empirical models are more straightforward.

The empirical Kostiakov model is frequently employed in this context due to its ability to accurately predict soil infiltration over short periods (Walker; Prestwich; Spofford, 2006; Yassin; Alazba; Mattar, 2016). The parameters are estimated from the regression curve that has been adjusted to the infiltration values collected in the field (Almeida, 2014).

The objective of this study was to estimate the basic infiltration rate and evaluate soil physical attributes in an Argissolo Vermelho Amarelo cultivated with Panicum maximum cv. Mombasa in the Brazilian Amazon.

## 2 MATERIALS AND METHODS

The experiment was conducted at the Federal Rural University of the Amazon (UFRA) in Parauapebas city, Brazil, between 2018 and 2019. The soil was classified as Argissolo Vermelho Amarelo, and *Panicum maximum* cv. Mombasa was cultivated (Santos *et al.*, 2018). Conventional soil preparation practices (use of plow and harrow) with a four-year history were in place until the implementation of Mombasa grass in December 2017.

The soil has a sandy-clay loam texture, as determined by the granulometric analysis conducted at the Soil Laboratory of UFRA using the Embrapa (2017) methodology. The particle sizes in the 0-20 cm layers are 562.41 g $kg^{-1}$ (sand), 264.62 g $kg^{-1}$ (clay), and 172.97 g $kg^{-1}$ (silt), and in the 20-40 cm layer, they are 514.55 g $kg^{-1}$ (sand), 254.50 g $kg^{-1}$ (clay), and 230.95 g $kg^{-1}$ (silt).

Parauapebas climate is classified as Aw according to the Köppen classification, which denotes a tropical savana climate with a distinct dry season. The city receives an average annual rainfall of 1,626 ± 84 mm, with an average relative humidity of 78.2 ± 0.8% and an average air temperature of 26.8 ± 0.2 °C.

Data on the total rainfall during the collection period of the basic infiltration rate (BIR) samples were acquired from the meteorological station situated in the experimental field, which amounted to 9.20 mm. There was no precipitation on the collection days.

The experimental design was a 3x2 factorial arrangement, with three positions in the landscape: T1 corresponds to the pediment (lower middle third), T2 to the slope (middle third), and T3 to the interfluve (upper middle third). The soil depths were 0 to 10 cm and 10 to 20 cm. For the basic infiltration rate (BIR), sampling was conducted with two replicates; three replicates for soil penetration resistance (PR) and gravimetric moisture (GM); and nine replicates for soil bulk density (SBD), particle density (PD), and total porosity (TP).

The Digital Elevation Model was generated using the kriging interpolation method in Surfer software (Golden Software), version 11.0 (Golden Software, 2016), and the elevation ranges of the evaluated area were determined from geographic information obtained from the GPS (Garmin e-trex10).

The variables BIR, PR, SBD, PD, TP, and GM were determined by collecting samples from July 2018 to January 2019. The BIR sampled points were used as a reference. In accordance with Bernardo, Soares e Mantovani (2006), the double-ring infiltrometer method was employed to evaluate BIR in the field. The internal cylinder's water level was measured at 0, 1, 2, 5, 10, 15, 20, 30, and 60 minutes, or until the infiltration rate stabilized. The time was verified using a digital stopwatch; infiltration was assumed to be constant when the observed values were repeated.

The infiltration results were compiled and submitted for analysis. The BIR is the result of the variation between two consecutive readings, as suggested by Bernardo, Soares e Mantovani (2006), in accordance with the time interval between them. Consequently, Excel software was implemented to compute and produce the BIR and accumulated infiltration graphs (Gondim *et al.*, 2010).

The potential expression of Kostiakov (1932) was used to modify the cumulative infiltration equation:

$$CI = aT^n \quad (1)$$

Where:
CI = cumulative infiltration (cm);
a = soil-dependent constant;
T = infiltration time (min);
n = soil-dependent constant ranging from 0 to 1

The parameters "a" and "n" are site-specific fitting parameters contingent upon soil conditions, including soil bulk density, soil texture, soil moisture content, and other soil properties (Uloma; Samuel; Kingsley, 2014). Kostiakov (1932) found that the constant "a" is linked to the characteristic of the surface soil, while "n" is associated with the initial moisture content and soil texture. There are no physical implications associated with the fitting parameters of the Kostiakov infiltration equation, as it is empirical (Khaliq; Iqbal; Anwar, 1994):

The infiltration rate can be quantified by employing the following equation (Kostiakov, 1932):

$$IR = 60anT^{n-1} \quad (2)$$

Where:
IR = infiltration rate (cm $h^{-1}$);
a = soil-dependent constant;
T = infiltration time (min);
n = soil-dependent constant ranging from 0 to 1.

