

TRANSFORMATIONS OF AN URBAN SOIL FROM THE IMPLANTATION OF AN AGROFOREST

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ABSTRACT

This study aimed to identify and understand the possible transformations occurred in an urban soil due to the implementation of an agroforestry in the Butantã campus of the University of São Paulo. To accomplish this objective, field surveys were carried out to study the soil of a grassy area and an agroforestry zone. Both areas share similar geomorphological and pedological conditions. The soil profiles were described morphologically, and samples were collected to perform physical and chemical analyses in the laboratory. The morphological attributes described in the field are: (i) color, (ii) texture, (iii) structure, (iv) wet consistency, (v) transition between horizons, (vi) depth, (vii) roots, and (viii) soil fauna. The following physical analyses were carried out in the laboratory: (i) grain-size, (ii) density, and (iii) aggregate stability. Finally, the main chemical parameters related to soil fertility were surveyed: pH H₂O, pH CaCl₂ 0.01 mol L⁻¹, O.M., P, K⁺, Ca²⁺, Mg²⁺, Al³⁺, H+Al, SB, CTC, V%, and m%. The results showed that the color of the surface horizon of the agroforestry area is browner than the analogous horizon of the grass area. In addition, an increase in the grade of the structure was identified in the soil of the agroforestry. The soil of this area also presents higher density of roots, which reach deeper horizons with respect to the grass area; ants and termites are absent (in contrast, they are very common in the grass area), but the presence of earthworms and beetles is common. The levels of soil density and acidity are smaller in the soil of the agroforestry. On the other hand, the O.M., P, K⁺, Ca²⁺, Mg²⁺ content and the SB, CTC, V% levels increased; only Al³⁺, H+Al, and m% decreased. Thus, we conclude that the identified soil changes in the agroforestry area suggest a recovery of soil and its functions faster than expected (1 year and 4 months), even in an urban soil whose natural conditions were deeply modified by anthropic actions.

Keywords: Agroforestry; Agroforestry Systems; Urban Soil; Rehabilitation of degraded areas

RESUMO

TRANSFORMAÇÕES DE UM SOLO URBANO A PARTIR DA IMPLANTAÇÃO DE UMA AGROFLORESTA. Este estudo se propôs a identificar e compreender as transformações ocorridas num solo urbano a partir da implantação de uma agrofloresta no campus Butantã da Universidade de São Paulo. Para tanto, foram realizados trabalhos de campo com abertura de trincheiras numa área de gramado e outra de SAF (Sistema Agroflorestal), vizinhas, sob as mesmas condições geomorfológicas e pedológicas. Os perfis de solo foram descritos morfológicamente e amostras foram coletadas para análises físicas e químicas em laboratório. Foram analisados e comparados os atributos morfológicos cor, textura, estrutura, consistência molhada, transição entre horizontes, profundidade, raízes e pedofauna, assim como granulometria, densidade,

estabilidade de agregado e pH H₂O, pH CaCl₂ 0,01 mol L⁻¹, MO, P, K⁺, Ca²⁺, Mg²⁺, Al³⁺, H+Al, SB, CTC, V% e m%. Os resultados mostraram que o solo da agrofloresta apresenta cor mais brunada que o do gramado, sugerindo maior quantidade de MO naquela área. Além disso, o solo da agrofloresta tem maior grau de desenvolvimento da estrutura, característica esta observada em campo e confirmada pelos ensaios de estabilidade de agregado realizados em laboratório. Destaca-se, ainda, a maior quantidade e profundidade de alcance de raízes no solo da agrofloresta, ausência de formigas e cupins, muito comuns no gramado, e presença de minhocas e besouros. Verificou-se também diminuição significativa da densidade do solo no SAF. Com relação aos atributos químicos, observou-se uma ligeira diminuição da acidez do solo da agrofloresta e um aumento substancial da quantidade de MO, P, K⁺, Ca²⁺, Mg²⁺, bem como da SB, CTC e V%. Em contrapartida, Al³⁺, H+Al e m% diminuíram. Nesse contexto, concluiu-se que ocorreram modificações no solo em todas as variáveis analisadas, o que sugere uma recuperação das funções do solo a partir da implantação da agrofloresta, no período de 1 ano e 4 meses. Assim, pode-se dizer que as mudanças encontradas no solo ocorreram num tempo muito curto, sobretudo se forem consideradas as condições do solo urbano analisado, cujas características naturais foram bastante modificadas pela ação antrópica.

Palavras-chave: Agrofloresta; Sistema Agroflorestal; Solo urbano; Recuperação de área degradada.

1 INTRODUCTION

The Green Revolution has provoked a series of changes in technology and agricultural management since the 1960s, turning monoculture cultivation into the most common and encouraged agricultural practice (OCTAVIANO 2010). In addition, other practices have been adopted, such as: use of genetically modified seeds; cultivation practices in which the soil remains bare between planting and growing periods; intensive irrigation by means of central pivoting or other techniques; employment of heavy agricultural machinery to optimize time and production capacity; and the intensive use of chemical inputs, such as fertilizers, insecticides, and herbicides.

Consisting of the cultivation of only one plant species on a large scale, monoculture has several negative impacts. Socially, it leads to the exclusion of small farmers, who can not acquire the proposed technological package, concentrating land ownership in the hands of a few people, contributing to increased poverty and unemployment in rural areas (OCTAVIANO 2010). Environmentally, monoculture is a major contributor to soil degradation, erosion, loss of biodiversity, contamination of groundwater and rivers, and climate change (MALTEZ *et al* 2016). Currently, almost 40% of the world's land

is used for agriculture using this model (MARIZ 2019).

According to the report “The State of the World’s Land and Water Resources for Food and Agriculture - Systems at the breaking point”, globally, 33% of arable soils are moderately or highly degraded with erosion removing between 20 and 37 billion tons of topsoil annually. This reduces crop yield and the capacity of the soil to store and recycle carbon, nutrients, and water, with losses in cereal production alone estimated at 7.6 million tons (UNITED NATIONS 2021, p. 1).

