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Soil physical properties in an oxisol under a syntropic agroforestry system: row *versus* inter-row

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ABSTRACT

Synthropic agroforestry systems are agricultural systems designed to reconcile agricultural production with environmental conservation. However, the benefits related to soil physical properties of these systems have only been documented for the planting rows. Thus, the physical behavior of the soil in the inter-rows remains unknown. The objective of this paper was to characterize the physical properties of the soil in the rows and inter-rows of a syntropical agroforestry system - SAS. For this, infiltration capacity (mini-disk infiltrometer) and soil resistance to penetration (STOLF Penetrometer) were measured in five ramdomly located blocks involving the rows and inter-rows. The results showed that there were no significant differences between row and inter-rows for both variables. The high species diversity, continuous addition of organic matter to the soil via pruning, the absence of heavy machinery use, and the vigorous growth of exotic grasses in the inter-row are the likely factors that explain the absence of differences reported here. We conclude that the rows and inter-rows of a SAS behave similarly in relation to the attributes evaluated. This demonstrates that such systems are highly beneficial for food production as well as maintaining soil physical properties.

Key-words: Sustainability; water permeability; agriculture; best management practices.

Propriedades físicas do solo em um latossolo sob um sistema agroflorestal sintrópico: linha *versus* entrelinha

RESUMO

Os sistemas agroflorestais sintrópicos são sistemas agrícolas criados com o intuito de reconciliar a produção agrícola com a conservação ambiental. Entretanto, os benefícios relativos às propriedades físicas do solo desses sistemas só foram documentados para as linhas de plantio. Assim, o comportamento físico do solo nas entrelinhas ainda permanece desconhecido. O objetivo deste artigo foi caracterizar as propriedades físicas do solo nas linhas e entrelinhas de um sistema agroflorestal sintrópico - SAS. Para isso, mediram-se a capacidade de infiltração (mini-disk infiltrometer) e a resistência do solo à penetração (STOLF Penetrometer) em blocos envolvendo as linhas e entrelinhas. Os resultados demonstraram que não houve diferenças significativas de linhas e entrelinhas para ambas as variáveis. A alta diversidade de espécies, adição contínua de matéria orgânica ao solo via podas, a ausência do uso de máquinas pesadas e o crescimento de gramíneas exóticas na entrelinha são os prováveis fatores que explicam a ausência de diferenças aqui reportadas. Conclui-se que as linhas e entrelinhas de um SAS se comportam de maneira similar em relação aos atributos avaliados. Isso demonstra que tais sistemas são altamente benéficos para produção de alimentos assim como manter as propriedades físicas do solo.

Palavras-chave: Sustentabilidade; permeabilidade da água; agricultura; boas práticas de manejo.

Introduction

The challenge of agroecosystems is to increase production from ecologically designed agricultural systems that can recover traditional practices combined with ecological knowledge that enhance ecosystem services (Neves & Imperador, 2022). The fragmentation of habitats - caused mainly by agriculture impacts biogeochemical cycles, biodiversity and the production of food and fiber (Zilli et al. 2020; Ma et al., 2023) affecting soil compaction and, consequently, the water infiltration capacity. Such changes alter the hydrological cycle locally and bring about serious reductions in aquifer recharge (Failache & Zuquete 2020).

In this context, it is evident the need to develop agricultural systems capable of combining food production with other ecosystem services. Some authors present studies that demonstrate other forms of food production in which there is the possibility of reducing dependence on fertilizers and pesticides and, consequently, minimize impacts on ecosystems, improving productive capacity over time (Sachs et al. 2010; Chen et al. 2022; Puech & Starkb, 2023). This approach takes place, from a sustainable vision, based on food security, human health, and the social and economic well-being of those who produce, consume, and live around these productions (Basche & DeLong 2019; Waldron et al. 2020; Das et al., 2022). Among these agricultural practices are syntropic agroforestry systems (SASs) which consist of a combination between several perennial plant species of agricultural interest. These systems are based on species succession, nutriente cycling, plant diversity and management through the use of severe pruning (Götsch 1997; Micollis et al. 2016; Roseto et al., 2021; Pereira et al. 2021; Mayer et al., 2022). Since SASs mimic natural ecosystems and their processes, this system is expected to bring other benefits beyond food production. For example, the high addition of organic matter from pruning may benefit soil infiltration capacity.