The Kostiakov (1932) model was selected due to its practicality. The parameters "a" and "n" were estimated using a log I versus log T graph, as recommended by Reichardt and Timm (2004), based on the observed infiltration values (I) as a function of time (T). The model is a valuable tool for estimating soil infiltration rates in practical applications, as the BIR was determined through these calculations.

$$BIR = 60\ an\ [-\frac{0.01}{60an(n-1)}]^{(n-1)/(n-2)} \quad (3)$$

Where:
BIR = basic infiltration rate (cm $h^{-1}$);
a = soil-dependent constant;
n = soil-dependent constant ranging from 0 to 1.

Soils are classified as follows by BIR: > 3 cm $h^{-1}$ (very high BIR), 1.5 to 3 cm $h^{-1}$ (high BIR), 0.5 to 1.5 cm $h^{-1}$ (medium BIR), and < 0.5 cm $h^{-1}$ (low BIR) (Mantovani; Bernardo; Palaretti, 2009).

Using a digital penetrometer (Falker penetroLOG® - 1020), the physical attributes of PR were evaluated at depths of 0 to 10 cm and 10 to 20 cm. The readings were converted to the MPa measurement unit. To ascertain GM, SBD, PD, and TP, soil samples were collected and analyzed in accordance with the methodologies outlined in the soil analysis methods manual (Embrapa, 2017).

The experimental data were subjected to a comprehensive analysis using descriptive statistical procedures, including the mean, variance, standard deviation, coefficient of variation, standard error of the mean, maximum, and minimum values. The data were further validated by comparing the treatment means using the Tukey test at 5% probability and analyzing the variance using the F test through the Sisvar statistical software version 5.6 (Ferreira, 2019).

The classification criterion proposed by Gomes (2000) was implemented to quantify the CV: low (CV < 10%), medium (10% < CV < 20%), high (20% < CV < 30%), and very high (CV > 30%). Freddi *et al.* (2006) have acknowledged that this

dimensionless measure has been widely accepted in soil-related research, as it enables the comparison of the variability of two variables.

## 3 RESULTS AND DISCUSSION

The soil penetration resistance was found to be very high (CV > 30%) and low (CV < 10%) at depths of 0-10 and 10-20 cm, respectively. The CV values of SBD, PD, and GM were low at both depths (CV < 10%). The values were classified as medium for TP, irrespective of the depth evaluated (10% > CV < 20%) (Table 1).

**Table 1.** The coefficient of variation of soil penetration resistance (PR), gravimetric moisture (GM), soil bulk density (SBD), particle density (PD), and total porosity (TP) at the various depths evaluated is based on the three positions in the landscape: T1 corresponds to the pediment (lower middle third), T2 corresponds to the slope (middle third), and T3 corresponds to the interfluve (upper middle third).

| Depths | Treatments | PR | GM | SBD | PD | TP |
|---|---|---|---|---|---|---|
| | | ---------- % ---------- | | | | |
| 0-10 cm | T1 | 36.18 | 8.18 | 8.846 | 1.93 | 12.12 |
| | T2 | 27.48 | 0.35 | 16.56 | 5.07 | 14.74 |
| | T3 | 20.89 | 10.82 | 16.85 | 5.37 | 16.67 |
| 10-20 cm | T1 | 6.11 | 2.91 | 4.73 | 2.03 | 10.91 |
| | T2 | 8.49 | 10.74 | 7.81 | 5.52 | 10.37 |
| | T3 | 0.08 | 14.59 | 3.27 | 1.94 | 5.34 |

Source: elaborated by the authors (2026).

The high CV values in PR indicate a high degree of heterogeneity in the vicinity of the mean. Data variability is crucial for site-specific management, as reported by Bernardi *et al.* (2014). This is especially important in regions with high soil variability, such as PR in the current study.