Agroforest or agroforestry system (AFS), defined as a polyculture farming system that combines crop production with forest development in an integrated system (EMBRAPA 2023), is an alternative to monoculture. The definition of agroforestry can be more complex, as explained by SINCLAIR (1999), who uses the term agroforestry practices rather than agroforestry systems as a unit of classification. At another stage of the definition of agroforestry, the author proposes a distinction between interdisciplinary land use analysis and a set of integrated land use practices.

Using local resources for soil coverage, the occupation of all strata using a great diversity of species and the dynamics of natural ecological succession, agroforestry “seeks to produce

food and other raw materials from a type of production system that resembles a biodiverse forest in structure and function” (PENEIREIRO 2003, p. 3). According to YOUNG (1997), agroforestry systems in tropical soils can reduce erosion by six to thirty times when compared to monocultures.

Thus, AFS presents advantages over monocultures, such as reestablishing the cycling of nutrients, attracting fauna, fixing carbon, increasing biodiversity, regulating the climate, improving the quality of air and water, retaining water in the soil, protecting the surface layer of soil, maintaining fertility, and even recovering degraded soils (MORAES & CAVICHIOLLI 2022).

In addition, agroforestry systems contribute to resilience, food security, and local economies by offering a diversity of food types during the whole year. It also allows the maintenance of small farmers in the countryside, as well as preserving their way of life, contributing to the economic and cultural diversity of rural regions, and, as shown by BOMBARDI (2011, 2019) protecting the health of farmers and the general population by not using pesticides.

Currently, there are numerous agroforestry implementation initiatives, including those within the boundaries of large cities, such as São Paulo/Brazil (e.g. SAIS & OLIVEIRA 2018), and often on degraded or modified soils. However, considering the projection of increased inhabitation of urban areas, from 55% to 68% for the world population (UNITED NATIONS 2019), and from 84% to 92% for the Brazilian population in 2050 according to IBGE (2012), the scarcity of studies on urban soils is remarkable (FURQUIM & ALMEIDA 2022). In this context, studying urban soils is important to verify the compatibility of their characteristics with their proposed use, as Fabrício Pedron pondered and proposed in his publication, Potential System of Urban Land Use (PEDRON 2005, PEDRON et al. 2006).

In general, soils in urban areas tend to be highly modified by human activity, for example cutting, landfill, construction of buildings, paved areas, and other infrastructural changes (MEUSER 2010, MOREL et al. 2017), making them more susceptible to erosion, compaction, nutrient loss and loss of biodiversity. Thus, studies on ways to rehabilitate or remediate them are also important, so that their ecosystem

services can be better used, improving the quality of life for humans and animals, and helping to mitigate typically urban problems, such as flooding.

According to the information previously mentioned and considering that agroforests have great potential in soil rehabilitation and conservation, the objective of this work is to identify and understand the possible transformations that have occurred in an urban soil since the implementation of an agroforest.

2 STUDY AREA SETTINGS

The study area is located in the Butantã campus of the University of São Paulo - USP (Figure 1), in São Paulo City (Southeastern Brazil). According to COUTINHO (1980) and PERROTA et al. (2005), the campus is in the transition zone from the crystalline basement (Precambrian) to the São Paulo Sedimentary Basin (Paleogene). In this region, the basement comprises migmatites, granite-gneisses, and eventual milonitized gneisses (COUTINHO 1980), the material on which the convex hills were sculpted. The sedimentary basin is comprised of clays, sands, and pebbles of the São Paulo Formation (RICCOMINI et al. 2004), sediments over which low convex hills were carved, occupying a very restricted area close to the Institute for Technological Research of the State of São Paulo (IPT) and the Institute of Energy and Environment (IEE). The lowest areas of the campus (about 720 m above sea level) comprise the fluvial plain of the Pinheiros River, nowadays occupied by the Sports Center (CEPE), Olympic rowing lane, IPT, Psychology Institute (IP), Clock Square, part of USP's Residential Complex (CRUSP), School of Education (FE), School of Physical Education and Sport (EEFE), and Polytechnic School (EP). At these sites, peat and sand deposits with pebbles dominate due to the Quaternary sedimentation of the Pinheiros river (SUGUIO 1971, LUZ & RODRIGUES 2013).

Current soil surveys of São Paulo city (OLIVEIRA et al. 1999, ROSSI 2017) consider the campus region as an urbanized area, thus its pedological coerture has not been studied. However, exploratory surveys carried out by our group identified Cambisols with silty clay texture covering especially the hills, e.g. in the area near the General Archives of USP. In

