UNIVERSIDADE DE BRASÍLIA – UnB
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PROGRAMA DE PÓS-GRADUAÇÃO EM CIÊNCIAS AMBIENTAIS

JOHNNY RODRIGUES DE MELO MURTA

EFEITO DE UM SISTEMA AGROFLORESTAL BIODIVERSO SINTRÓPICO SOBRE AS PROPRIEDADES FÍSICO-HÍDRICAS DO SOLO

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Dissertação apresentada como requisito para obtenção do título de Mestre em Ciências Ambientais no Programa de Pós-Graduação em Ciências Ambientais da Universidade de Brasília.

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Orientador: Prof. Dr. Luiz Felippe Salemi.

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Johnny Rodrigues de Melo Murta

Dissertação de Mestrado

EFEITO DE UM SISTEMA AGROFLORESTAL BIODIVERSO SINTRÓPICO SOBRE AS PROPRIEDADES FÍSICO-HÍDRICAS DO SOLO

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An old Cherokee is teaching his grandson about life:

"A fight is going on inside me," he said to the boy.
"It is a terrible fight and it is between two wolves. One is evil – he is anger, envy, sorrow, regret, greed, arrogance, self-pity, guilt, resentment, inferiority, lies, false pride, superiority, and ego."

He continued, "The other is good – he is joy, peace, love, hope, serenity, humility, kindness, benevolence, empathy, generosity, truth, compassion, and faith. The same fight is going on inside you – and inside every other person, too."

The grandson thought about it for a minute and then asked his grandfather: "Which wolf will win?"

The old Cherokee simply replied, "If you feed them right, they both win."
and the story goes on:

"You see, if I only choose to feed the white wolf, the black one will be hiding around every corner waiting for me to become distracted or weak and jump to get the attention he craves. He will always be angry and will always fight the white wolf."

"But if I acknowledge him, he is happy and the white wolf is happy and we all win. For the black wolf has many qualities — tenacity, courage, fearlessness, strong-willed and great strategic thinking –that I have need of at times. These are the very things the white wolf lacks. But the white wolf has compassion, caring, strength and the ability to recognize what is in the best interest of all."

"You see, son, the white wolf needs the black wolf at his side. To feed only one would starve the other and they will become uncontrollable. To feed and care for both means they will serve you well and do nothing that is not a part of something greater, something good, something of life."

"Feed them both and there will be no more internal struggle for your attention. And when there is no battle inside, you can listen to the voices of deeper knowledge that will guide you in choosing what is right in every circumstance."

"Peace, my son, is the Cherokee mission in life. A man or a woman who has peace inside has everything. A man or a woman who is pulled apart by the war inside him or her has nothing."

"How you choose to interact with the opposing forces within you will determine your life. Starve one or the other or guide them both."

The Tale of Two Wolves – Cherokee Legend

SUMÁRIO

Apresentação Geral

A conversão de uso da terra e seu manejo inadequado ameaça a manutenção de serviços ecossistêmicos importantes e potencializa distúrbios ambientais, como fragmentação de habitats, perda de biodiversidade, invasão biológica, erosão e poluição hídrica (Grecchi et al. 2014; Sano et al. 2019). O manejo da agricultura convencional, por exemplo, modifica significativamente os atributos físico-hídricos do solo (Reichert et al. 2003). As principais alterações são diminuição do volume de macroporos, do tamanho de agregados, da taxa de infiltração de água e o aumento da resistência à penetração de raízes e da densidade aparente do solo (Souza et al. 2006), o que gera perda gradativa de matéria orgânica, sendo que a presença dela no solo aumenta a capacidade de infiltração, reduzindo a ocorrência de escoamento superficial e erosão (Kobiyama et al. 2001). Em última análise, o desmatamento e a conversão para terras cultivadas têm efeitos importantes sobre os processos hidrológicos, incluindo aumento das inundações e redução do fluxo de água nos períodos de seca (Toohey et al. 2018).

De fato, os recursos hídricos têm-se tornado cada vez mais escassos, dada sua contínua e crescente exploração para o abastecimento da população e manutenção da cadeia de produção (Ridoutt and Pfister 2010; Rodell et al. 2018), especialmente no bioma Cerrado, onde predomina a agricultura intensiva (Grecchi et al. 2014; Sano et al. 2019). Além de aumentar a perda de biodiversidade de espécies endêmicas (Klink and Machado 2005), o desmatamento no Cerrado ameaça ainda a produção hídrica e elétrica em todo o país, uma vez que o bioma abriga as nascentes de três grandes bacias hidrográficas no Brasil (Paraná, São Francisco e Araguaia-Tocantins) e sustenta mais de 50% da energia hidroelétrica do país (Lima 2011; Sano et al. 2019).

Na busca por sistemas de manejo que promovam melhoria na estrutura do solo e, consequentemente, na retenção e no armazenamento de água, vale considerar modelos de agricultura conservacionista (Figueiredo et al. 2009). O plantio direto, por exemplo, fundamenta-se no não revolvimento da camada superficial do solo, na cobertura permanente dele, e na rotação de culturas (Scopel et al. 2013). Com esse manejo é possível se evitar perdas causadas pela erosão que, além do solo, carrega para os cursos d’água, adubos e outros produtos sintéticos, constituindo-se em fonte de poluição e de degradação de corpos hídricos (Embrapa 1998). Os benefícios obtidos são frequentemente explicados pelo aumento da porosidade do solo e altas quantidades de resíduos de superfície da colheita (Scopel et al. 2013).

