Chapter

Physical Quality of Soils in a Toposequence of a Forest Fragment under Livestock Activity in a Watershed in South Brazil

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Abstract

The conservation of native forests is fundamental to the preservation of hydric resources in the landscape. The use of animals in forest fragments has resulted in degradations in the soil, resulting in the grating of these. Thus, soil classes were studied and physical parameters of forest soils were evaluated in areas without and with cattle grazing in the "Arroio Pelotas" watershed, Pelotas, Rio Grande do Sul, extreme south of Brazil. The results were submitted to statistical analysis with the Kruskal–Wallis nonparametric test with a significance level of 5%. The means of the physical parameters of soil in the same toposequence and layers with and without the presence of livestock were compared. By analyzing soil physical attributes (density, macroporosity, and microporosity) it can be seen that the structural quality of the soil is affected by the access of animals inside the forest fragments, especially in the upper layer of the soil (0–5 cm deep). In forest fragments without access to animals, the physical structure of the soil presented the best conditions of macroporosity and, consequently, greater protection of nutrients, microorganisms, and water resources. Therefore, it is concluded that conservation by the isolation of protective forests in rural property planning benefits the quality of forest soils.

Keywords: physical attributes of the soil, cattle grazing, forest soils, environmental management, soil degradation

1. Introduction

Forests are important for the conservation of water resources at the landscape level. Thus, the need for conservation and recovery of forests in watersheds is fundamental, according to the new Brazilian forest code [1]. Currently, forests are negatively impacted in different ways. Livestock activity carried out without planning in rural properties can determine negative environmental impacts on the environment and production. The influences of livestock in forest fragment part of the interference in vegetation until the degradation of forest soils, where the animals travel in search of fodder and end up exploring part of the fragments [2]. Soil degradation in livestock areas ends up resulting in low-quality pastures by overgrazing, gullies, sanding, pasture compactions and in the path of animals, floods, siltations, and loss of ravines on the banks of watercourses, among others.

The access of animals in forest areas, as well as their exploitation, promotes a grating and fragmentation of forest areas [2], with this there is a greater luminosity input inside that stimulates the growth of grasses in these areas. These conditions intensify the trampling of the animal and, consequently, soil compaction, due to the demand for fodder in forest areas. Compaction is influenced by texture, aggregation, soil moisture at the time of management practices, traffic and frequency of vehicle trafficking, intentional soil manipulations, and the loss of organic matter [3–5].

Compaction by animal trampled results in changes in soil physical properties, with a rearrangement of mineral and organic solid particles due to the mechanical force applied to the surface and transmitted mainly by soil solids [6]. Compaction is defined as the process of soil porosity decrease, especially the macroporosity occupied by air, increasing the density and resistance to root penetration in the soils. It also decreases water infiltration along the soil profile, causing surface erosion and removals of high soil volumes [7]. Compaction promotes the reduction of the pores of the inter and intra-aggregates, resulting in a dense and massive porous system, which may lead to more pronounced horizontal water flow, and consequently, greater soil erosion [8, 9].

Forest growth is affected by compaction and, consequently, their productivity is reduced, as well as impairs the protection and conservation of soils and water. Increased compaction negatively affects seed germination of native species, root growth of plants, and productivity of mature commercial plantations [5, 10]. This is due to the restriction of root development, through low water infiltration and redistribution, limitation of adsorption and/or absorption of nutrients in the soil, and the precarious aeration of the soil [5, 11].

The main cause of compaction in forest soils is the trafficking of machinery for the management and harvesting of forests, as well as the trafficking of people and animals in the area [12]. Studies also show that anthropic soil compaction occurs with different management practices according to each activity. For example, by the displacement of agricultural machinery in the forest, grain and fruit harvest [9, 13, 14], in fallow areas, no-tillage and no-tillage system of grains [15, 16], and trampled by large domestic animals [17, 18].

The results of soil quality compaction are the breakdown and reduction of macroporosity. In study on orange orchard, Lima et al. [19] found superficial compaction by the farm and by the traffic of machines, affecting the shape and distribution of the poorly space, and the most affected were the biopores.

According to Han et al. [20], pores derived from biological activity (or biopores) formed by the mineralization of the root system and organisms of the soil macrofauna. It is important to understand that vegetables and animals produce biopores and other various ecosystem services to the rural property ecosystem, as shown in **Table 1**. In addition to the roots, soil fauna produces biopores. This soil fauna includes microscopic organisms, such as nematodes, mites, and colêmbolos, to easily visible organisms, such as earthworms, spiders, ants, termites, and beetles [21].

With compaction, there are changes in the distribution of soil aggregate size, changes in macroporosity and microporosity, increased mechanical impediment, decreased pore continuity, loss of water retention and infiltration capacity, weak internal drainage, and increased heat conduction. All these environmental impacts promoted by compaction affect soil quality, whether an agricultural soil of cultivation or pasture, as in the forest soils of this study.