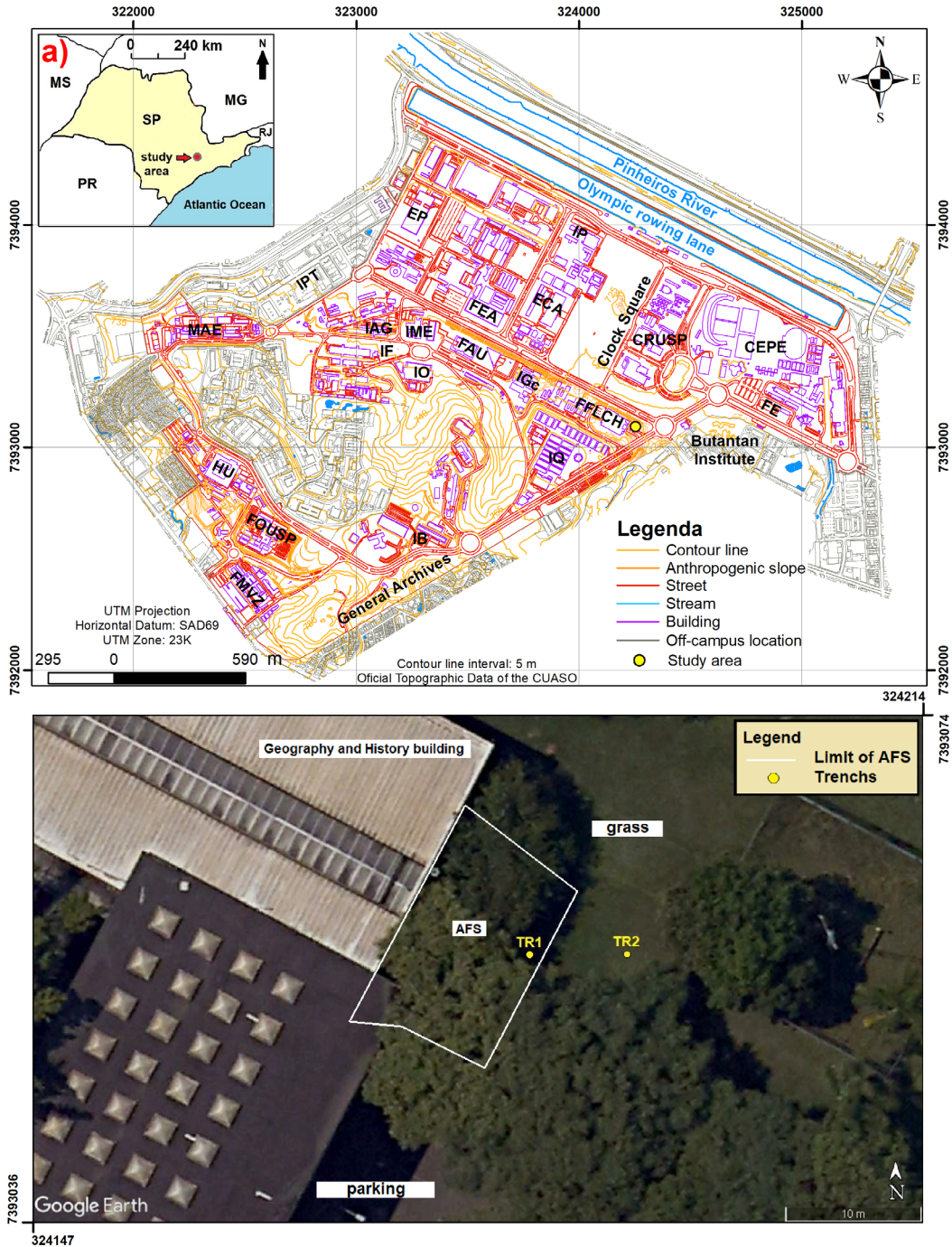


FIGURE 1 – (a) Location of the study area. (b) Location of the trenches.

addition, Gleysols were described near the springs and watercourses (i.e. Iquiririm stream), (PICHLER 2017). Other hydromorphic soils are common in the former Pinheiros floodplain, but are currently under landfills.

Regarding the general climatic aspects, according to SETZER (1966), the campus is in

a warm climate region (Cwa), whose average temperatures of the hottest and coldest months are above 22° and below 18°, respectively. The average annual precipitation is 1356 mm (Climate-data), with approximately 42 mm of rain in the driest month (August) and approximately 224 mm in the wettest month (January).

In these environmental conditions, the Geography and History building was created in 1966 (Figures 1 and 2), in the middle third sector of a hill sculpted over probable granite-gneiss. A large cut was made in this hill, thus a great volume of soil was mobilized, as can be seen in figure 2, which shows the building's construction period.

In the area of this study, indicated in Figure 1b, landscaping was carried out for the formation of flat slopes. Grass was planted over part of these slopes (Figure 3), preserved until today by the university. This grassland is mowed periodically, about 4 times a year. No inputs or new soil have been added to the soil coverture in this area.



FIGURE 2 – Geography and History building under construction, in 1964. Author: unknown. Source: CCS, *Jornal da USP*.



FIGURE 3 – Slope where the lawn was installed. In the background, the AFS study area. TR1 and TR2 are the location of the trenches excavated in the areas under AFS and grass, respectively. Author: M. R. Pinheiro. Date: January 2023.

The management of the area today constituted as an agroforestry system (Figures 3, 4 and 5) began in late 2018, by initiative of the geographer Rodrigo Ferreira Santos (Pedology Laboratory of the Department of Geography of the University of São Paulo), with a small plantation of *taioiba* in the lawn, only around the *Jibóia* (*Epipremnum pinnatum*), under a pre-existing mulberry tree whose canopy provided initially more light input than today, due to the growth of this tree. During the same period, sweet potato, yam, arrowroot, brejo cane (*cana do brejo*), *pitanga*, *juçara*, and peanut were introduced and periodically small amounts of domestic vermicompost were applied. This organic compost is produced by the action of worms of the California red species (*Eisenia fetida*) raised in domestic compost bins, which results in the degradation of food residues, vegetables, fruits, egg shells, coffee grounds. The compost is mixed with sawdust and grass straw from the area itself to control acidity and humidity.

At the end of 2019, manioc was introduced. Then the area was left untouched throughout 2020 due to the Covid-19 pandemic, which allowed tegus lizards and opossums to circulate in the AFS, as well as lush growth of grass among the planted species.

In October 2021, the campus administration cut the lawn with a mower. This exposed an environment that had previously

been shaded, in which a slightly darker and friable layer had formed on the soil surface. Different species were planted, which have different morphological characteristics, such as plant size and root system. Among the cover species planted were corn, beans, manioc, daisy, guandú beans, arrowroot, ginger, saffron, *chuchu*, passion fruit, *ingá*, *cará*, pineapple, avocado, melissa, wild tobacco, brejo cane (*cana do brejo*), *boldo*, and English potatoes. In addition, the area received organic compost every 20 days, and freshly cut grass every time the surrounding lawn was mowed.