Table 2 presents the average BIR values for the treatments and their respective intensity classifications (Mantovani; Bernardo; Palaretti, 2009). As demonstrated by the comparison of various agricultural, forestry, and livestock cultivation systems, the BIR value is significantly influenced by the physical structure of the soil and the level of vegetation cover (Silva *et al.*, 2017).

**Table 2.** The average values of basic infiltration rate (BIR), soil penetration resistance (PR), gravimetric moisture (GM), soil bulk density (SBD), particle density (PD), and total porosity (TP) of an Argissolo Vermelho Amarelo cultivated with Mombasa grass at the various depths evaluated are as follows: T1 corresponds to the pediment (lower middle third), T2 corresponds to the slope (middle third), and T3 corresponds to the interfluve (upper middle third).

| Treatments | BIR (cm $h^{-1}$) | Classification |
|---|---|---|
| T1 | 0.90 c* | Medium |
| T2 | 1.75 b | High |
| T3 | 5.60 a | Very high |
| CV (%) | 3.93 | |
| MSD | 0.63 | |

| Treatments | SBD (Mg $m^{-3}$) | PD (g $cm^{-3}$) | TP ($m^3$ $m^{-3}$) | PR (MPa) | GM (kg $kg^{-1}$) |
|---|---|---|---|---|---|
| | ---------- 0 a 10 cm ---------- | | | | |
| **T1** | 1.51 a | 2.50 a | 0.39 a | 0.98 a | 18.66 a |
| **T2** | 1.29 b | 2.45 a | 0.47 b | 0.97 a | 15.60 ab |
| **T3** | 1.38 ab | 2.52 a | 0.45 ab | 0.99 a | 13.36 b |
| | ---------- 10 a 20 cm ---------- | | | | |
| **T1** | 1.69 a | 2.54 a | 0.33 b | 2.95 a | 19.69 a |
| **T2** | 1.55 ab | 2.54 a | 0.38 ab | 2.56 ab | 15.18 b |
| **T3** | 1.47 b | 2.61 a | 0.43 a | 2.20 b | 12.07 b |
| **CV (%)** | 10.90 | 4.13 | 13.10 | 13.05 | 10.56 |
| **MSD** | 0.18 | 0.12 | 0.02 | 0.51 | 4.00 |

*Statistically significant differences, as demonstrated by the Tukey test at a 5% probability, are indicated by mean values followed by distinct letters
Source: elaborated by the authors (2026).

Vilarinho *et al.* (2019) investigated the BIR of a dystrophic concretionary petrisol cultivated with *Brachiaria decumbens* Stalf over more than a decade. Their findings indicated a value of 9.57 cm $h^{-1}$, emphasizing the significant impact of soil characteristics, including porosity and pore size, on water dynamics in the soil.

There is a statistical distinction between the treatments, as T1 exhibits the lowest TP averages (0.39 $m^3$ $m^{-3}$ from 0 to 10 cm and 0.33 $m^3$ $m^{-3}$ from 10 to 20 cm) in Table 2. The low values of BIR and TP may have result from increased accumulation of sediments in the evaluated area, which may have been arranged among the soil aggregates as a result of erosion processes following soil management. Soil particles are transported downslope by erosion processes, resulting in the formation of soil deposits in the lowest regions of the terrain (Carvalho, 1988).

At a depth of 0-20 cm, the SBD values of treatments T2 and T3 were statistically different from those of T1. The increase in SBD directly correlates with the rise in PR and the decrease in TP and BIR. According to Silva, Tormena e Imhoff (2002), this phenomenon occurs because an increase in SBD can result in the rearrangement and accommodation of soil particles, which in turn leads to a decrease in TP and an increase in PR.

The highest BIR averages were directly correlated with the lowest SBD values. In T2, the BIR average was 1.75 cm $h^{-1}$, and the SBD averages were 1.29 Mg $m^{-3}$ (0 to 10 cm) and 1.55 Mg $m^{-3}$ (10 to 20 cm). In T3, the BIR average was 5.60 cm $h^{-1}$, and the SBD averages were 1.38 Mg $m^{-3}$ (0 to 10 cm) and 1.47 Mg $m^{-3}$ (10 to 20 cm). The infiltration rate was significantly reduced as a result of the undulating relief associated with the landscape position of T2 during the rainy season, which promoted an increase in surface runoff.