Service category	Service	Ecosystem process	Contribution of fauna
Provision	Available water	Infiltration and storage of water in the soil	Bioturbation, increased infiltration, and water retention in the soil.
	Food	Biomass production	Food for humans and animals.
Support*	Nutrient cycling	Decomposition and humification	Fragmentation, ingestion, stimulation of the de-compositorcing microbial community.
		Regulation of nutrient losses	Mineralization prevents leaching and continuous circulation of nutrients.
	Primary productivity	Stimulation of symbiont activity and growth-promoting microorganisms	Stimulation of symbiotes in the rhizosphere, intestines and coprolites, and change in the activity of microorganisms promoting plant growth.
		Protection against pests and diseases	Production of repellent substances. Pest control by increasing biodiversity and population balance.
Regulation*	Flood control	Drainage, infiltration, and storage of water in the soil	Change in roughness and soil structure, increasing porosity and surface biopores that increase retention and infiltration.
	Climate regulation	Carbon sequestration	Formation of stable aggregates rich in organic matter in the form of substances.
	Pollination	Pollination	Insects with the phase of life in the soil contribute to pollination.
Cultural	Recreation	Social and natural interaction	Food for some organisms, creation or collections as a hobby, theme for exhibitions, art, literature.
	Education	It only cares who knows the soil	Instrument for environmental education and information in rural extension.

**Main services of soil animals (indirect).*
Adapted from Parron et al. [21] according to Millennium Ecosystem Assessment (2005).

Table 1.
Ecosystem services of soil fauna.

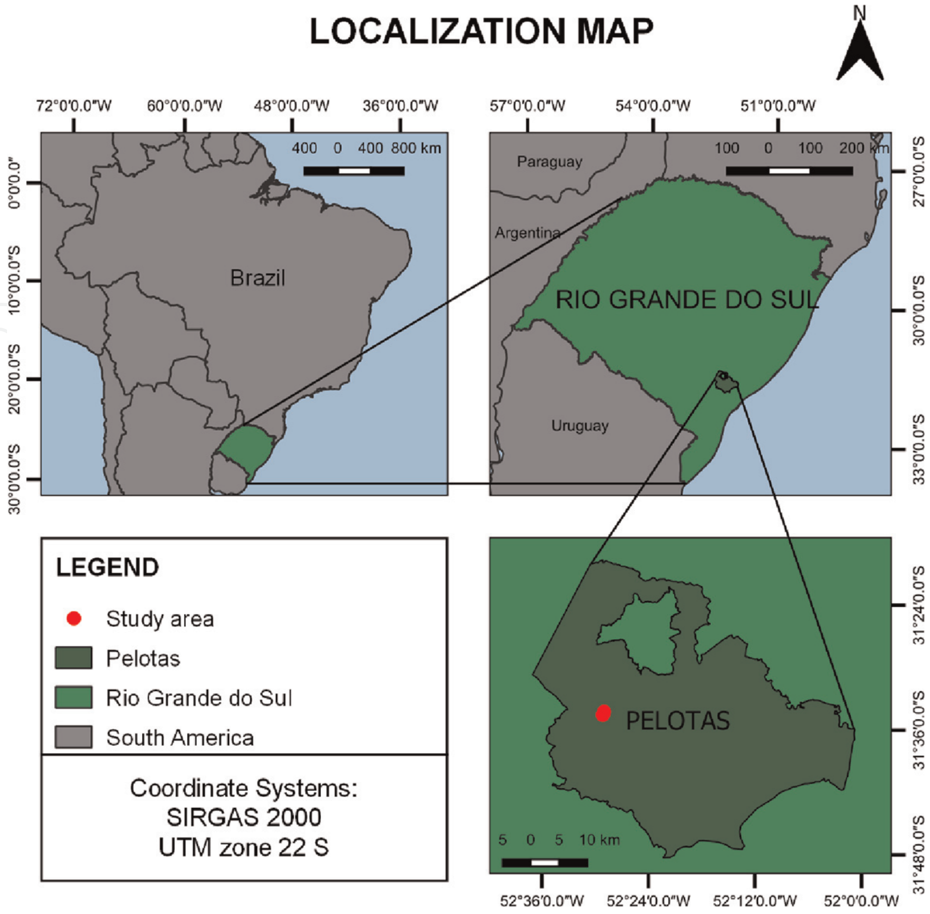

Figure 1.
Location map of the study area.

There are few studies on soil quality within native forests in Brazil. Thus, there is a need to evaluate the environmental impacts of livestock on forest soils, in a context of producing with good environmental practices and with social, economic, and environmental sustainability. For this, the objective was to evaluate soil physics parameters in soil toposequence shards in fragments of native forests with and without livestock, on the banks of the watercourse toward the top of the hill in a part of the Arroio Pelotas watershed, in the state of Rio Grande do Sul, and in the extreme south of Brazil (**Figure 1**).