The mulberry tree was pruned to allow a campus topography survey in December 2021, reducing the shaded area in the AFS. This allowed the expansion of the borders of the beds, which received *pitanga*, *jabuticaba*, *guava*, sweet potato, *juçara*, *chuchu*, banana, pork bean, papaya, tomato, physalis, mint, and yam. The *guandú* beans were harvested in October 2022 and at this time almost all plants in the plot were pruned. The area has been managed with very low intensity since then, consisting only in the sporadic manual grass removal.

It is important to note that all planting was carried out in lines following the contour lines and using the tip of the machete to achieve minimal soil disruption, which was kept covered with cut grass whenever it was available.



FIGURE 4 – Detail of the AFS and planting lines.

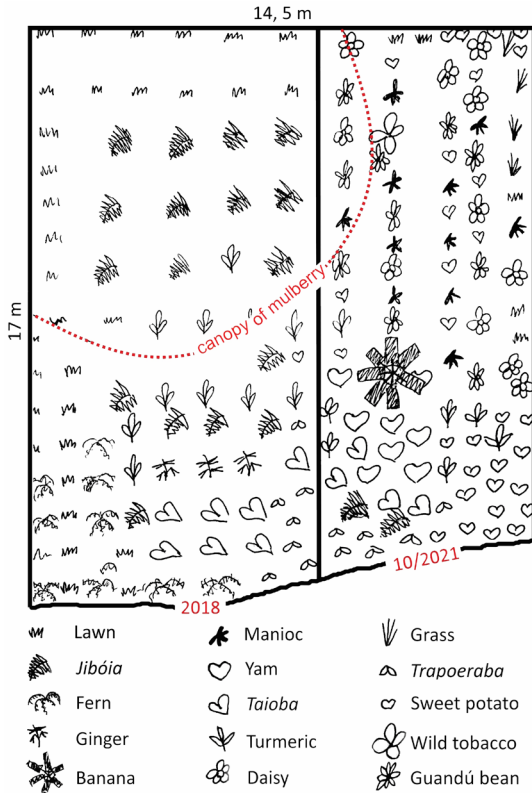


FIGURE 5 – Sketch of the AFS area, whose current area is about 209 m², showing the limits (black line) of the area in different periods, as well as the distribution of the main introduced species. The red dashed line marks the limit of the mulberry tree canopy.

3 METHODOLOGY

In order to identify and understand the possible changes that may have occurred in an urban soil since the implantation of an agroforestry, two areas on the same slope were chosen: (1) under the grass [324.195 m E / 7393052 m S - UTM Zone 23]; (2) under AFS [324.188 m E / 7393052 m S - UTM Zone 23] (Figures 1b and 3), both described in the previous item. The areas are contiguous and were pre-defined after bibliographic and cartographic surveys, besides an initial visit to the site and an interview with the person responsible for implementation of the AFS. The high degree of similarity of the geomorphological and pedological characteristics of the two areas was also considered, as this is fundamental for the comparison of the soils under two different regimes.

In the field, two trenches measuring about 80 cm (length of side) x 60 cm (depth) were opened, one in the AFS and the other in the lawn. According to SANTOS et al. (2015), the following morphological attributes of the soils were described: color (wet), texture, structure (shape, size, and grade), plasticity and stickiness (wet soil consistency), depth, thickness and transitions of the horizons, presence of roots and pedofauna.

Samples were taken from each horizon for physical and chemical analyses in the laboratory, as well as undisturbed samples to determine density and aggregate stability. The following physical analyses were performed in the Pedology Laboratory of the Department of Geography (LABOPED/FFLCH-USP): the grain-size analyses (maximum margin of error of the tests: 2%) were carried out by means of sieving (sand) and pipetting (silt and clay) methods, according to CAMARGO et al. (2009) and the analytical mark of the referred laboratory; the density was determined by the volumetric ring technique, in duplicate, according to EMBRAPA (2017), whereas the soil aggregate stability was carried out by wet sieving, following the proposal of GROHMANN (1960). The latter test was not carried out in duplicate because there was not enough sample to repeat the analyses.

The chemical analyses were performed in the Soil Laboratory of ESALQ/USP, where the following characteristics were evaluated: pH_{H₂O}, pH CaCl₂ 0.01 mol L⁻¹, O.M. (Organic Matter), P, K⁺, Ca²⁺, Mg²⁺, Al³⁺, H+Al, CEC, base saturation, V%, and m%. From the physicochemical data, the acidity and fertility of the soils were evaluated, according to the parameters defined by SOBRAL et al. (2015). These tests were carried out on a single sample, without duplicates or triplicates.

The soil profiles were also classified according to a Brazilian proposal to classify Anthroposols (CURCIO et al. 2004) and by the World Reference Base (IUSS WORKING GROUP WRB 2022), an international system that contemplates soils profoundly modified by human action.

4 RESULTS

4.1 Morphological description of the soils

In order to distinguish the trenches and facilitate the understanding of the results, the acronym TR1 was adopted to refer to

the agroforestry trench and TR2 to refer to the grass trench. Similarly, the acronym H1 were adopted for horizon 1, H2 for horizon 2, H3 for horizon 3, and H4 for horizon 4.

As observed in the field survey (Figure 6) and summarized in the tables 1 and 2, the surface horizon in both trenches were dark (dark reddish brown), becoming lighter and presenting a greater variety of colors within a reddish matrix as the depth increases. The exception was a thin (4 cm), dark red horizon (horizon 2) in the soil profile under grass.

The textural variation was similar in the two soil profiles, ranging from silty clay (topsoil) to clayey, silty clay loam, and silt loam (deeper horizon) as the depth of the TR1 and TR2 increases, except for the H2 horizon of TR2, whose texture was clayey.