In their 2013 study of a Argissolo Vermelho Amarelo with the native field, Prevedello *et al.* (2013) discovered SBD results of 1.35 and 1.50 Mg $m^{-3}$ at a depth of 0 to 10 and 10 to 20 cm, respectively. In dryland areas cultivated with Mombasa grass, Ramos *et al.* (2020) found that changes in soil density caused by land use influenced water infiltration into the soil.

The lowest PR averages were observed at depths of 10 to 20 cm (2.56 MPa in T2 and 2.20 MPa in T3) and were directly correlated with the highest BIR averages, 1.75 cm $h^{-1}$ (T2) and 5.60 cm $h^{-1}$ (T3).

No statistical difference was observed between treatments, and the lowest PR values were obtained in the 0 to 10 cm layer in T1, T2, and T3. This phenomenon is likely the result of the management practices implemented during soil preparation, which were associated with crop development and resulted in an increase in porosity in the 0 to 10 cm layer. Clayey-sandy loam soils exhibit a higher concentration of PR in layers deeper than 10 cm that are subject to agricultural machinery traffic, according to Cavalieri *et al.* (2009).

The average PR of T1 was 2.95 MPa at a depth of 10 to 20 cm, while that of T2 was 2.56 MPa. Imhoff, Silva e Tormena (2000) establish 2.5 MPa as the critical limit of soil mechanical impedance for the assessment of the physical quality of soil under pasture.

The soil class with a Bt horizon (textural B) was responsible for the increase in PR. This horizon is characterized by the accumulation of illuvial clay, which is associated with the excessive use of heavy agricultural implements. The accumulation of the clay in the soil increases SBD, increases PR, and reduces TP and BIR, resulting in the formation of a compacted layer (plow pan).

According to Pacheco and Cantalice (2011), the spaces between the larger pores in soils with varying particle size distributions may be filled by smaller particles, which in turn fill the spaces between these smaller particles with very fine particles. This allows for the formation of compacted layers when external pressures are applied, as may have occurred in T1. The particle influx from the upper slope resulted in a decrease in BIR.

The indirect method was employed to calculate TP by determining PD. The treatments did not exhibit any statistically significant differences due to the uniform source material on the slope under investigation. Pereira *et al.* (2019) did not observe any statistical difference in PD at a depth of 0 to 20 cm when assessing the physical attributes of the soil under various production systems in sandy-textured soils.

The analysis of Table 2 revealed that the lowest averages of PR (0.97 and 0.98 MPa) and SBD (1.29 and 1.38 Mg $m^{-3}$) were not correlated with the highest average values of GM (18.66 and 19.69 kg $kg^{-1}$), nor did they exhibit performance proportional to the highest averages of TP (0.47 and 0.45 $m^3$ $m^{-3}$). This implies that the relationship between GM, PR, and SBD is more complex than a straightforward inverse correlation, and additional research is required to gain a comprehensive understanding of it.

Mombasa grass root characteristics may have been positively influenced by the presence of soil cover, which may have enhanced moisture maintenance by aggregating soil particles, improving the structure, increasing the capacity for water absorption and retention, and reducing direct soil evaporation as a result of crop canopy closure.

Santos *et al.* (2018) reported comparable behavior. They found that the grass may have enhanced the cohesion between soil particles by increasing the capacity for

water absorption and retention through the characteristics of the root system, as evidenced by the GM intensity of a soil cultivated with Tifton (*Cynodon* spp.).

Figures 1, 2, and 3 illustrate the graphical representations of the observed and estimated values, as well as the potential equations employed to estimate the cumulative infiltration and BIR for each repetition (R1 and R2) of each treatment (T1, T2, and T3). Additionally, the respective values of the determination coefficients ($R^2$) are provided.

The cumulative infiltration increased over time, culminating in a final average value of 16.6 cm for T1, 43.05 cm for T2, and 114.30 cm for T3. Conversely, the BIR decreased until it approached stability, with values of 0.90 cm $h^{-1}$ for T1, 1.75 cm $h^{-1}$ for T2, and 5.60 cm $h^{-1}$ for T3. This behavior is comparable to that observed in conventional planting systems (Alves Sobrinho *et al.*, 2003) and minimum tillage (Cunha *et al.*, 2011).