2. Material and methods

2.1 Study area

2.1.1 The watershed of the Arroio Pelotas

The study area in the municipality of Pelotas is inserted in the Arroio Pelotas watershed (**Figure 2**). The hydrographic basin of this watercourse is located under two phytogeographic regions: pioneer formation areas and the semidecidual seasonal forest, according to the classification of the Brazilian Institute of Geography and Statistics [22]. The two phytogeographic regions are distinct and conditioned by the geomorphological characteristics of the relief. The areas of pioneer formations, as [23]

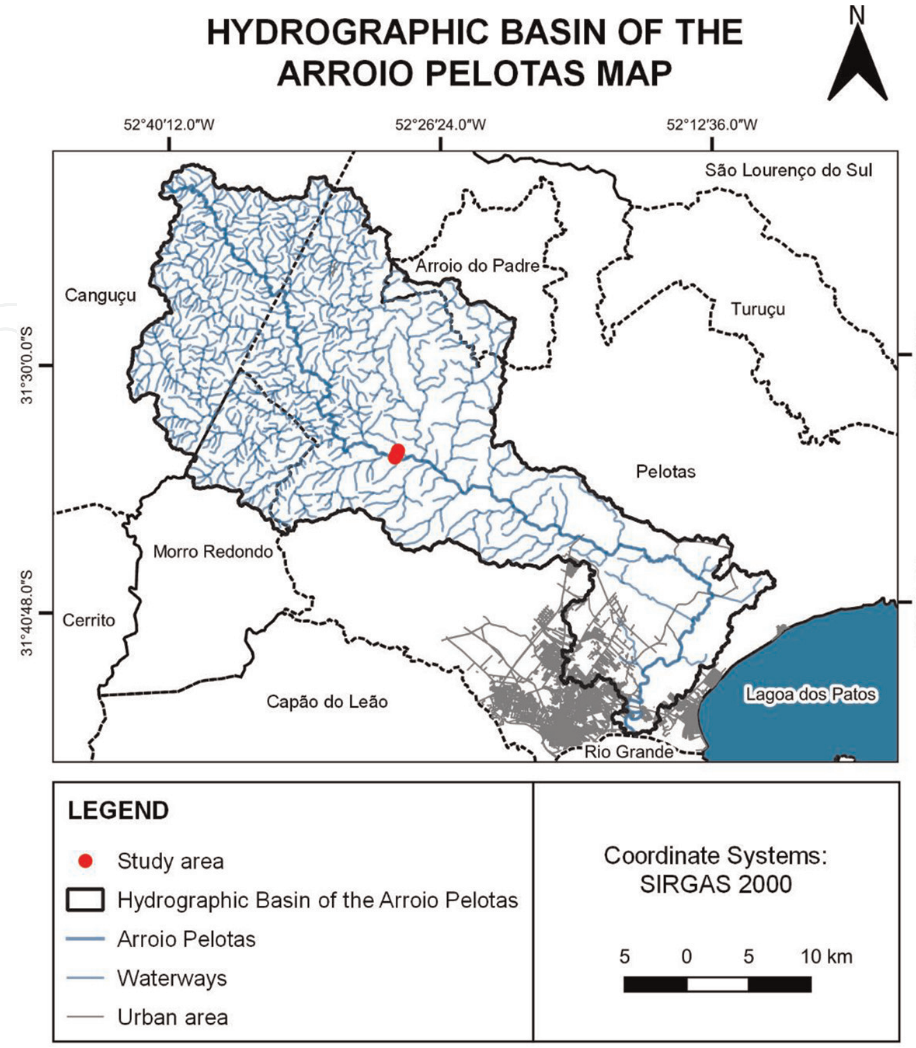

Figure 2.
Hydrographic basin of the Arroio Pelotas map, Pelotas, RS, Brazil.

called restinga are located predominantly in the internal and external coastal plain with vegetation of dry and humid fields, bathed, riparian forests, and capons of restinga forests. The other region, called semidecidual seasonal forest, was the site of this study and forest vegetation is typical (**Figure 3**) [22].

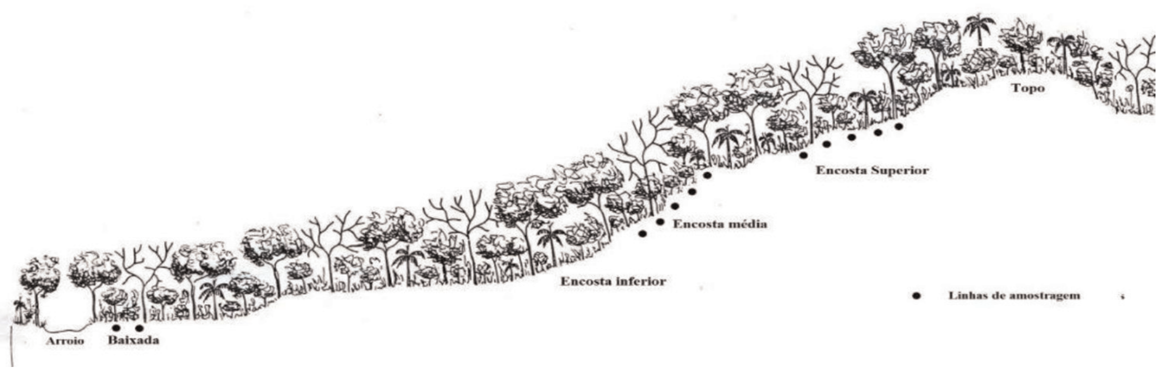

Figure 3.
Illustrative scheme of the topographic profile of the forest areas sampled along the relief in Pelotas, RS, Brazil. •= quematic distribution of soil sample collections. Source: Adapted Image of Phytogeographic Manual of Brazilian Vegetation IBGE [22].