Outra prática sustentável de uso da terra emergente são os sistemas agroflorestais, que utilizam árvores e plantas convencionais simultaneamente na mesma área, para benefícios ambientais e econômicos (Nair 1993). Esses sistemas são manejados de modo a tirar proveito de interações ecológicas positivas, minimizando a competição. O objetivo é que o sistema seja mais eficiente na utilização dos recursos disponíveis – água, luz e nutrientes – que os plantios convencionais (Nicodemo 2011; Nair et al. 2017). Sistemas agroflorestais fornecem serviços de abastecimento, como alimentos e forragem; serviços regulatórios, incluindo modificação do microclima, controle da erosão e sequestro de carbono para a mitigação das mudanças climáticas; ou serviços de suporte, como melhoria da fertilidade do solo, conservação da biodiversidade e polinização (Nair et al. 2017; Alagele et al. 2018).

É importante destacar que há diferentes tipos de sistemas agroflorestais, classificados de acordo com seus aspectos estruturais e funcionais (Nair 1985, 1993), de modo que a provisão de serviços ecossistêmicos e a recuperação da biodiversidade difere dependendo do tipo de sistema. Dentre as diferentes classificações, há os sistemas agroflorestais biodiversos, que têm potencial de manter maiores níveis de biodiversidade e provisão de serviços ecossistêmicos quando comparados a sistemas agroflorestais com um menor número de espécies. Portanto, o uso de sistemas agroflorestais biodiversos como alternativa aos sistemas de produção convencionais aumenta a habilidade de agroecossistemas terem menor impacto negativo sobre a biodiversidade e provisão de serviços ecossistêmicos (Miccolis et al. 2016). Da perspectiva de um sistema de produção, sistemas agroflorestais biodiversos são mais similares a ecossistemas naturais em termos de conservação da biodiversidade e provisão de serviços ecossistêmicos (Santos et al. 2019).

Sistemas agroflorestais têm mostrado evidências sólidas de seu papel na melhoria das propriedades físico-hídricas do solo (Chen et al. 2017; Dollinger and Jose 2018; Alagele et al. 2018). No entanto, os estudos em sistemas agroflorestais que avaliam as propriedades físico-hídricas do solo se concentram em consórcios entre poucas espécies (Anderson et al. 2009; Silva et al. 2011; Kumar et al. 2012; Pezarico et al. 2013; Benegas et al. 2014; Wang et al. 2015; Sahin et al. 2016; Sun et al. 2018), sem registros desta avaliação para sistemas agroflorestais biodiversos. Neste sentido, é fundamental entender como a mudança no uso da terra afeta as propriedades físico-hídricas do solo e, consequentemente, a capacidade de infiltração de água no solo, especialmente considerando os sistemas agroflorestais biodiversos. Nesta perspectiva, o presente trabalho tem como objetivo caracterizar um sistema agroflorestal biodiverso em termos de atributos físico-hídricos do solo e compará-lo com sistemas naturais e agrícolas.

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Physical and hydraulic soil properties in a biodiverse agroforestry system: a comparative approach

Abstract

Land-use change is a global threat to ecosystem services. In the scenario of high agricultural production to feed a growing worldwide population, agroforestry systems emerge as alternative agriculture system with a greater possibility for long-term sustainability. However, little is known about the extent to which biodiverse agroforestry systems modify the soil physical and hydraulic properties. Thus, the objective of the present study was to characterize a biodiverse agroforestry system in terms of soil physical and hydraulic properties. In order to evaluate such properties, a comparison was carried out with natural (Brazilian Tropical Savanna) and agricultural systems (soy-maize rotation under no tillage). The biodiverse agroforestry system had a higher infiltration capacity (720.4 ± 142.5 $mm.h^{-1}$; $p < 0.01$) than Cerrado típico (625.7 ± 212.9 $mm.h^{-1}$) and no tillage system (571.5 ± 272.3 $mm.h^{-1}$). We concluded that soil permeability in the agroforestry system studied was significantly higher than that of a no tillage system and a natural environment, probably due to high organic matter content and higher biological activity in the soil. Therefore, we reinforce that agroforestry systems are an efficient alternative to maintain water infiltration and soil conservation in conjunction with agricultural activities and other ecosystem services.

Keywords**:** Land-use. Hydraulic conductivity. Soil water infiltration. No-till. Cerrado. Ecosystem services.

Introduction

Maintaining productivity to meet the growing demand for food, fiber, and fuel is a major challenge for agriculture (Robertson and Swinton 2005). In contrast, the increasing land-use change to monoculture causes major changes in the hydrological cycle (Spera et al. 2016; Zwartendijk et al. 2017). This intensive use promotes soil degradation and reduction of soil water infiltration capacity (Hunke et al. 2015), an essential process for soil groundwater recharge and maintenance of water bodies (Brandão et al. 2006). Therefore, one of the consequences of converting native vegetation to conventional agriculture is a decrease in the water supply (Foley 2005).

The land-use type influences water supply since land management alters the physical and hydraulic soil properties (Bruijnzeel 2004; Neris et al. 2012). The main changes can be found in macropore volume, aggregate size, water infiltration capacity, penetration resistance and bulk density (Souza et al. 2006). In general, natural ecosystems have well-structured soils, high porosity, low density and, consequently, higher infiltration capacity (Zwartendijk et al. 2017; Vezzani et al. 2018) when compared to agroecosystems under conventional agriculture, which generally have opposite characteristics due to excessive soil tillage, heavy machinery and intensive traffic (Wendling et al. 2012).

In this scenario, agroforestry systems emerge as an alternative agriculture system with greater possibility for long-term sustainability (Jose 2009; Kremen and Merenlender 2018), since the presence of forest components, combined with higher species diversity (Nair 1993) can: (i) increase the organic matter content in the soil (Benegas et al. 2014; Nair et al. 2017); (ii) increase soil nutrient availability; and (iii) improve microbial activity, which positively influences soil quality (Dollinger and Jose 2018).