Murta et al. (2020) demonstrated that the infiltration capacity of a SAS was similar to that of a natural ecosystem (Brazilian Tropical Savannah). However, that study evaluated the infiltration only in the rows. Therefore, it is not yet known whether the same pattern would be found inter-row, which are generally more subjected to physical disturbances due to the transit of heavy machinery. In this sense, understanding the SAS in a more systemic way, that is, including the row and inter-row, allows a more holistic assessment regarding the effective benefit that the SASs can bring about.

The objective of this article is to characterize the infiltration capacity and soil penetration in the rows and inter-rows of a SAS. Given that previous studies indicated that rows generally have better soil physical properties compared to the inter-rows (Silva et al., 2014; Santos et al., 2020; Guillot et al., 2021; Las Casas et al., 2022), starting from these premises, we hypothesized that rows are more permeable than inter-rows.

Material and methods

Study areas

The study was carried out at Elo Florestal Inkóra Farm, which is located in the Núcleo Rural Taquaras, in Planaltina-DF, in the Preto river watershed, at UTM coordinates 244,850.00 mE and 8,275,995.59 mS (Figure 1).

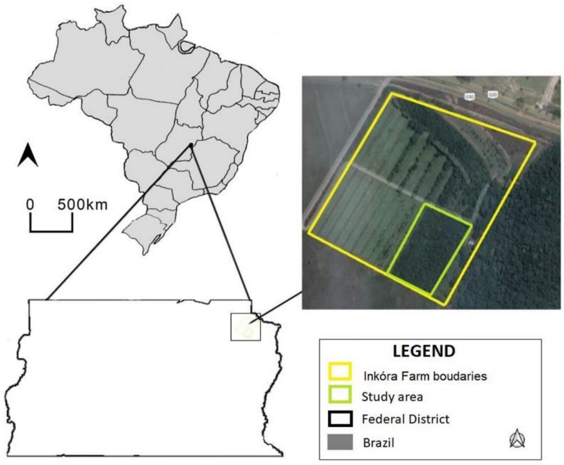

Figure 1: Location of the study area, Fazenda Inkóra Florestal, Planaltina, Federal District, Brazil.

The soil is classified as Oxisol. This type of soil is characterized as thick, highly weathered, with moderate A horizon and latosolic B horizon, rich in sesquioxides, highly porous and well drained (Santos et al., 2018).

The mean annual precipitation in the Federal District is 1477.4 mm (Instituto Nacional de Meteorologia [INMET], 2021) with two well defined seasons (rainy season from October to April and dry from May to September). according to Köppen-Geiger (Alvares et al. 2013).

The syntropic agroforestry system (SAS) in the study area is characterized as a mature system (20 years old) with a 4 m inter- row spacing and 1 or 2 m between individuals within the row. The area was used for soybean cultivation between 1985 and 2000. After the 2000s, it underwent a fallow period of two years and, in 2002, SAS was introduced (Figure 1). SAS is organized in rows and inter-rows constituting an agroforestry system with high diversity. There are more than 20 species 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* and *Musa sp* (Figure 2A).

Figure 2: Syntropic agroforestry system: rows (A) and inter-row (B).

Typically, inter-rows serve as transit areas for management which can involve both both manual and/or mechanized methods. In the current SAS, apart from the regular crops, the inter-rows exhibit vigorous growth of exotic grasses (*Urochloa* sp, *Pennisetum purpureum*) and other spontaneous plants. In addition, inter-row are subjected to litter deposition (Figure 2B).