The structure of peds in the first horizon of TR1 and the first two in TR2 is blocky, but some granules were also

identified. The grade of the peds in H1 is moderate (the structure of H1 in TR2 is slightly less developed than that of the analogous horizon in TR1: the peds break down into granules in TR2 - see figure 7), while that of H2 in TR2 is weak. H2, H3, and H4 from TR1 have no pedogenetic structure, as do H3 and H4 from TR2. The wet soil consistency of all horizons in both trenches is sticky and plastic, whereas the transitions are flat, ranging from clear to gradual.

The presence of roots and pedofauna varies significantly between the trenches. Fine roots were present until a depth of 18 cm, the lower limit of H2 in TR2, after that they become rare, giving way to coarse roots that penetrate the underlying horizons. In turn, the pedofauna comprises ants, termites, and earthworms in H1 of TR2. In H2, only termites were present, but they were more common than in H1. No

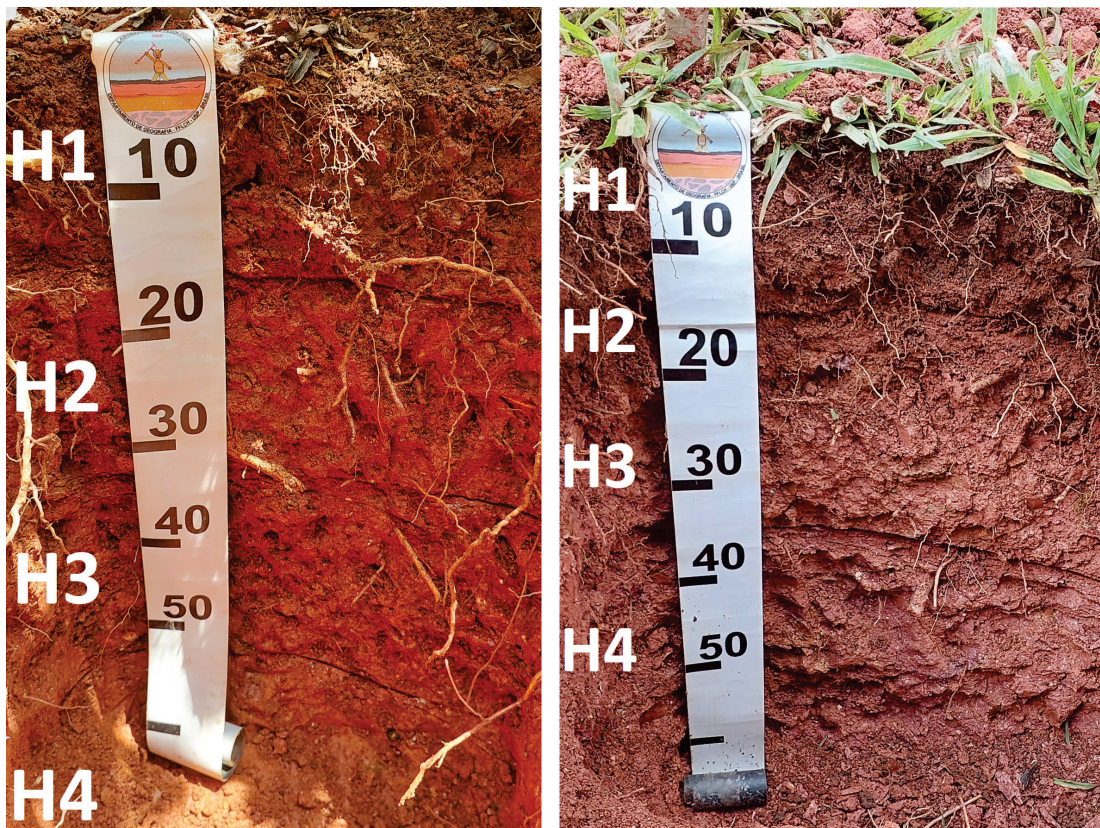


FIGURE 6 – Trench 1 (left) and Trench 2 (right), showing the soil profiles in the AFS and the lawn areas, respectively. Author: M. R. Pinheiro. Date: January 2023.

TABLE 1– Soil morphology description - Trench 1.

Land use: Agroforestry
Slope: 5° Position on the relief: top of slope

Horizon	Depth (cm)	Color (wet)	Texture	Structure			Wet Consistency	Transition	Roots	Remarks
				Shape	Size	Grade				
H1	0 to 12	5 YR 3/4	Silty Clay	Blocky and granular	Medium	Moderate	Sticky and plastic	Flat, clear	Thin roots: frequent. Coarse roots: rare	Presence of 2 earthworms and 2 beetles. Accumulation of organic matter and granular peds in biopores.
H2	12 to 29	10YR 4/8: matrix; 10YR 6/8: volumes ≤1 mm (5%)	Clay	No pedogenetic structure			Sticky and plastic	Flat, gradual	Thin and coarse roots are rare.	Presence of 1 earthworm. 2 biopores of up to 2 mm
H3	29 to 51	Variogated: 10R 4/8: 70%; 5R 4/4: 25%; 10YR 9.5/2 5%.	Silty clay loam	No pedogenetic structure			Sticky and plastic	Flat, gradual	Thin and coarse roots are rare.	Many fragments of little weathered rock. 1 biopore of up to 2 mm.
H4	51 to 60	Variogated: 2.5YR 4/8: 60%; 10YR 5/8: 30%; 10YR 6/6: 10%.	Silt loam	No pedogenetic structure			Sticky and plastic	Flat, gradual	Thin and coarse roots are rare.	Many fragments of little weathered rock. 1 angular pebble.

TABLE 2 – Soil morphology description - Trench 2.