The term agroforestry broadly refer to an interface between agriculture and forestry including different types of land use (Nair 1993), which means that there is a diversity of agroforestry systems classifications considering its functional and structural aspects (Nair 1985, 1987). An emerging type of agroforestry system is the biodiverse agroforestry system (Miccolis et al. 2016; Santos et al. 2019), similar to that adopted by Ernst Götsch, (1995) where the management, with severe pruning and high litterfall, as well as a systematic irrigation, associated with high plant diversity, enhances ecosystem services (Jose 2009, 2012; Udawatta et al. 2019). However, studies assessing soil physical and hydraulic properties on agroforestry systems focus mainly on intercropping among few species (Anderson et al. 2009; Silva et al.

2011; Kumar et al. 2012; Pezarico et al. 2013; Benegas et al. 2014; Wang et al. 2015; Sahin et al. 2016; Sun et al. 2018), with no record of these assessments for biodiverse agroforestry systems.

Therefore, it is fundamental to understand how land-use change affects soil physical and hydraulic properties, especially considering biodiverse agroforestry systems. The objective of the present study was to characterize a biodiverse agroforestry system in terms of soil physical and hydraulic properties. In order to evaluate such properties, a comparison was carried out with natural (Brazilian Tropical Savanna) and agricultural systems (soy-maize rotation under no-till). Since there is a high litterfall on this type of agroforestry system (Miccolis et al. 2016), we expected that the physical and hydraulic properties of its soil would be more similar to those found in a natural environment. Furthermore, we expected a higher soil physical quality in agroforestry compared to those in a no-tillage system.

Materials and Methods

Study areas

We selected three areas under different land-use types: soy-maize rotation under no-till (NT), biodiverse agroforestry system (BAS) and Brazilian savanna regionally known as *Cerrado típico* (NV). The study areas are located in a rural area of Planaltina, Distrito Federal, Brazil, within the Santa Rita sub-basin (Fig. 1). The distance between the BAS and the other treatments is 2.6 km, and the distance between the NV and NT is 4.3 km. According to Köppen-Geiger, the climate is classified as Aw, with two well-defined seasons (dry and wet). The average annual rainfall is 1500 mm, and more than 90% of the rainfall is distributed between October and April. The assays were performed in the rainy season of the Cerrado biome, between October 2018 and March 2019 (Ribeiro and Walter 2008). The predominant soil type in all three areas is Latossolo, according to the Brazilian Soil Classification System (Embrapa 2018) (Oxisols in the US Soil Taxonomy). In order to characterize the soil texture of all treatments, the Bouyoucos (1926) method was carried out. All soil texture samples were classified as clay, based on the USDA Department of Agriculture (USDA) soil classification.

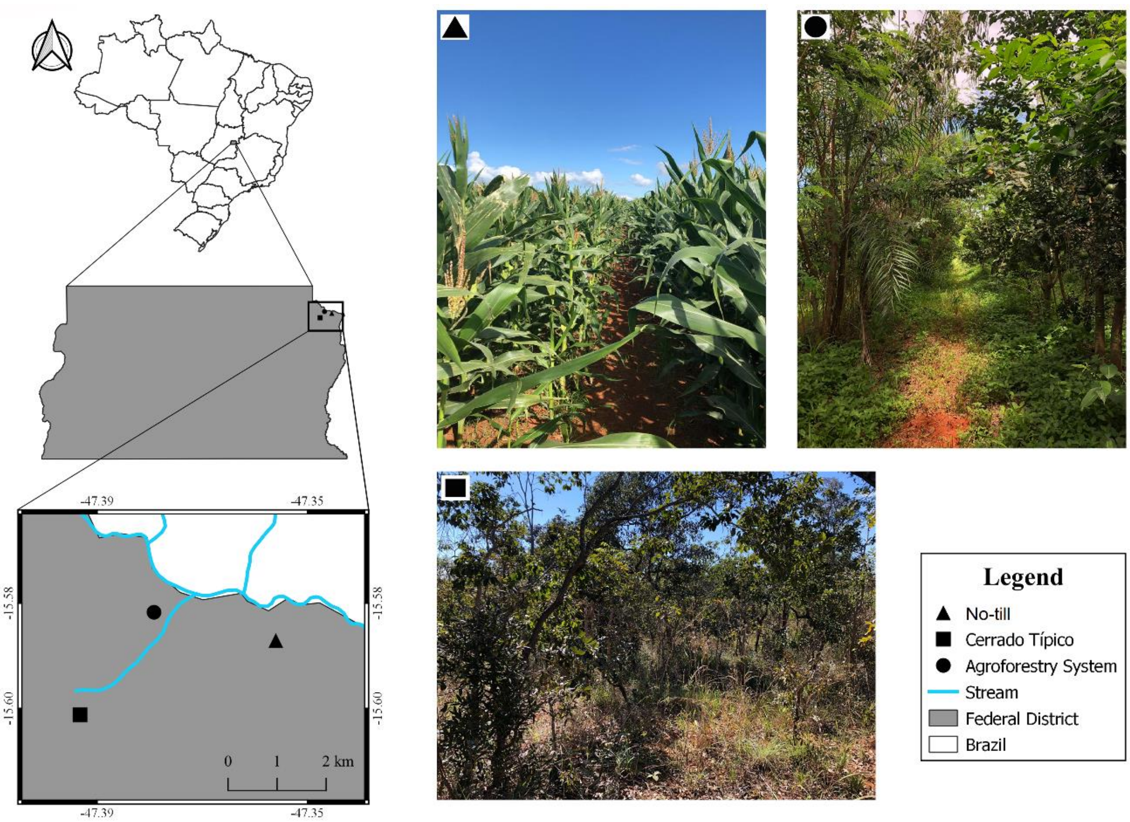

Fig. 1 Location of the study areas

Regarding land-use history, in the BAS area, from 1985 to 2000, conventional agricultural production activities with soybean and maize were developed. After two years under fallow, the management of the BAS began in 2002. The BAS here is characterized as a biodiverse agroforestry system (Miccolis et al. 2016; Santos et al. 2019), implemented and managed to mimic the natural ecological succession dynamics of native forests. Regarding its management, there is severe pruning and irrigation regularly, the leaves and branches are placed under the plants. There are over 20 plant species intercropped in the area, including *Senna obtusifolia, Leucaena leucocephala, Hymenaea courbaril, Ceiba pentandra, Swietenia macrophylla, Dipteryx alata, Inga marginata, Cajanus cajan, Tephrosia candida, Morus nigra, Cosmos sulphureus, Hylocereus undatus, Citrus sinensis, Bixa orellana, Persea americana, Citrus limon, Ananas comosus, Psidium guajava, Annona squamosa, Carica papaya, Musa sp*. This BAS has been subject of studies that investigated soil carbon and nitrogen dynamics (Alves et al. 2014), the use of nitrogen fertilizers and carbon credits quantification in this land-use type (Sampaio et al. 2014), as well as the benefits of mechanization in agroforestry implantation (Moura and Hoffmann 2009).