2.1.2 Soils in the Arroio Pelotas river basin

The area is inserted in the geomorphological province of "escudo Sul-Rio-Grandense" besides being ancient, is geologically very complex, because it comprises several plutonic igneous rocks, mainly of granite composition associated with belts of metamorphic rocks, which were covered by sequences of sedimentary rocks and volcanic rocks [24]. On the edges of this heterogeneous geological province, is inserted approximately half of the area of the municipality of Pelotas. In this region, three main soil units are found: association LUVISSOLO HÁPLICO Órtico with NEOSSOLO REGOLÍTICO Distro-úmbrico, ARGISSOLO VERMELHO-AMARELO Distrófico and PLANOSSOLO HÁPLICO Eutrófico associado with GLEISSOLO MELÂNICO Tb Eutrófico, covering respectively the high, middle and low relief of the slope of the Escudo Sul-Rio-Grandense [24].

2.2 Soil sampling

2.2.1 Description and collection of soil profiles

For soil classification, the environmental characteristics of the site (external characteristics, such as relief, drainage, erosion, vegetation, and source material) were described, which constitutes the general description, and the morphological characteristics of the soil, such as thickness, arrangement, transition and characteristics between horizons and horizon characteristics (color, texture, structure, and consistency, etc.) as Santos et al. [25]. Soil profiles were described and collected at the top, on the upper slope, on the middle slope, and on the lowered slope. Soil horizon samples were physically and chemically characterized in the laboratories of the Soil Department of FAEM/UFPel[1] following the methodology set out in Teixeira et al. [26], and were subsequently classified according to the Sistema Brasileiro de Classificação de Solos, developed by the National Soil Research Center [27], and world reference base for soil resources [28].

2.2.2 Survey of soil physical attributes along the toposequence

Deformed samples (unpreserved structure) and undisturbed samples (preserved structure) of soil were collected in six different treatments distributed along two environmental gradients of the toposequence in the Pelotas Stream. For each gradient with three sample blocks distributed on the upper slope, on the middle slope, and on the lowered slope on the margin of the watercourse (**Figure 3**). The low slope and top relief sections were not sampled by the absence of adequate forest fragments in the study region. The gradients were divided into an area with access to cattle grazing and areas without grazing, witness for comparison. The control of areas of isolated forest fragments without access to animals and in conditions of relief similar to treatments with livestock access. The maximum distance between the areas is approximately 1400 m. The altitude of the plots ranged from 39 to 116 meters at sea level. Forest fragments were distributed in three small rural properties.

The undisturbed samples (preserved soil structure) were collected using the volumetric ring method [26]. The rings were 3 cm tall and 4.8 cm in diameter, with an

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[1] FAEM: Faculty of Agronomy Eliseu Maciel of Federal University of Pelotas (UFPel).

average volume of 54.9 cm^3 per sample. For the collection in the field, the insertion site of the ring was cleaned in the soil, removing the litter until the soil was fully discovered for the insertion of the rings. After the rings were inserted, using shovels, the ring was carefully removed from the ground, so as not to disaggregate the sample. Subsequently, each ring was wrapped in aluminum foil, sealed and labeled. The undeformed samples on the foil were carefully transported to avoid damage to the soil structure contained inside the ring.

Fourteen samples were collected per sample block, totaling 42 total samples per gradient, seven rings in the 0–5 cm layer and seven other rings in the 5–10 cm layer. The sampling points were approximately 10 meters from each other, inside the sample block of the collection of native forest vegetation (**Figure 3**). With the excess of soil in the layers of 0–5 and 5–10 cm, the deformed samples were collected, where they were placed in plastic bags, sealed, and labeled.

The deformed and undeformed samples were taken to the pedology laboratory, sample preparation room, and to the soil chemistry and physics laboratories of Faculty of Agronomy Eliseu Maciel of Federal University of Pelotas. The deformed samples were placed to dry at room temperature in the sample preparation room. After 5–7 days they were destroyed with a wooden roll and passed in 2 mm sieves, and then placed in plastic bags labeled and stored in the Pedology Laboratory/UFPel, constituting the air-dried soil samples. The undeformed samples were stored in the pedology laboratory and taken to the soil physics laboratory FAEM/UFPel, for the preparation and evaluation of attributes of soil density, microporosity (pores smaller than 0.05 mm), macroporosity (pores greater than 0.05 mm), and total porosity.

The determinations of the chemical attributes of the soil were made according to Tedesco et al. [29] and Teixeira et al. [26]. The determinations of pH (H_2O), pH (KCl), Ca, Mg, K, Na, and Al e P available were carried out in accordance with Tedesco et al. [29]. Organic carbon and H + Al were used in the study by Teixeira et al. [26]. The texture of the soil profile layers was analyzed by the granulometry method following the methodology proposed by Teixeira et al. [26].