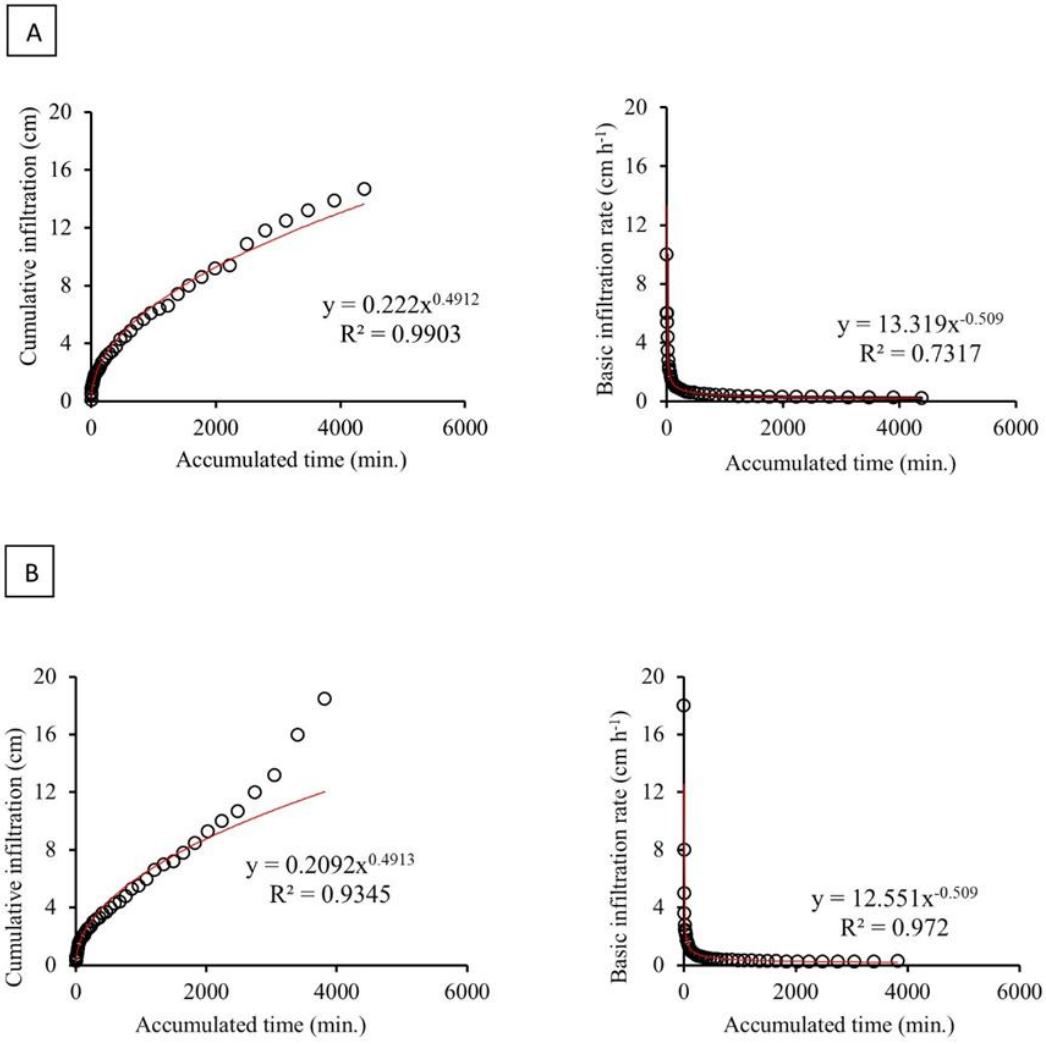



**Figure 1.** The basic infiltration rate and cumulative infiltration rate of replicates R1 (A) and R2 (B) in the lower middle third (T1) of Argissolo Vermelho Amarelo, which is cultivated with Mombasa grass. Source: elaborated by the authors (2026).