The NV area is a phytophysiognomy of the Cerrado biome, a savanna formation classified as Cerrado *stricto sensu,* more specifically *Cerrado típico* (physiognomic subdivision). This phytophysiognomy is characterized by its predominantly arboreal-shrub vegetation, with low, sloping, crooked trees with irregular and twisted branches. Tree cover is from 20% to 50% and average tree height varies between 3 m to 6 m (Ribeiro and Walter 2008).

The NT area is part of a private rural property where maize and soybeans are produced under no-tillage system, which is a form of conservation management where, in addition to crop rotation, there is permanent mulch cover and no soil tillage (Embrapa 1998).

Soil physical and hydraulic properties and sampling design

In order to compare soil physical and hydraulic properties of the three areas under different land-use types, we evaluated: soil water infiltration capacity ($mm.h^{-1}$), soil bulk density ($g.cm^3$), total soil porosity (%), organic matter content (%), and soil resistance to penetration (cm and MPa).

In each area, we performed 30 water infiltration capacity assays. We established three linear transects (Silva et al. 2011; Salemi et al. 2013) and ten infiltration assays were distributed per transect, with an average distance of 1m between each one (Fig. 2). In the agricultural systems (BAS and NT), we performed the assays on the planting rows, and each assay was located at an average distance between two plants. We selected the transects by randomizing the planting rows using a standard randomizer (randomizer.org), which randomized the row on which the assays should be performed. In the NV area, although there are no planting rows as in the agricultural areas, three linear transects were established arbitrarily following a sampling design similar to the one used in the agricultural systems.

We measured the soil infiltration capacity using a mini disc infiltrometer - Decagon devices Inc., USA (IMD), an instrument that uses the analytical solution proposed by Zhang (1997), convenient for determining the infiltration characteristics and soil permeability (Bhave and Sreeja 2013). To increase the contact area between the IMD and the soil, we removed the litterfall and performed the tests on horizontal surfaces, ensuring the stability of the device. Also, a thin layer (< 1 mm) of sand was used, as proposed by Gonzalez-Sosa et al. (2010). In this study, the suction pressure was 0 kPa.

We collected ten soil cores (100 cm^3) at a depth of 0-10 cm in each area to measure physical properties of the soil - bulk density, total porosity, and organic matter content using Uhland soil sampler. Each point was randomly selected in the transects defined in the sampling design of the infiltration capacity, following the same pattern in the planting rows (Fig. 2). To measure soil bulk density, we followed the volumetric cylinder method proposed in Embrapa (2017). We oven-dried the samples for 48 hours at a temperature of 105 ºC and weighed them after this process on a 0.001 g precision scale. Soil bulk density was then calculated using equation 1:

$$Bd = \frac{Dsm}{V} \quad (1)$$

Where: Bd = soil bulk density (g.cm³); Dsm = oven-dried soil mass (g); V = soil core volume (cm³).

Total porosity was calculated with bulk density values using equation 2, assuming that the soil particle density was 2.65 g.cm³ (Rowell 1994).

$$Tp = \left(1 - \left(\frac{Bd}{\rho s}\right)\right) * 100 \quad (2)$$

Where: Tp = total porosity; Bd = bulk density; ρs = soil particles' density.

Organic matter content was obtained by the difference between the oven-dried soil mass and soil mass after ignition (500 ºC) for 5 hours, following Embrapa (2017).

We measured soil penetration resistance ten times in each treatment following the same pattern in the planting rows (Fig. 2). Soil penetration resistance was measured using the Stolf impact penetrometer by KAMAQ (Stolf et al. 1983). We arbitrarily selected four impacts to calculate soil resistance. We converted the depth reached at each impact (cm) into penetration resistance (MPa) using the Excel spreadsheet available in Stolf et al. (2014).