The pH in water (active acidity) was determined at the ratio of 1:1 (soil:water) by immersion of a glass electrode connected to a pot. The pH in KCl (potential acidity – H + Al) was extracted with calcium acetate and determined by titration with NaOH. Calcium extraction (Ca^{+2}), magnesium (Mg^{+2}) e aluminum (Al^{+3}) exchangeable were made with KCl 1 mol L^{-1} and determined in the atomic absorption spectrophotometer (Ca^{+2} e Mg^{+2}) and by titration with NaOH (Al^{+3}). Potassium content (K^+) available and sodium (Na^+) were estimated by the double extractor method of $Mehlich^{-1}$ and analyzed by flame photometry. Based on the results of the analyses, the base saturation was calculated (BS%), the cation exchange capacity (CEC), and aluminum saturation (m%). Base saturation is calculated by the sum of the bases Ca^{+2}, Mg^{+2}, and K^+ e Na^+. A CTC = (Sum of bases + H^+ + Al^{+3}). Aluminum saturation (m%) is calculated by Eq. (1) below:

$$m\ (\%) = \left[Al^{+3}/\left(SB + Al^{+3}\right)\right] \times 100 \tag{1}$$

SB = sum of bases

Soil physical attributes were determined by the volumetric ring method, using the dry soil mass in a greenhouse to 105°C for 24 hours in the volumetric ring of known volume [26]. To calculate soil density by mass, the equation was used (2):

$$Bd = Dsm/Va \tag{2}$$

Bd = soil bulk density ($g.cm^{-3}$)
Dsm = dry soil mass contained inside the volumetric ring (g)
Va = volumetric ring volume (cm^3)

The determination of the porosity of the total soil was performed by the tension table method, using volumetric rings [26]. Through total porosity, the microporosity and macroporosity of the soil were determined, using the height of the suction water column of 60 cm to obtain a 0.006 MPa. The total porosity was calculated by Eq. (3) shown below:

$$\mathrm{Pt} = [(\mathrm{P1} - \mathrm{P3}) - \mathrm{P4}/\mathrm{Va}] \times 100 \tag{3}$$

Pt = total porosity (%)
P1 = saturated sample weight with fabric and rubber alloy (g)
P3 = weight of rubber alloy and saturated fabric (g)
P4 = weight of the kiln-dried sample (g)
Va = volumetric ring volume (cm^3)

Microporosity (mp) was calculated from Eq. (4) below:

$$\mathrm{mp} = [(\mathrm{P2} - \mathrm{P4})/\mathrm{Va}] \times 100 \tag{4}$$

mp = micropores (%)
P2 = balance sample weight (g)
P4 = weight of the kiln-dried sample (g)
Va = volumetric ring volume (cm^3)

Macroporosity (Mp) was calculated by the difference of total porosity by microporosity (mp), through the Eq. (5):

$$\mathrm{Mp} = \mathrm{Pt}–\mathrm{mp} \tag{5}$$

Mp = macroporosity (%)
Pt = total porosity (%)

In the soil physics laboratory, for each volumetric ring, the aluminum foil packaging was first removed. After removal of the package, the sample toilet was performed with the use of a stiletto, scissors, knife, and water spray. The toilet consisted of the process of removing excess soil at the lower and upper ends of the ring to equalize the ring volume with the volume of the soil sample. Following the toilet procedure, at the bottom of the ring was placed a piece of appropriate fabric fastened with rubber alloy [26]. The fabric has the function of handling possible sections of soil that detach from the ring. In the sequence, each ring was numbered and placed for saturation in trays by capillary rise, with water placed up to ¾ from the height of the ring, outdoors in the laboratory environment for at least 48 hours [26]. Subsequently, the rings were removed from the water and weighed on a precision scale, and then the saturated rings were placed for drainage on a tension table and a tension corresponding to 60 cm of water column height corresponding to macropore drainage was applied.

The samples of the volumetric rings were placed in Richard's pressure chamber and remained until the drainage of the excess moisture for each voltage ceased. After the volumetric rings came out pressure chamber, these were weighed to obtain the weight of the ring in balance and discounted the weights of the fabric and rubber alloy saturated. Subsequently, the rings in equilibrium were placed to dry in a greenhouse for 48 hours at a temperature of 105°C [26]. The rings were removed from the greenhouse and weighed on a precision scale to obtain the weight of the dry soil.

After obtaining the weight of the saturated soil, the balance soil weight and the dry soil weight of each volumetric ring, the soil of the ring was removed, which was washed, dried, and weighed to obtain the weight of the ring without soil to use in the subtraction in the weight of the samples. For each volumetric ring, it was measured, the diameter and height for calculating the volumetric ring volume, using the Eq. (6) below:

$$Va = \text{д} \times r2 \times h \tag{6}$$

Va = volumetric ring volume (m^3)
д = pi = 3.1428
r = geometric radius of the ring (m)
h = height (m)

The results were submitted to statistical analysis, which was performed by the PAST software with the Kruskal–Wallis nonparametric test with a significance level of 5%. The means of the physical parameters of soil in the same toposequence and layers with and without the presence of livestock were compared.