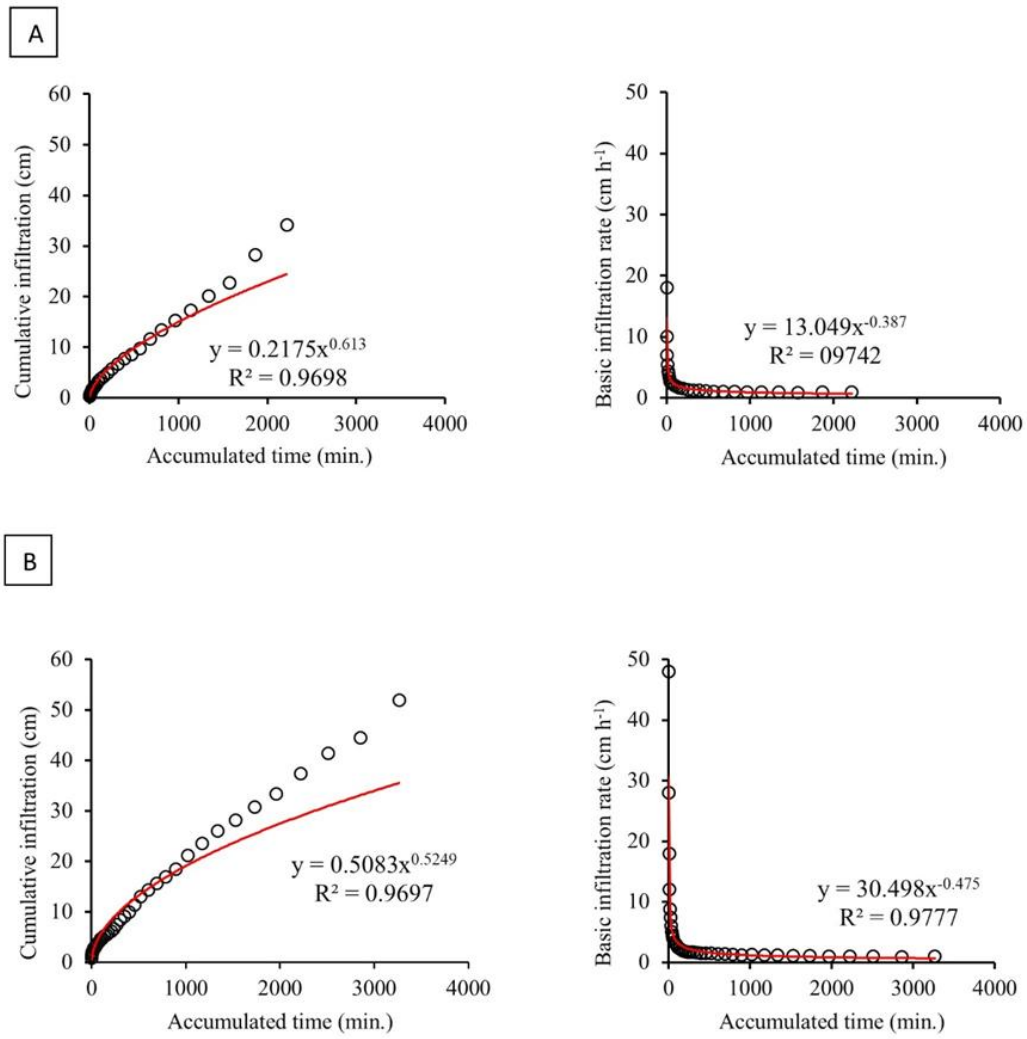



**Figure 2.** The basic infiltration rate and cumulative infiltration rate of replicates R1 (A) and R2 (B) in the middle third (T2) of Argissolo Vermelho Amarelo cultivated with Mombasa grass.
Source: elaborated by the authors (2026).

It is important to note that the $R^2$ of cumulative infiltration and BIR in the analyzed treatments was greater than 0.94, suggesting a high level of confidence in the accuracy of these measurements.

These results emphasizes the reliability of the Kostiakov equation in estimating BIR, a finding also reported by Pádron *et al.* (2015) in their investigation of a Yellow Argisol. The Kostiakov equation is the most appropriate model for estimating BIR, as it exhibits higher $R^2$ values in comparison to other mathematical methods, as reported by Cunha *et al.* (2015).