Land use: Grass
Slope: 5° Position in the relief: top of slope

Horizon	Depth (cm)	Color (wet)	Texture	Structure			Wet Consistency	Transition	Roots	Remarks
				Shape	Size	Grade				
H1	0 to 14	5 YR 3/4	Silty clay	Blocky and granular	Medium	Moderate	Sticky and plastic	Flat, gradual	Thin roots: frequent; Coarse roots: rare	Presence of 6 earthworms, 1 beetle, many termites and ants. Accumulation of organic matter in dark crumbs.
H2	14 to 18	2.5YR 3/6	Clay	Blocky and granular	Medium	Weak	Sticky and plastic	Flat, clear	Thin roots: frequent.	Many termites
H3	18 to 35	10R 4/8	Silty clay loam	No pedogenetic structure			Sticky and plastic	Flat, gradual	Thin and coarse roots are rare.	Many fragments of little weathered rock
H4	35 to 60	Variogated: 10R 4/8: 70%; 7.5YR 4/6: 25%; 5R 2.5/4: 5%.	Silt loam	No pedogenetic structure			Sticky and plastic	Flat, gradual	Thin and coarse roots are rare.	Many fragments of little weathered rock

roots and pedofauna were found in the deeper horizons.

Under agroforestry, roots are less concentrated in the topsoil. They are thin and frequent in H1, and gradually rarer until H4, with thick roots crossing horizons 2, 3, and 4.

Earthworms and beetles were found, but rarer than in TR2. Ants and termites were absent. Biopores up to 2 mm were common in horizons 2 and 3. In summary, in TR1 the pedofauna is restricted to earthworms and beetles, while in TR2 ants and termites also occur.

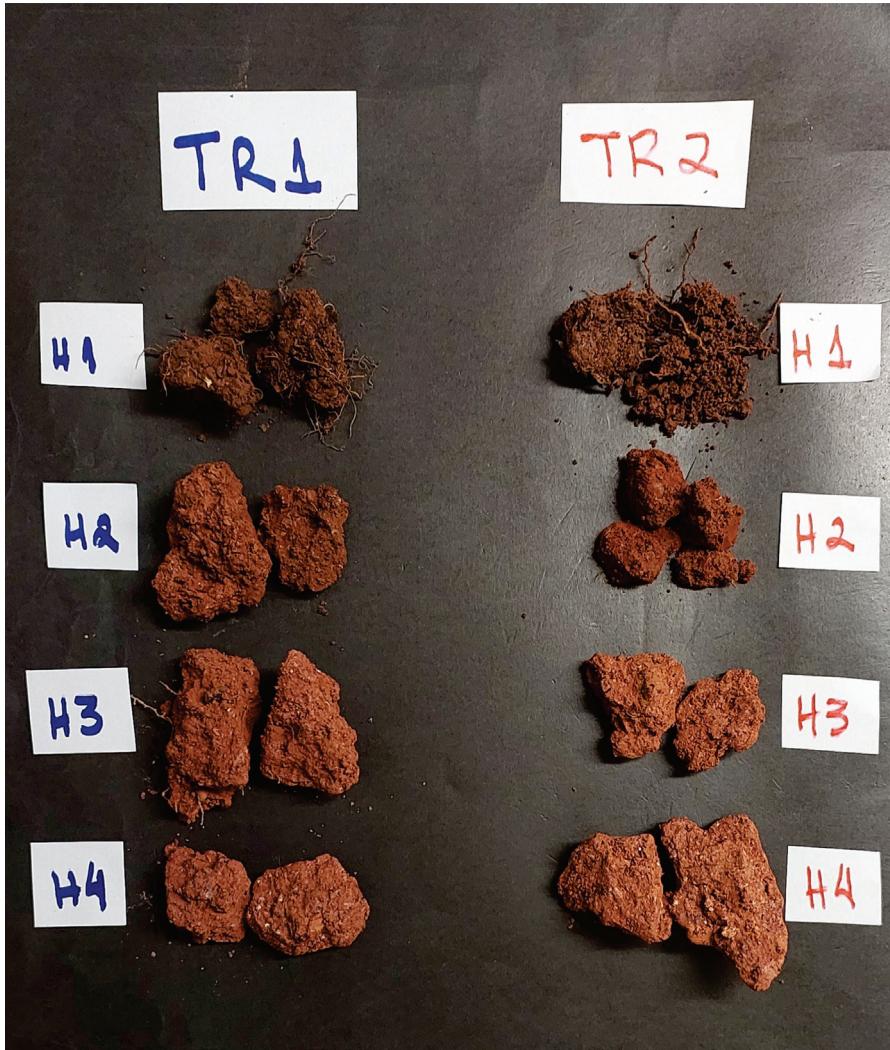


FIGURE 7 – Color and structure variation in the horizons of the two trenches. Note the difference in the soil structure of H1 in the two profiles.

4.2 Physical analysis of the soils

4.2.1 Granulometric analysis

As shown in table 3, in H1 of TR1, the silt and clay content was high, above 30%, with the clay proportion reaching 41.76%. This increased substantially to 51.19% in H2 and decreased in H3 and increased in H4, where the silt values reached 42.27% and 53.14%, respectively. The sand content was lower, not exceeding 27.39%, and varied little between the horizons.

In TR2 (Table 3), the percentage of the clay fraction is higher in the first two horizons,

46.42 and 62.44% in H1 and H2, respectively, decreasing to 39.17% in H3 and 18.17% in H4. On the other hand, the silt content was low in H1 (25.70%) and H2 (12.15%), but increased substantially in H3 (39.72%) and H4 (59.83%). However, the percentage of sand was low in all horizons and varied little along the soil profile, not exceeding 27.88%. These granulometric results confirm the observations made in the field survey.

4.2.2 Soil density

There was a considerable increase in the density (Table 4) as a function of the increase

in depth in both trenches, from 0.78 to 1.46 g.cm³ in TR1, and from 0.94 to 1.37 g.cm³ in TR2, with similar values observed in the two areas from H2 downward. However, the density value of H1 from TR1, 0.78 g.cm³, is lower than that of H1 from TR2, 0.94 g.cm³. The H2 of TR2, which is only a thin transition horizon, was not considered in this analysis because enough material could not be collected using a volumetric ring. In terms of morphological characteristics, H2 from TR1 resembled H3 from TR2 enough to consider them equivalent.