Variables and sample design

Two variables were measured: infiltration capacity and soil resistance to penetration in the rows and inter-row. In this sense, five randomized blocks were established through the use of a randomizer. In each block, a total of 6 infiltration samples were collected – three from within the row and three from the inter-row (Figure 3). The same procedure was followed for measuring soil penetration resistance.

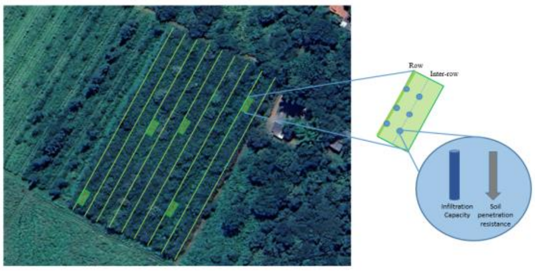

Figure 3: Sampling design employed in the present study involved randomly situating five blocks (depicted as green rectangles) in the field. Each block covered both the rows and inter-rows. Within each treatment, three repetitions were collected for both infiltration capacity and soil penetration resistance.

Infiltration capacity

We measured infiltration capacity using a mini-disc infiltrometer (Decagon devices Inc., USA) which uses the analytical solution proposed by Zhang (1997).

During the collection, we carefully removed the leaf litter and performed the tests on horizontal surfaces, ensuring the stability of the device. In addition, a thin layer (<1 mm) of fine sand was used to improve the contact between the infiltrometer and the soil surface. To capture the widest range of soil pores, we used a suction pressure of 0 kPa. Water discharge rates through the Mini-Disk, as inferred from changes in water levels in the device's storage chamber, were recorded until the flow rates reached a steady state.

In cases where no steady state flow rate was achieved, the measurement procedure was repeated until steady state flow rates were recorded three consecutive times. Therefore, our infiltration capacity estimates were similar to the soil saturated hydraulic conductivity. After each measurement, we inspected the area being measured to verify proper (round) contact between the steel disc and the ground surface. When no round shape was detected, we repeated the measurement until a perfect round shape was achieved.

Soil Penetration Resistance

The soil resistance to penetration was measured using the Stolf impact penetrometer (Stolf et al. 1983) by KAMAQ. Three measurements were taken in the rows and inter-rows. To minimize the effect of soil moisture on soil penetration resistance, measurements were carried out in the dry season, when soil moisture is negligible.

Data analysis

The normality of the residuals and the homogeneity of variance were evaluated using the Shapiro-Wilk and Levene normality tests, respectively. Residuals were found to be normally distributed for both variables, but homoscedasticity was detected. Consequently, Welch analysis of variance (Welch-ANOVA) was performed at a significance level of $\alpha = 5\%$ to assess whether there were differences between row and inter-row. The analysis was performed using the PAST statistical software (Hammer et al. 2001) and the R Program software (R Development Core Team 2016).

Results

The average (± standard deviation) of the infiltration capacity in the rows was 330.38 (± 135.48) mm.h-¹ and interrow it was 643,342.42 (± 342.42) mm.h-¹. There were no significant differences between rows and between rows ($p < 0.07$) regarding water infiltration (Figure 4).

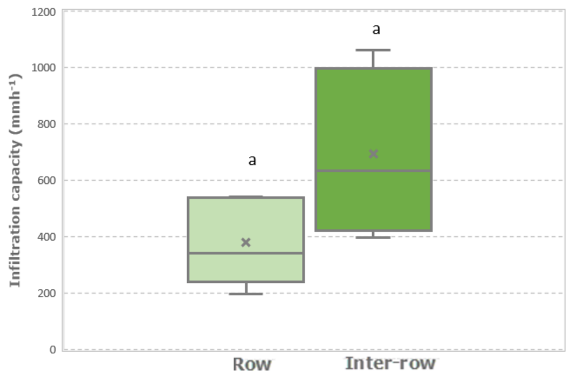

Figura 4: Box-plot showing infiltration in the rows and inter-rows of the syntropic agroforest. The horizontal lines within the box represent the median. The x represents the mean. The horizontal boundaries of the boxes represent the first and third quartiles. The ends of the vertical lines represent the maximum (top) and minimum (bottom) values. Different letters indicate that there were no significant differences.