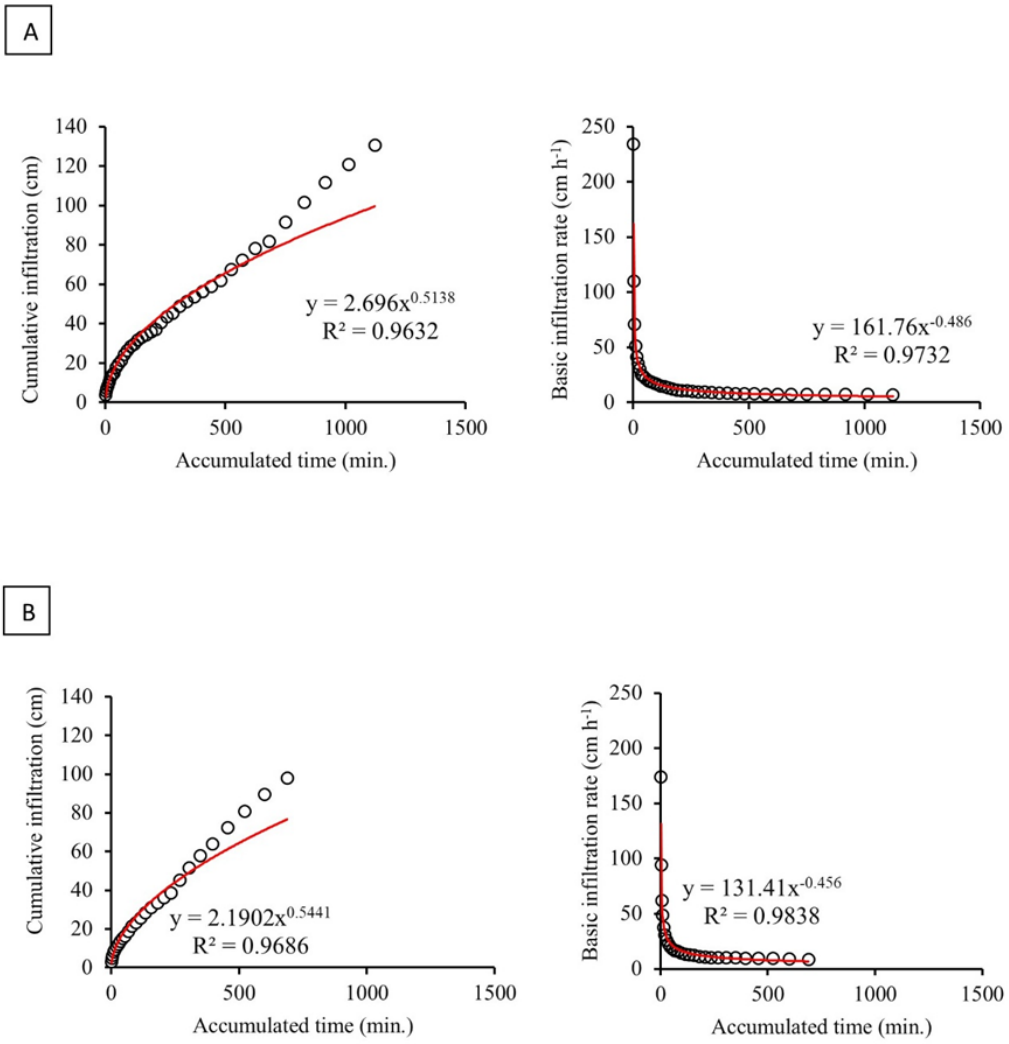



**Figure 3.** In the upper middle third of the slope (T3) of Argissolo Vermelho Amarelo, which is cultivated with Mombasa grass, the cumulative infiltration and basic infiltration rate for replicates R1 (A) and R2 (B).
Source: elaborated by the authors (2026).

## 4 CONCLUSIONS

The research has shown that the interfluve region on the incline of the Argissolo Vermelho Amarelo is where the most elevated basic infiltration rate (5.60 cm $h^{-1}$) is observed. The structural arrangement of the soil promotes the reduction of total porosity and increased soil penetration resistance and bulk density, resulting in the lowest basic infiltration rate value (0.90 cm $h^{-1}$) being observed in the pediment of the Argissolo Vermelho Amarelo studied.

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