4.2.3 Aggregate stability

Aggregate stability was evaluated only in the horizons 1 and 2 from the two profiles,

since the underlying horizons presented no structure development. The wet sieving results (Table 5) revealed higher aggregate stability in H1 of both trenches, with higher stability in H1 from TR1, about 3.26, while its analogue in TR2 presented a WAD (Weighted Average Diameter) value of 3.21.

On the other hand, an important change was observed in the underlying horizons: as already mentioned in the density item, H2 of TR1 is morphologically similar to H3 of TR2, suggesting that they are equivalent. However, H2 of TR1 shows aggregate formation, which does not occur in H3 of TR2, where it was not possible to perform aggregate stability tests.

TABLE 3 – Grain size analysis (%) of the Trenches 1 and 2.

Trench	Horizon	Depth (cm)	Sand						Silt	Clay
			VFS	FS	MS	CS	VCS	TOTAL		
TR1	H1	0 - 12	9.31	7.84	6.32	3.26	0.66	27.39	30.86	41.76
	H2	12 - 29	7.41	7.23	6.04	4.20	0.99	25.87	22.93	51.19
	H3	29 - 51	10.56	7.19	3.51	1.12	0.37	22.77	42.27	34.97
	H4	51 - 60	12.24	8.11	3.25	1.31	0.28	25.19	53.14	21.68
TR2	H1	0 - 14	6.65	9.12	5.91	4.42	1.79	27.88	25.70	46.42
	H2	14 - 18	6.37	7.33	6.04	3.97	1.69	25.41	12.15	62.44
	H3	18 - 35	8.98	6.60	2.78	1.87	0.89	21.11	39.72	39.17
	H4	35 - 60	12.26	6.48	2.17	0.81	0.28	22.00	59.83	18.17

VFS: Very fine sand; FS: Fine sand; MS: Medium sand; CS: Coarse sand; VCS: Very coarse sand.

TABLE 4 – Soil density of the trenches 1 and 2.

Trench	Horizon	Depth (cm)	Density (g/cm ³)
TR1	H1	0 - 12	0.78
	H2	12 - 29	1.27
	H3	29 - 51	1.23
	H4	51 - 60	1.46
TR2	H1	0 - 14	0.94
	H3	18 - 35	1.26
	H4	35 - 60	1.37

TABLE 5 – Aggregate stability of the horizons 1 and 2 of the soil profiles.

Trench	Depth (cm)	Horizon	WAD
TR1	0 - 12	H1	3.26
	12 - 29	H2	3.10
TR2	0 - 14	H1	3.21
	14 - 18	H2	3.14

4.3 Chemical and physicochemical analysis of the soils

According to the Practical Guide for the Interpretation of Soil Analysis Results (SOBRAL *et al.* 2015), the soils studied present low fertility (Table 6). Despite this, the O.M., P, Ca²⁺, Mg²⁺, and K⁺ contents were higher in TR1, especially in H1. In this context, a significant increase in the CEC was observed, with values of 13.4 cmolc.dm³ in H1 of TR2 and 15.4 cmolc.dm³ in H1 of TR1. In the latter horizon, this value is considered a high CEC, while the former is equivalent to a medium value. In the underlying horizons of both profiles, the CEC decreases significantly, not exceeding 6.4 cmolc.dm³ (TR1 - H2) in any horizon and decreasing with depth.

Conversely, the values of Al³⁺, H+Al, and m% were lower in all horizons of profile TR1 (Table 6), accompanying the higher concentration of exchangeable bases and the slightly less acidic pH in both H₂O and CaCl₂, always ≥ 5.72 and 4.8, respectively. In TR2, the concentration of aluminum in the exchange complex was much higher, reaching 29% in H3, compared to 0 in horizon 3 of TR1, and presented more acidic pH values, ranging between 5.26 and 5.61 (H₂O) and 4.36 to 4.98 (CaCl₂).

Considering the morphological characteristics and the laboratory analyses, TR1 could be considered a Decapitic or Mobilic Anthroposol, according to the classification proposal of CURCIO *et al.* (2004), and Thyric Technosol (Loamic, Eutric, Transportic), according to the international system of WRB (IUSS WORKING GROUP WRB 2022). Similarly, TR2 could be classified as a Decapitic or Mobilic Anthroposol in the classification of CURCIO *et al.* (2004) and as

Thyric Technosol (Clayic, Dystric, Transportic) by WRB (IUSS WORKING GROUP WRB 2022).

5 DISCUSSION

Considering that trench 1 was opened in January 2023, the transformations occurred in the soil due to the implementation of the AFS took place over a very short period of time, approximately 1 year and 4 months. Even after this short period of time, the results presented indicate obvious changes in the soil, although the data have limited statistical representation, since only two trenches were analyzed and the chemical analyses were made without repetitions.

The surface horizons were dark reddish brown and present no significant variation between trenches. Brown colors are classically attributed to the presence of organic matter in the soil (LEPSCH 2021). Thus, these soils probably presented similar concentrations of O.M. However, the data show that in the H1 horizon of the AFS area (TR1), there was a greater amount of organic matter when compared to that of the surface horizon of TR2. In TR1-H1, the O.M. content was 100.4 g.kg⁻¹ and decreased to 21.3 g.kg⁻¹ in H2 at a depth of 29 cm, in contrast to the soil under the grass, whose O.M. concentration was only 78.3 g.kg⁻¹ in H1 and dropped to 21.7 g.kg⁻¹ at a depth of only 18 cm.