The soil resistance to penetration in impacts 0, 1 and 2, respectively, showed the following means (± standard deviation) in the rows, 1.79 (± 0.97), 6.27 (± 1.38) and 10.37 (± 2.60) cm; and in the inter-rows 1.80 (± 0.61), 5.67 (± 1.85) and 8.13 (± 1.56) cm. There were no significant differences in the rows and inter-rows (Figure 5).

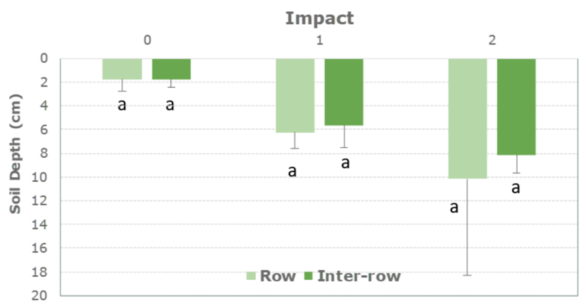

Figure 5: Mean and standard deviation of soil depth reached in each impact during penetration resistance measurements. Different letters indicate significant differences between row and inter-row.

Discussion

We could not find significant differences between row and inter-row regarding soil penetration resistance and infiltration capacity. Thus, our hypothesis that rows would have greater permeability compared to inter-row could not be accepted.

Previous studies have already focused on the effect of row and inter-row in soil physical properties (Silva et al., 2014; Santos et al., 2020; Las Casas et al., 2022). For example, Blum et al. (2014) documented increases in macroporosity and saturated hydraulic conductivity in row compared to inter-row after furrowing in a no-tillage soybean system. These results are in line with those by Silva et al. (2014) and Santos et al. (2020) which showed that soil physical properties like soil penetration resistance and soil bulk density were greater in the inter-row compared to the row. Our study, on the other hand, showed a different pattern, that is, no significant difference between the row and the inter-row for infiltration capacity and penetration resistance. The likely cause of such absence of difference may reside in the active plant growth of exotic grasses *(Urochloa* sp, *Pennisetum purpureum)* in the inter-row combined with the lack of heavy machinery passage. In other words, the inter-row remained under fallow for two years. More studies are needed to assess differences between row and inter-row when heavy machinery is actively used to manage the SASs.

Pruning management may also have contributed to our results. Severe pruning is practiced twice a year and usually adds a large amount of above ground biomass to the soil (Murta et al., 2020). Such organic matter input potentially modifies the physical, chemical and microbiological structure of the soil (Micollis et al., 2016; Murta et al., 2020; Pereira et al., 2021). Previous studies demonstrated the effect of organic matter on aggregate formation promoting increased soil porosity which, in turn, enhances the water infiltration process (Fransluebbers, 2002; Arévalo-Gardini et al., 2015; Basche & DeLong, 2019; Wang et al., 2021). Through field observations, it was noted that the accumulation of litter on the soil was greater in the rows compared to the inter-rows.

A further cause may have also influenced our results: plant diversity. A high diversity of species generates a greater variation of rooting depth (Chen et al., 2022) which affects the soil in three interrelated forms: (i) roots expand to the inter-rows and, consequently, affect the soil in such region, (ii) root turnover may promote pore formation which, in turn, may lead to increased in infiltration capacity (Shi et al., 2021) and (ii) roots exudates and mycorrhizas may increase soil aggregates formation and stability which, once more, may increase soil infiltration capacity (Le Bissonnais et al., 2018; Zhu et al., 2019).