3. Results and discussion

The pedological survey was carried out with a methodology that aims to identify, characterize, and classify soil profiles [25]. Soil classification resulted in three soil classes at the order level: Leptosol, regosol, and acrisol, according to the classification proposed by IUSS working group WRB [28], and in two soil classes at the order level: Neossolo and Argissolo, according to the classification proposed by Santos et al. [27] (**Table 2**; **Figure 4**). It has been classified as Argissolo in the downloaded and Neossolos on the middle slope, top slope, and top (**Figure 5**). Soil classification was performed by means of analytical data interpretation (**Tables 3** and **4**), physic and chemical attributes, and morphological description of profiles.

The class of Argissolos in general, are soils of varying depth, from strong to imperfectly drained, with reddish or yellowish colors and rarely brunadas or grayish. It has a sandy texture to clayey on horizon A and medium to very clayey on horizon B, always having a textural gradient of clay from horizon A to B, which characterizes the textural horizon B (Bt). The transition usually between horizons A and Bt is clear, abrupt, or gradual. They are strong to moderately acidic soils, predominantly kaolinitic with high or low base saturation [27].

Soil profile	SiBCS	WRB
P1	NEOSSOLO LITÓLICO Distrófico fragmentário (RLd)	Dystric Leptosol (LPdy)
P2	NEOSSOLO REGOLÍTICO Distrófico leptofragmentário (RRd)	Leptic Regosol (Rgle)
P3	NEOSSOLO REGOLÍTICO Eutrófico típico (RRe)	Eutric Regosol (RGeu)
P4	ARGISSOLO AMARELO Distrófico típico (PAd)	Haplic Acrisol (ACha)

SiBCS = Sistema Brasileiro de Classificação de solos [27]; WRB = World reference base for soil resources [28].

Table 2.
Equivalence of classification systems.

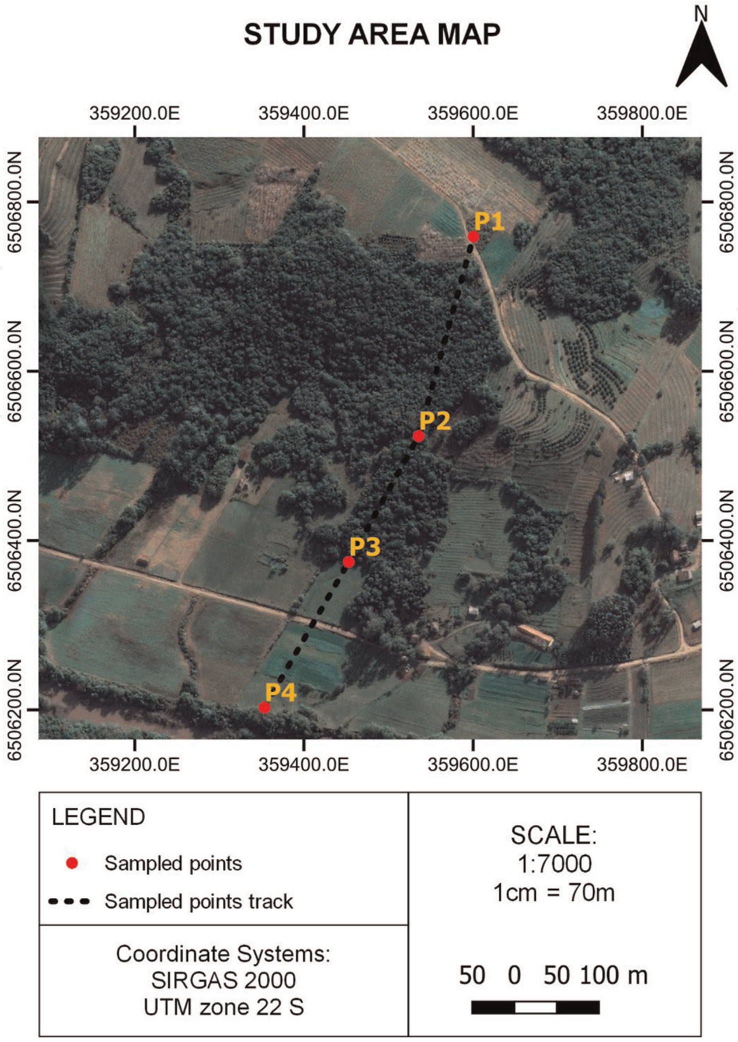

Figure 4.
Study area map. P1 – NEOSSOLO LITÓLICO Distrófico fragmentário (RLd) /Dystric Leptosol (LPdv), P2 – NEOSSOLO REGOLÍTICO Distrófico leptofragmentário (RRd)/Leptic Regosol (RGle), P3 – NEOSSOLO REGOLÍTICO Eutrófico típico (RRe)/Eutric Regosol (RGeu) and P4 – ARGISSOLO AMARELO Distrófico típico (PAd)/Haplic Acrisol (ACha).