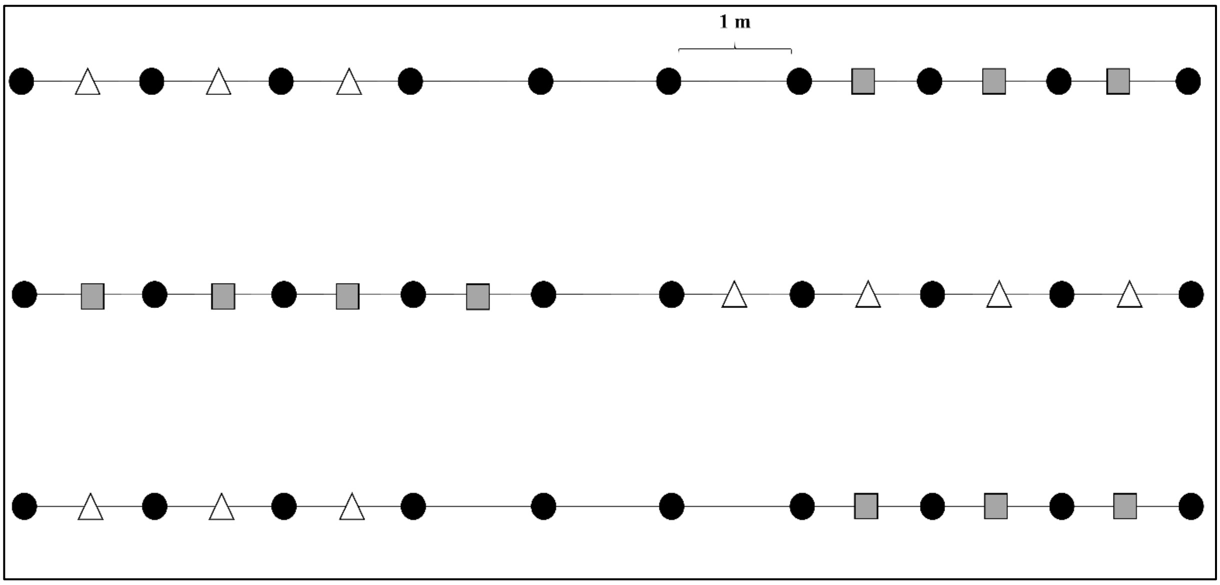

Fig. 2: Schematic of assays performed in all treatments. Each horizontal line represent a planting row. Black circles represent soil infiltration capacity measurements; grey squares represent soil samples collected; and white triangles represent soil penetration resistance measurements

Statistics

The Shapiro-Wilk test showed that the soil physical and hydraulic data were non-normal. Therefore, a Kruskal-Wallis test was performed to identify significant differences between the treatments studied. Subsequently, a Mann-Whitney pairwise test was performed for multiple comparisons between each variable in the treatments. Statistical analyses were performed in Paleontological Statistic - PAST software version 3.22 at $p < 0.05$.

Results

The mean infiltration capacity (± standard deviation) in the BAS was 720.4 (± 142.5) $mm.h^{-1}$, in the NV was 625.7 (± 212.9) $mm.h^{-1}$, and in the NT was 571.5 (± 272.3) $mm.h^{-1}$ (Fig. 3). The infiltration capacity in the BAS was significantly higher ($H = 11.58$; $p < 0.01$) than in the other treatments. On the other hand, there was no significant difference between NV and NT regarding the infiltration capacity.

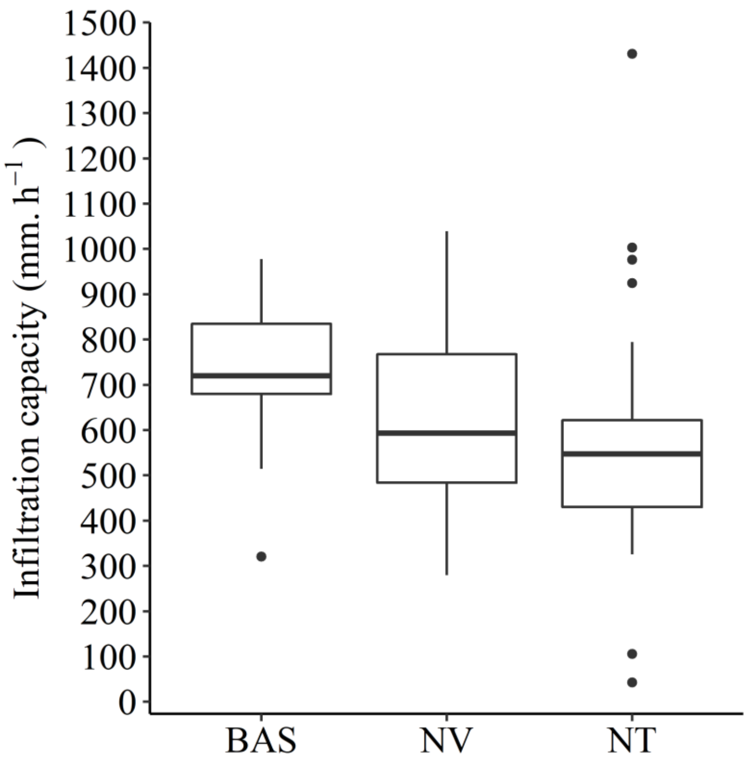

Fig. 3: Boxplot showing the soil water infiltration capacity under agroforestry system (BAS), *Cerrado típico* (NV) and no-till maize (NT). The horizontal lines within the boxes represent the median of the results, the horizontal boundaries of the boxes represent the first and third quartiles, the tips of the vertical lines represent the maximum and minimum values, and the black dots represent the outliers

As for bulk density, there was a significant difference between the treatments ($H = 7.55$; $p < 0.03$). BAS's bulk density was significantly higher than that of NV ($p < 0.01$), and there was no significant difference between NT and the other treatments regarding the bulk density. The mean bulk density (± standard deviation) in BAS was 0.87 (±0.09) g/cm³. In NT, the mean bulk density was 0.84 (± 0.07) g/cm³, and in NV it was 0.80 (± 0.05) g/cm³ (Fig. 4a).

Soil total porosity was proportional to bulk density results, so there was also significant difference between treatments (H = 7.63; $p < 0.03$). Total porosity in NV was significantly higher than that of BAS ($p < 0.01$), and there was no significant difference between NT and the other treatments for this variable. The mean total porosity (± standard deviation) in NV was 70 (± 2) %, while NT presented mean total porosity of 68.3 (± 2.5) %, and in BAS it was 67 (± 3.4) % (Fig. 4b).