The increase in O.M. may explain, in part, the slight change in the grade of soil structure of the surface horizons, considering that in the grassy trench the blocks are less developed and break up into granules. This characteristic observed in the field was confirmed by the aggregate stability data, which showed a higher WAD in H1 of the AFS, approximately 3.26, whereas under the lawn the surface horizon presented a WAD of 3.21. These

TABLE 6 – Chemical and physical-chemical data of soil profiles 1 and 2.

Trench Horizon	Units		g.kg ⁻¹		mg.dm ⁻³		cmolc.dm ⁻³		mg.dm ⁻³		cmolc.dm ⁻³			%											
	pH _{H₂O}	pH _{CaCl₂}	M.O.	P	Ca	Mg	K	Al	H+Al	SB	CTC (pH7.0)	V	m												
TR1	H1	5.92	M	5.52	M	100.4	H	3.8	L	8	H	2.2	H	114	H	<0.1	L	4.9	10.5	15.4	H	68	M	0	L
	H2	6.01	H	5.12	M	21.3	M	1	L	2.4	M	0.5	M	53	M	<0.1	L	3.4	3	6.4	M	47	L	0	L
	H3	5.72	M	4.8	L	7.4	L	0.9	L	1.6	M	0.2	L	20	L	<0.1	L	2	1.9	3.9	L	49	L	0	L
	H4	5.97	M	5.23	M	3.6	L	<0.9	L	1	L	0.1	L	13	L	<0.1	L	1.1	1.1	2.2	L	50	M	0	L
TR2	H1	5.61	M	4.98	L	78.3	H	2.3	L	5.1	H	1.3	H	100	H	<0.1	L	6.7	6.7	13.4	M	50	M	0	L
	H2	5.54	M	4.63	L	21.7	M	<0.9	L	1.2	L	0.3	L	34	M	0.3	L	4	1.6	5.6	M	29	L	16	L
	H3	5.26	M	4.36	L	10.7	L	<0.9	L	1	L	0.1	L	23	L	0.5	M	3	1.2	4.2	L	29	L	29	L
	H4	5.35	M	4.48	L	3.1	L	<0.9	L	0.9	L	<0.1	L	11	L	0.2	L	1.4	0.9	2.3	L	39	L	18	L

H – High; M – Medium; L – Low.

data are in agreement with the ideas of SILVA et al. (2005), in which organic matter has a strong influence in the process of structure formation and stabilization. Following the ideas of VEZZANI & MIELNICZUK (2011), we propose that the higher content of clay and polyvalent cations in the AFS may also influence the cementation process.

The relatively higher ped stability of the transition horizon (TR2-H2) of the lawn area can be explained by the biological activity of termites there, since, as indicated by MIKLÓS (1992, 2012), the cementing action can be enhanced by the salivary and metabolic secretions of pedofauna.

The density is significantly lower in the AFS soil, especially in the surface horizons. As the degree of development (grade) of the structure increases, roots can penetrate more easily, contributing to increased porosity, probably accompanied by greater pore connection, which allows infiltration and conductivity of water and gases, restoring soil functions.

In addition, the greater physical protection of the soil by the presence of plants and litter over the H1 under AFS prevents the direct action of solar radiation and rain on the peds, minimizing erosion (splash) and leaching, maintaining local moisture and reducing the speed of organic matter mineralization, defined in classic soil conservation studies (e.g. WISCHMEIER & SMITH 1978, BERTONI & LOMBARDI NETO 2018).

Moreover, the results show that a new microclimate has been created in the soil under AFS, favoring soil colonization by earthworms, identified in the field, whose action on the formation of peds and pores is recognized in Soil Science, as demonstrated by DIOGO FILHO (2017) and DIOGO FILHO & QUEIROZ NETO (2020).

The higher fertility values in the studied profile under AFS can be explained by the capacity of plants to modulate the presence of soil minerals and nutrients below and around them, as demonstrated by ZINKE (1962) and as observed in studies on legumes (e.g. NASCIMENTO et al. 2003).

Considering the precepts of PRIMAVESI (1981) and CAMPOS (2015), it can also be inferred that the increase in O.M. is derived mostly from the leaf litter, cut grass kept on the topsoil, general pruning after the harvest of guandú bean, and contribution of organic compost. This argument is reinforced by the work of OZIEGBE et al. (2011), who observed that litter is the main pathway for the cycling of calcium, magnesium, nitrogen

and all the investigated micronutrients, and also pointed out that precipitation is the main pathway for the cycling of potassium, phosphorus, sulfur, and traces of toxic metals (mercury and lead) in a forest.

Finally, the morphological and physical characteristics of the soils, especially the absence of structure (in the subsurface horizons), high density, low connectivity between the pores, and clear differentiation between the horizons, indicate that an overlapping of the soil layers has occurred due to anthropic activities, probably the construction of the Geography and History building. In this context, landscaping, suppression of the original surface horizon, and artificial compaction of this soil, probably with the use of machinery, have occurred.

6 CONCLUSION

Agroforestry allows the creation of a soil environment that is more humid and protected from solar radiation, favoring the diversification of the pedofauna, to the detriment of the dominance of ants and termites in the soil under the lawn.

The soil under the agroforestry system presented lower density and a higher degree of aggregation (grade), important characteristics that indicate increased porosity and, possibly, permeability, reducing the susceptibility of the soil to erosion.

Besides the decrease in soil acidity under agroforestry, there is an increase in the amount of organic matter, P, Ca²⁺, Mg²⁺, and K⁺, as well as an increase in base saturation and CEC. These changes favor the establishment of diverse vegetation, oriented towards food production, if desirable.

The implementation of an agroforestry system serves not only as a food production tool, but also as a soil recovery and protection tool against degradation and erosion, even in an urban environment.

The laboratory data were consistent with the literature and field data, which gives reliability to the results of this study. However, considering the lack of repetition in the chemical analysis tests, which prevents a more accurate statistical analysis, further studies are necessary to validate the reduction in soil acidity and the increase of fertility, including the Nitrogen indices, which are not part of the scope of this study.

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