Conclusion

Rows and inter-rows within a syntropic agroforestry system exhibited comparable physical attributes. This observation highlights the significant benefits of SAS in enhancing soil water infiltration. The demonstrated improvement is not confined to the rows alone, emphasizing the broader positive impact of SAS. Thus, SASs play a crucial role in contributing to agricultural systems that not only yield food production but also contribute to essential ecosystem services, including water and soil maintenance.

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References

Alvares, C. A., Stape, J. L., Sentelhas, P. C., de Moraes Gonçalves, JL & Sparovek, G., 2013. Mapa de classificação climática de Köppen para o Brasil. Meteorologische Zeitschrift , v. 22 (6), 711–728. http://doi.org/10.1127/S0941-2948/2013/0507

Arévalo-Gardini, E.; Canto, M.; Alegre, J.; Loli, O.; Julca, A.; Baligar, V., 2015. Changes in Soil Physical and Chemical Properties in Long Term Improved Natural and Traditional Agroforestry Management Systems of Cacao Genotypes in Peruvian Amazon. PLoS ONE, v. 10, 1-29. https://doi.org/10.1371/journal.pone.0136784

Basche, A.; Delong, M. S., 2019. Comparing infiltration rates in soil managed with conventional and alternative farming methods: A meta-analysis. Plos One, v. 14 (9). DOI: https://doi.org/10.1371/journal.pone.0136784

Bauer, T.; Strauss, P.; Kumpan, M.; Guzmám, G.; Gómez, J. A.; Stiper, K.; PopescoU, D.; Guernion, M.; Nicolai, A.; W,, S.; ZALLER, J. G., 2017. Effects of inter row management intensity on soil physical properties in European vineyards. Geophysical Research Abstracts, v.. 19, 2017-2218.

Bhave, S. & Sreeja, P., 2013. Influence of initial soil condition on infiltration characteristics determined using a disk infiltrometer. ISH Journal of Hydraulic Engineering, v. 19 (3), 291– 296. https://doi.org/10.1080/09715010.2013.808445

Blum, J.; Giarola, N. F. B.; Silva, A. P.; Gudes Filho, O.; Silva, S. G. C.; Eberhardt, D. N.; Araújo, S. R., 2014. Assessment of soil physical attributes at sowing row and inter-row under no-till system. Revista Ciências Agronômicas, n. 42. https://doi.org/10.1590/S1806-66902014000500004

Chen, C; Zou, X.; Singh, A. K.; Zhu, X.; Jiang, X.; Wu, J.; Liu, W., 2022. Effects of grazing exclusion on soil infiltration and preferential flow in savannah grazing systems. LDD - Land Degradation & Development, v. 33 (16), 3010-3022. https://doi.org/10.1002/ldr.4368

Das, B. S.; Wani, S. P.; Benbi, D. K.; Muddu, S.; Bhattacharyya, T.; Madal, B.; Santra, P.; Chakrabarty, D.; Bhattacharyya, R.; Basak, N.; Reddy, N. N., 2022. Soil health and its relationship with food security and human health to meet the sustainable development goals in India. Soil Security, v. 8. https://doi.org/10.1016/j.soisec.2022.100071

Failache, M. & Zuquette, L. V., 2021. Soil water infiltration under different land use conditions: in situ tests and modeling. Brazilian Journal of Water Resources, v. 26, 2-17. https://doi.org/10.1590/2318-0331.262120210063

Fischer, J; Brosi, B.; Daily, GC, Ehrlich, P. R.; Goldman, R.; Goldstein, J.; Lindenmayer, D. B.; Manning, A. D.; Mooney, H. A.; Pejchar, L.; Ranganathan, J.; Tallis, H., 2008. Should agricultural policies encourage land sparing or wildlife-friendly farming? Frontiers in Ecology and Environment, v.. 6 (7), 380-385.