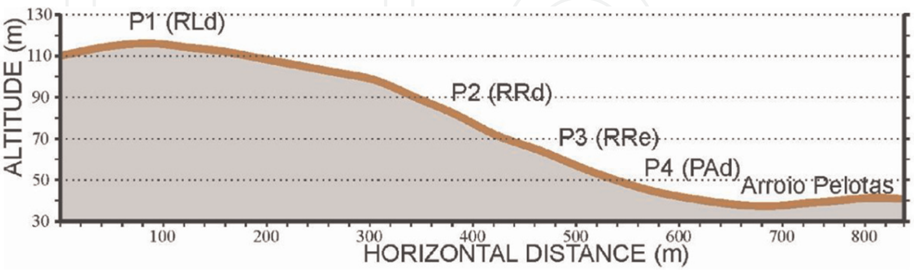

Figure 5.
Toposequence of the study area with the respective topographic profiles in the landscape and the respective soils. P1 – NEOSSOLO LITÓLICO Distrófico fragmentário (RLd)/Dystric Leptosol (LPdv), P2 – NEOSSOLO REGOLÍTICO Distrófico leptofragmentário (RRd)/Leptic Regosol (RGle), P3 – NEOSSOLO REGOLÍTICO Eutrófico típico (RRe)/Eutric Regosol (RGeu) and P4 – ARGISSOLO AMARELO Distrófico típico (PAd)/Haplic Acrisol (ACha).

In downloaded, profile P4 (**Figure 4**), the soil was classified as ARGISSOLO AMARELO Distrófico típico, presenting sequence of horizons A-AB1-AB2-Bt, deep soil (>100 cm), with yellowish color, indicating a sign of good drainage and low base

Soil profile	Hz	pH H_2O	pH HCl	Ca	Mg	K	Na	Al	H	CEC	BS	m	OC	P
				$cmol_c.kg^{-1}$							%		$g.kg^{-1}$	$mg.kg^{-1}$
	NEOSSOLO LITÓLICO Distrófico fragmentário													
P1	A	7.3	5.4	3.5	1.4	0.2	0.0	0.1	2.9	8.2	62	2.8	11.8	9.9
	A/CR/R	6.4	4.4	2.9	1.4	0.2	0.0	0.7	5.1	10.3	44	13.2	10.1	3.5
	CR/R	5.3	3.9	2.6	1.4	0.2	0.0	1.9	4.6	10.7	39	31.3	6.0	2.0
	NEOSSOLO REGOLÍTICO Distrófico leptofragmentário													
P2	A	4.9	4.1	3.8	0.9	0.2	0.0	1.1	7.1	13.0	38	17.8	25.7	2.8
	AC	4.9	3.8	1.8	0.4	0.1	0.0	1.9	5.5	9.7	23	46.3	10.1	1.0
	C	4.9	3.9	1	0.2	0	0.0	1.2	2.9	5.4	24	48.3	5.4	0.8
	C/CR	5	3.8	1.2	0.3	0	0.0	1.4	2.6	5.6	29	46.6	4.9	1.1
	NEOSSOLO REGOLÍTICO Eutrófico típico													
P3	A	5.2	4.2	5.9	1	0.1	0.1	0.8	6.1	14.0	51	9.8	16.3	2.0
	AC	5.6	4.2	3.8	0.4	0.0	0.1	0.5	3.1	8.0	54	11.0	6.4	1.1
	C1	5.6	4.1	3.1	0.7	0.0	0.1	0.5	1.5	5.9	67	11.0	2.7	1.7
	C2	5.6	4.0	3.2	0.8	0.0	0.1	0.6	0.9	5.7	73	13.1	2.0	1.4
	ARGISSOLO AMARELO Distrófico típico													
P4	A	5.5	4.7	2.2	0.6	0.1	0	0.6	1.4	4.9	59	16.6	7.0	24.5
	AB1	5.3	4.1	1.4	0.7	0.1	0	0.7	2.3	5.1	42	23.9	5.8	21.9
	AB2	5.2	4.0	1.8	0.7	0.0	0	0.4	2.9	6.0	44	14.1	5.6	7.0
	Bt	4.9	3.8	2.9	0.9	0.1	0	1.2	3.0	8.0	48	23.2	5.2	4.3

P1 – NEOSSOLO LITÓLICO Distrófico fragmentário (RLd) /Dystric Leptosol (LPdv), P2 – NEOSSOLO REGOLÍTICO Distrófico leptofragmentário (RRd) /Leptic Regosol (RGle), P3 – NEOSSOLO REGOLÍTICO Eutrófico típico (RRe) /Eutric Regosol (RGeu) and P4 – ARGISSOLO AMARELO Distrófico típico (PAd)/Haplic Acrisol (ACha). Hz= Soil profile horizon; CEC= cation exchange capability; BS= base saturation; m= aluminum saturation; OC= organic carbon.

Table 3.
Chemical characteristics of the toposequence profiles in the Arroio Pelotas, RS, Brasil.

saturation (<50%). These characteristics, together with the chemical attributes described in **Table 2**, corroborate with Streck et al. [24] which gives these soils parameters of low natural fertility, high acidity, and low cation exchange capacity (CEC).

The second soil class identified was that of the Neossolos, present in the sampling points P1, P2 e P3 (**Figure 4**). The Neossolos are characterized by being soils of recent formation, consisting of mineral or organic material that does not present express changes in relation to the source material, due to the low intensity of action of the pedogenetic processes, and that does not present horizon B diagnosis [27]. Despite having good natural fertility, this class has limitations in the production of annual crops, since it has a strong restriction on the entry of mechanization due to stoniness and rockiness, which impairs root development and water storage by low effective profundiade [24].