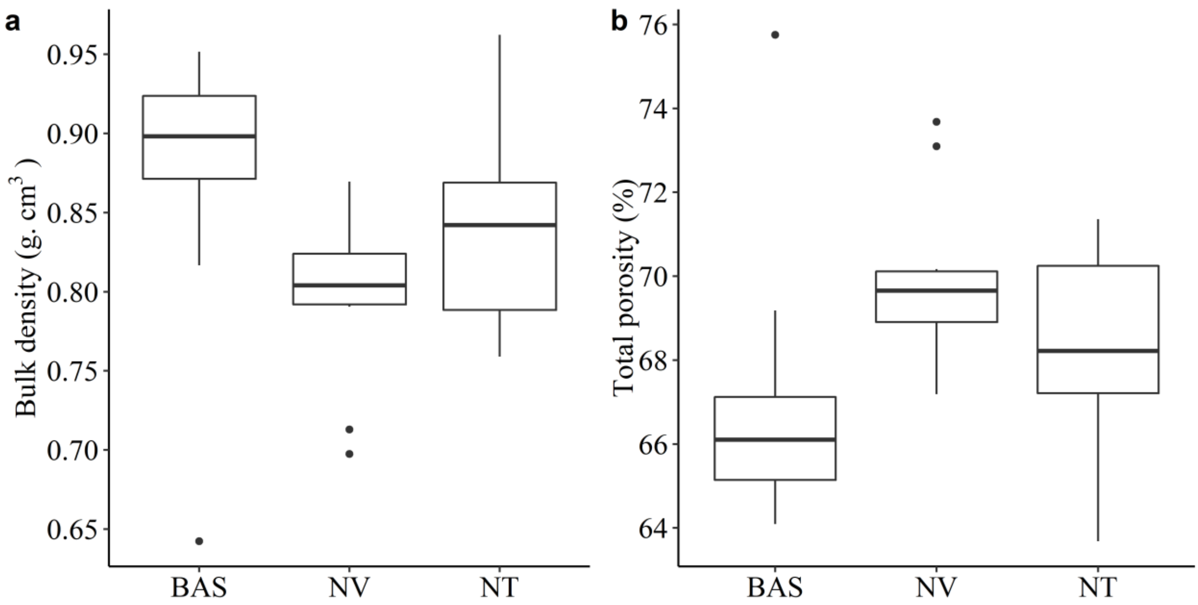

Fig. 4: Boxplots showing the soil bulk density (a) and total porosity (b) in agroforestry system (BAS), *Cerrado típico* (NV) and no-till maize (NT). The horizontal lines within the boxes represent the median of the results, the horizontal boundaries of the boxes represent the first and third quartiles, the tips of the vertical lines represent the maximum and minimum values, and the black dots represent the outliers

Organic matter content had a significant difference between the treatments (H = 18.13; $p < 0.001$). The organic matter content in NT and BAS was significantly higher than in NV ($p < 0.001$). However, NT and BAS did not differ from each other. NT presented a mean organic matter content (± standard deviation) of 22.4 (± 1.46) %, in BAS the mean was 22 (± 2.97) %, and in NV it was 19 (± 0.79) % (Fig. 5).

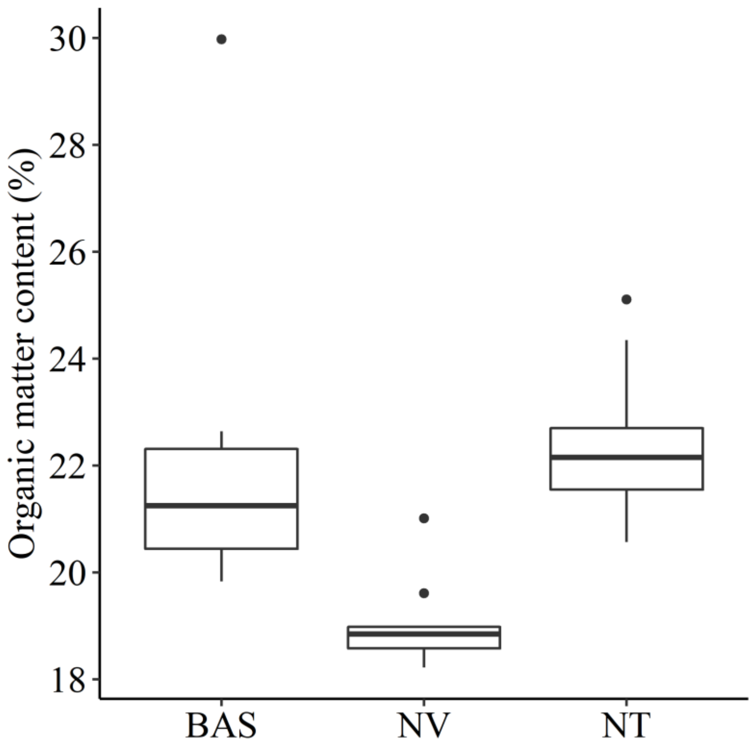

Fig. 5: Boxplot showing the soil organic matter content under agroforestry system (BAS), *Cerrado típico* (NV) and no-till maize (NT). The horizontal lines within the boxes represent the median of the results, the horizontal boundaries of the boxes represent the first and third quartiles, the tips of the vertical lines represent the maximum and minimum values, and the black dots represent the outliers

The soil penetration resistance in the impacts 0, 1, 2, and 3, BAS reached average depths of 6.29, 11.17, 14.22, and 16.85 cm respectively. NT, in turn, in the same impacts, reached average depths of 4.87, 8.93, 11.55, and 13.75 cm respectively. On the other hand, the four impacts on NV reached average depths of 3.58, 8.11, 10.46, and 12.39 cm, respectively (Fig. 6a). BAS, at a depth of 0-2.5 cm, showed average penetration resistance of 0.56 MPa, at a depth of 2.5-5 cm, 0.60 MPa, and at a depth of 5-7.5 cm, 1.49 MPa. NT, at a depth of 0-2.5 cm, also showed a mean penetration resistance of 0.56 MPa, at a depth of 2.5-5 cm, 1.49 MPa, and at a depth of 5-7.5 cm, 2.36 MPa. NV, on the other hand, at a depth of 0-2.5 cm, showed a mean penetration resistance of 0.74 MPa, at a depth of 2.5-5 cm, 1.53 MPa, and at a depth of 5-7.5 cm, 2.23 MPa (Fig. 6b). There was a significant difference in soil penetration resistance between treatments. The soil of BAS had resistance to penetration significantly lower than NV on all impacts. On the other hand, there were no significant differences between NT and the other treatments on any impacts.