Fransluebbers, A. J., 2002. Soil Organic Matter Stratification Ratio as an Indicator of Soil Quality. Soil and Tillage Research, v. 66, 95-106. https://doi.org/10.1016/S0167-1987.02000181

Guillot, E.; Bertrand, I.; RumpeL, C.; Gomez, C.; Arnal, D.; Abadie, J.; Hinsinger, P., 2021. Spatial heterogeneity of soil quality within a Mediterranean alley cropping agroforestry system: Comparison with a monocropping system, v. 105. https://doi.org/10.1016/j.ejsobi.2021.103330

Götsch, E. Homem e natureza na cultura. 2 ed. Recife: Centro Sabiá, 1997.

Hammer, Ø.; Harper, D. A. T.; Ryan, P. D., 2001. PAST: Paleontological Statistics, v. 4, (9). https://palaeo-electronica.org/2001_1/past/issue1_01.htm

Instituto Nacional de Meteorologia do Brasil – INMET. 2021. Normas Climatológicas. Brasília - DF. Disponível em: https://portal.inmet.gov.br.

Las Casas, G.; Ciaccia, C.; Lovino, V.; Ferlipo, F.; Torrisi, B.; Lodolini, E. M.; GiuffridA, A.; Catânia, R.; NIcolosI, E.; Salvatori, B., 2022. Effects of Different Inter-row Soil Management and Intra-row Living Mulch on Spontaneous Flora, Beneficial insects, and Growth of Young Olive Trees in Southern Italy. Plants, v. 11 (545). https://doi.org/10.3390/plants11040545

Le Bissonnais, Y.; Pietro, I.; RoumeT, C.; Nespoulous, J.; Metayer, J.; Huon, S., 2018. Soil aggregate stability in Mediterranean and tropical agro-ecosystems: effects of plant roots and soil characteristics. Plant and Soil, v. 424,303-317. https://doi.org/10.1007/s11104-017-34236

Lin, B. B. & Fuller, R. A., 2013. Forum: Sharing or sparing? How should we grow the world's cities? Journal of Applied Ecology, v. 50 (5), 1161-1168.https://doi.org/10.1111/1365-2664.12118

Ma, S.; Wang, L.; Jiang J.; Zao, Y., 2023. Direct and indirect effects of agricultural expansion and landscape fragmentation processes on natural habitats. Agriculture, Ecosystems & Environment, v. 351. https://doi.org/10.1016/j.agee.2023.108555

Mayer, S.; Wiesmeier, M.; Sakamoto, E.; HUbner, R.; Cardinael, R.; KuhneL, A.; KogeL-Knabner, I., 2022. Soil organic carbon sequestration in temperate agroforestry systems – A meta-analysis. Agriculture, Ecosystem and Environment, v. 323 https://doi.org/10.1016/j.agee.2021.107689

Micollis, A.; Penereiro, F. M.; MarqueS, H. R.; Vieira, D. L. M.; Arco-Verde, M. F.; Hoffmann, M. R.; Rehder, T.; Pereira, A. V. B. (2016). Restauração ecológica com sistemas agroflorestais: como conciliar conservação com produção - opções para o Cerrado e Caatinga (1ª Edição) Instituto Sociedade, População e Natureza – ISPN / Centro Internacional de Pesquisa Agroflorestal - ICRAF [E-book].

Murta, J. R. de M.; Brito, G. Q.; Mendonça Filho, S. F.; Hoffman, M. R.; Salemi, L. F., 2020. Understanding the effect of na agroforestry system with high litter input on topsoil permeability. Soil Use Manage, v. 20, 802-809.https://doi.org/10.1111/sum.12647

Neves, J. A.; Imperador, A. M., 2022. A transição Agroecológica: desafios para agricultura sustentável. Revista GEAMA, Scientific Journal of Environmental Sciences and Biotechnology, 8 (3), 05-14.

Pereira, S. M.; Jacobson, T. K. B.; Gomide, C. S.; de Paula, A. M., 2021. Características químicas, físicas e microbiológicas de sistemas agroflorestais em diferentes estágios sucessionais em Brasília. Revista Verde, v. 16 (3), 280-290. https://doi.org/10.18378/rvads.v16i3.8638

Perfecto, I. & Vandermeer, J., 2010. The agroecological matrix as alternative to the land-sparing/agriculture intensification model. PNAS, v. 107 (13), 5786-5791. https://doi.org/10.1073/pnas.090545510

Puech, T.; Starkb, F., 2023. Diversification of an integrated crop-livestock system: Agroecological and food production assessment at farm scale. Agriculture, Ecosystem & Environment, v. 344. https://doi.org/10.1016/j.agee.2022.108300

Roseto, A.; Borek, R.; CANALI, S., 2021. Agroforestry and organic agriculture. Agroforestry System, v. 95, 805-821. https://doi.org/10.1007/s10457-020-00559-6

Sachs, J., 2010. Monitoring the world's agriculture. Nature, 466, 558-560.

Santos, M. L.; Compagnon, A. M.; Pimenta Neto, A. M.; Arriel, F. H.; Cintra, P. H. M., 2020. Variabilidades espacial das propriedades físicas do solo em primeiro ano de colheita de cana-de-açúcar / Spatial variability of physical soil in first cane sugar crop year. Brazilian Journal of Development, v. 6 (5), 27667-27682. https://doi.org/10.34117/bjdv6n5-278

Santos, H. G. dos; Jacomine, P. K. T.; Anjos, L. H. C. dos; Oliveira, V. A. de; Lumbreras, J. F.; Coelho, M. R.; Almeida, J. A. de; Araujo Filho, J. C. de; Oliveira, J. B. de; Cunha, T. J. F. Sistema Brasileiro de Classificação de Solos. EMBRAPA Solos, 5ª edição, revista e ampliada, Brasília-DF.

Shi, X.; Qin, T.; Yan, D.; Tian, F.; Wang, H. 2021. A meta-analysis on effects of root development on soil hydraulic properties. Geoderma, v. 403 (1). https://doi.org/10.1016/j.geoderma.2021.115363

SIlva, A. P.; Ball, B. C.; Tormena, C. A.; Giarola, N. F. B.; Guimarães, R. M. L., 2014. Soil structure and greenhouse gas production differences between row and interrow positions under no-tillage. Scientia Agricola, v. 71 (2). https://doi.org/10.1590/S0103-90162014000200011

Stolf, R., Fernandes, J. & Furlani Neto, V. L. Recomendação para o uso do penetrômetro de impacto modelo IAA/Planalsucar-Stolf, 1983.

Waldron, A.; Garrity, D.; Malhi, Y.; Girardin, C.; Miller, D. C.; Seddon, N., 2020. Agroforestry

Can Enhance Food Security While Meeting Other Sustainable Development Goals. Tropical Conservation Science, 10, 1-6. https://doi.org/10.1177/1940082917720667

Wang, B; Verheyen, K.; Baeten, L.; DE SMEDT, P., 2021. Herb litter mediates tree litter decomposition and soil fauna composition. Soil Biology and Biochemistry 152.

Zilli, m.; Scarabello, M.; Soterroni, A. C.; Valin, H.; Mosnier, A.; Leclere, D.; Havlík, P.; Kraxner, F.; Lopes, M. A.; Ramos, F. M., 2020. The impact of climate change on Brazil's agriculture. Science of the Total Environonment, v. 740.https://doi.org/10.1016/j.scitotenv.2020.139384

Zhu, T.; Ringler, C.; Rosegrant, M., 2019. Viewing Agricultural Water Management Through a Systems Analysis Lens. Water Resources Research, v. 55, 1778-1791. https://doi.org/10.1029/2017WR021007