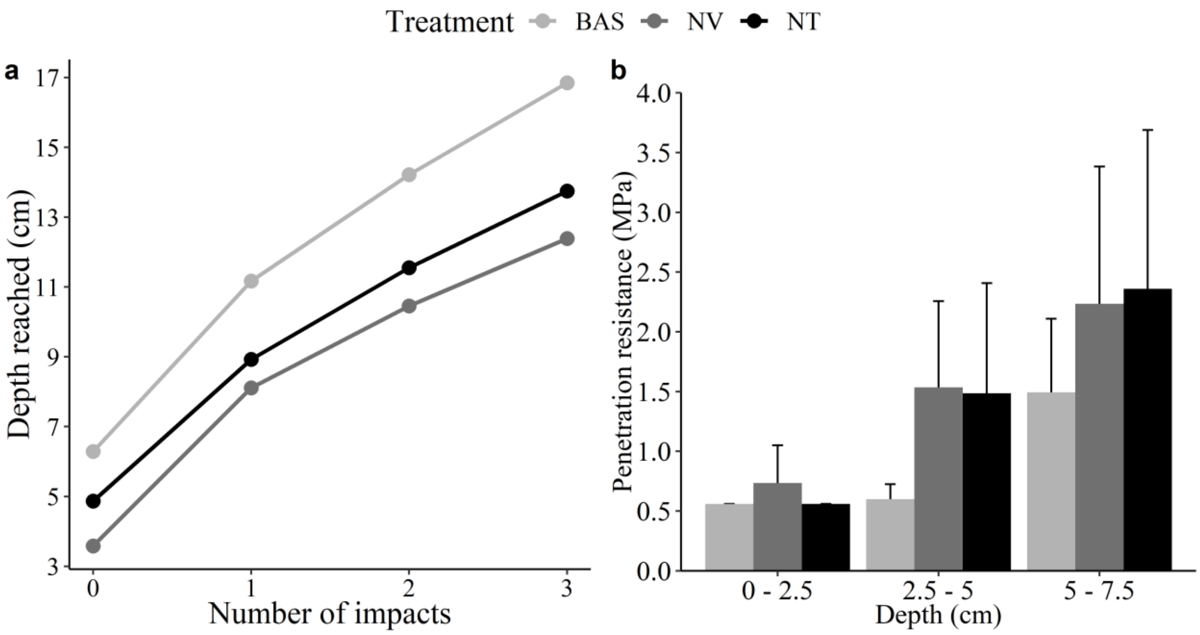

Fig. 6: Average soil penetration resistance in centimeters (a) and pressure in Megapascal (b)

Discussion

Considering the high plant diversity and the high mulch (litter) accumulation on biodiverse agroforestry soil surface (Miccolis et al. 2016), we hypothesized that the soil physical and hydraulic properties in BAS would be closer to those found in natural environments when compared with soils under no-till system. However, the soil infiltration capacity in BAS was significantly higher when compared to NV and NT, which was probably a consequence of the high litterfall in BAS due to pruning. On the other hand, the absence of significant difference between the NV and NT in infiltration capacity probably results from the no-till management in NT, where there is minimal soil compaction, combined with the constant maintenance of the straw that protects the soil surface.

Through biological activity, soil organic matter induces increased porosity, reduced density and resistance to penetration and, consequently, increased water infiltration into the soil. This occurs because organic matter is the energy source for soil organisms (Weil and Brady 2016), which, by consuming organic matter, form more stable and resistant macroaggregates, mechanically incorporate soil residues and dig channels through which water and air can flow (Franzluebbers 2002; Nair et al. 2017; Dollinger and Jose 2018; Alagele et al. 2018; Udawatta et al. 2019). In fact, during field campaigns, several insects were observed on the soil in BAS. That was not the case for NV and NT. Further studies are needed in order to clarify the soil fauna under these systems.

In this study, the organic matter content in BAS was significantly higher than in NV, probably due to the higher litterfall in BAS. In fact, Valenti et al. (2008) demonstrated that a Cerrado *stricto sensu*, with characteristics similar to NV, produces on average 5.8 $t.ha^{-1}$.year of litterfall, while biodiverse agroforestry systems produces on average 10.2 $t.ha^{-1}$.year (Arato et al. 2003). Moreover, in the NV (*Cerrado típico*), given the Oxisol characteristics of being acidic, with low content of essential nutrients such as phosphorus and nitrogen, and having high levels of aluminum (Eiten 1972), the organic matter content tends to vary naturally from medium to low (Ribeiro and Walter 2008). The organic matter content in NT was also significantly higher than in NV, which may be linked to mulching and the absence of frequent disturbance by plowing, which generates an increase in the organic matter content incorporated into the soil (Sharma et al. 2013; Nunes et al. 2018).

Despite the infiltration capacity and organic matter content results, total porosity in NV was significantly higher than that of BAS. This is probably due to a difference in the distribution of macro and micropores because the infiltration capacity depends mainly on the distribution, size and continuity of the macropores, which facilitate the movement of water in the soil (Alagele et al. 2018). Silva et al. (2011) documented that an agroforestry system, under the same soil type as the natural vegetation (Caatinga - small and thorny trees) had lower total porosity than natural vegetation, however, the agroforestry system had higher macroporosity and lower microporosity than natural vegetation. In this sense, studies should assess the amount of micro and macropores in the total porosity in agroforestry systems and natural environments. Also, we must highlight that BAS, although a conservationist system, is a type of agricultural land use and still has not shown low porosity. The mean total porosity results found in BAS (67 ± 3.4 %) were similar to those found by Carvalho et al. (2004) in an agroforestry system with 20 tree species and annual crops under Oxisol, where, at depths of 0-10 cm, the mean total porosity ranged from 66.64% to 66.82%, which was attributed to the higher biological activity provided by management of the area and the consequent effects on soil aggregation. This occurred due to the high diversity of tree species in the biodiverse BAS, increasing the amount and diversity of root architecture in the soil (Nair et al. 2017), thus increasing the macropores created by those roots. The total porosity results found in NT (68.3 ± 2.5%) agree with Goedert et al. (2002), who investigated soil compaction under no-till in Oxisol where the mean total porosity ranged from 67.8 to 68.0%. The authors also pointed out that these results are considered normal for areas of Oxisol.

Soils with higher porosity and fewer solid content have lower densities, which means that any factor influencing soil porosity affects bulk density (Weil and Brady 2016). That being said, BAS's bulk density was significantly higher than that of NV, which agrees with the results of the study mentioned above by Silva et al. (2011), who found that an agroforestry system had a significantly higher bulk density than soil under native vegetation. Furthermore, the bulk density values found in BAS (0.87 ± 0.09 $g.cm^3$) were similar to those found by Carvalho et al. (2004), where the bulk density ranged from 0.84 to 0.87 $g.cm^3$ at depths of 0-10 cm, being considered an average bulk density value by the authors, that was attributed to the protection provided by tree species, which reduce the impact of raindrops on the soil and maintain the soil organic matter content (Young 1989). The management of the agroforestry system reported by the authors (Carvalho et al. 2004) is similar to BAS, where all plant remains from pruning were left on the soil surface, undergoing a natural process of decomposition.

There was no significant difference between NT and the other treatments (BAS and NV) concerning bulk density. However, it should be noted that bulk densities in all treatments were low, probably due to the high rates of litterfall, since soil surface particle aggregation is highly dependent on the management, especially the accumulation of mulch without soil incorporation (Franzluebbers 2002). Bulk density under NT (0.84 ± 0.07 $g.cm^3$) was similar to that found in the study mentioned above by Goedert et al. (2002), who found in the soil superficial layers (0-20 cm) bulk densities ranging from 0.79 to 0.92 $g.cm^3$, concluding that such values are not above that considered critical, meaning that no-tillage system does not lead to superficial or deep soil compaction.

Also, generally soils under native vegetation tend to have lower bulk density than related land-uses. This might be attributed to a more structured soil, with a higher number of stable macroaggregates (Vezzani et al. 2018). On the other hand, agricultural activities such as soil preparation break down these macroaggregates of the soil, changing the size and continuity of the macropores, consequently increasing the soil bulk density (Vezzani et al. 2018). The lack of continuity also has negative effect on the infiltration capacity. Soil density of BAS was higher than that of NV probably because the soil of NV is the only one that has not been managed in any way, i.e. the soil maintains its natural structure and porosity, even though we are evaluating conservation land-use types in this study, specifically an agroforestry and no-till systems, which tend to maintain soil properties (Carvalho et al. 2004; Zhang et al. 2012).

Soil bulk density and porosity directly influence penetration resistance (Weil and Brady 2016). Therefore, the lower resistance in BAS, which mirrors the infiltration results found, was probably a consequence of the higher litterfall and higher macroporosity in this system. The same applies to the similarity found between the resistance to penetration in NT (due to the maintenance of organic matter as mulch) and NV (for having a preserved soil structure).

Practical implications

The no-till management, which is a type of conservation agriculture, has a high organic matter content, improves the physical properties of the soil and favors water infiltration (Scopel et al. 2013; Sharma et al. 2013; Nunes et al. 2018). However, its contribution is more expressive for food production, while it reduces the availability of other ecosystem services such as habitat connectivity, biodiversity maintenance, pollination and pest control because it has less complex relationships (Kremen and Merenlender 2018). On the other hand, agroforestry systems emerge as an alternative in conservationist agriculture (Nair 2007), promoting the merge of productivity with soil conservation and other ecosystem services (Kremen and Merenlender 2018). Several studies have already proven a positive relationship between the presence of agroforestry systems and the maintenance of ecosystem services (Udawatta et al. 2019). This is because these systems, especially when they are biodiverse (Isbell et al. 2017), are more similar to natural ecosystems in terms of soil and biodiversity conservation (Santos et al. 2019). Agroforestry influences, for instance, improvement of animal habitat, erosion control, nutrient retention, water recharge and quality, increasing soil fertility and health and air quality (Jose 2012).

In hydrological terms, several studies have found benefits of implementing agroforestry systems for the local water balance, such as reduced runoff and peak flow (Narain et al. 1997), soil erosion (Jackson and Wallace 1999) and soil moisture loss (Lin 2010). However, models indicate that these systems increase water interception, transpiration, and decrease in water yield (Mwangi et al. 2016). On the other hand, among the types of land use studied here, BAS was the one with the highest infiltration capacity. This result together with those mentioned above demonstrate that similar to natural forests, biodiverse agroforestry systems favor infiltration capacity and conserve soil water functions. However, empirical data are still lacking in order to know the interception and evapotranspiration capacity of these systems. Thus, this study contributes to the understanding of the benefits of agroforestry systems for water and soil conservation, but it is necessary to expand experimental research to understand how the implementation of agroforestry influences the water balance of basins and to know their impacts on water yield and groundwater recharge, processes that are highly related to infiltration capacity.

Conclusions

The soil permeability in the agroforestry system studied was significantly higher than that of a no-till system and the soil of natural environment of the Cerrado, probably due to the high litterfall, and biological activity in the soil. Therefore, it emerges as an alternative to maintain water infiltration and soil conservation in conjunction with agricultural activities.

Land-uses influenced soil physical and hydraulic properties of the soil due to the characteristics of management. Conservationist agricultural practices, such as agroforestry systems and no-till, are favorable options for the conservation and maintenance of ecosystem services, the former by mimicking natural ecosystems and the latter by combining soil conservation with production.

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