Soil profile	Horizon	Depth	Thick sand	Fine sand	Silt	Clay
		cm		$(g.kg^{-1})$		
		NEOSSOLO LITÓLICO Distrófico fragmentário				
P1	A	0–10/15	207	374	297	123
	A/CR/R	10/15–16/25	182	339	328	151
	CR/R	16/25–40+	116	345	355	184
		NEOSSOLO REGOLÍTICO Distrófico leptofragmentário				
P2	A	0–20	298	260	276	167
	AC	20–38	191	331	305	174
	C	38–60/70	228	370	276	126
	C/CR	60/70–85+	343	245	268	144
		NEOSSOLO REGOLÍTICO Eutrófico típico				
P3	A	0–22	205	226	371	198
	AC	22–42	284	228	364	124
	C1	42–65/70	312	245	339	105
	C2	65/70–100+	290	262	344	104
		ARGISSOLO AMARELO Distrófico típico				
P4	A	0–25	296	554	113	37
	AB1	25–50	204	530	201	65
	AB2	50–80	130	553	234	83
	Bt	80–100+	23	464	392	121

P1 – NEOSSOLO LITÓLICO Distrófico fragmentário (RLd) /Dystric Leptosol (LPdv), P2 – NEOSSOLO REGOLÍTICO Distrófico leptofragmentário (RRd) /Leptic Regosol (RGle), P3 – NEOSSOLO REGOLÍTICO Eutrófico típico (RRe) /Eutric Regosol (RGeu) and P4 – ARGISSOLO AMARELO Distrófico típico (PAd) /Haplic Acrisol (ACha).

Table 4.
Granulometric characteristics of the toposequence profiles in the Arroio Pelotas, RS, Brasil.

At the top, profile P1 (**Figure 4**), the soil was classified as NEOSSOLO LITÓLICO Distrófico fragmentário, presenting a sequence of horizons A-A/CR/R-CR/R, an effective profunity less than 50 cm that configures with shallow soil, high base saturation on horizon A (>50%) and lithic contact between 50 and 100 cm from the surface of the soil.

On the top slope, profile P2 (**Figure 4**). The was classified as NEOSSOLO REGOLÍTICO Distrófico leptofragmentário, presenting a sequence of horizons A-AC-C-C/CR, an effective depth between 50 and 100 cm configuring as shallow soil, low base saturation along the profile (<50%) and fragmentary lytic contact at a depth greater than 50 cm and less than or equal to 100 cm from the soil surface.

On the middle slope the soil was classified, the P3 (**Figure 4**), in NEOSSOLO REGOLÍTICO Eutrófico típico presenting a sequence of horizons A-AC-C1–C2, an effective depth greater than 100 cm configuring as deep soil, high base saturation (>50%) and lithic contact greater than 50 cm from the soil surface.

The average results for soil density determinations, total porosity, macroporosity, and microporosity are presented in **Table 5**. Forest soil density varied between 1.00

Position on relief	Macroporosity		Microporosity		Total porosity		Density	
	0–5 cm	5–10 cm	0–5 cm	5–10 cm	0–5 cm	5–10 cm	0–5 cm	5–10 cm
			%				Mg m^{-3}	
Upper slope SG	31.4a	25.5a	27.8a	24.5a	59.2	50	1.00a	1.24a
Upper slope CG	19.6b	21.5a	37.9b	29.3a	57.5	50.8	1.09a	1.27a
Middle slope SG	28.2a	21.0a	21.1a	23.2a	49.3	45.1	1.06a	1.26a
Middle slope CG	18.9b	21.4a	31.2b	22a	51.7	50	1.21a	1.45b
Lowland (ciliar) SG	19.8a	18.8a	32.5a	31.6a	52.3	50.3	1.06a	1.20a
Lowland (ciliar) CG	12.0b	21.4a	41.4a	30.8a	52.1	52.9	1.15a	1.23a

SG: no access of cattle in the forest and CG: with access of cattle to the interior of the forest. Means followed by the same letter do not differ statistically from each other by the Kruskal–Wallis nonparametric test ($p < 0.05$).

Table 5.
Physical parameters of the forest soils in the 0–5 cm and 5–10 cm layers in toposequence in the Arroio Pelotas Hydrographic Basin, Rio Grande do Sul, Brasil.

Mg m^3 and 1.45 Mg m^3. Regardless of the position in the relief or access of the animals inside the fragments, the density was lower in the upper layer (0–5 cm) ranging between 1.00 Mg m^3 and 1.21 Mg m^3. While in the lower layer (5–10 cm), the density varied between 1.20 Mg m^3 and 1.45 Mg m^3. Although forest areas with animal access showed a soil density generally higher than the fragments without access, statistical difference was detected only in the lower layer (5–10 cm) on the middle slope. The critical density values found for sandy soils under agricultural use are cited and range from 1.6 to 1.8 [19], well above that found in this study.

This lower soil density in the upper layer (0–5 cm) was found in studies in natural forests [19, 30, 31]. This general pattern of natural or anthropic soils is caused by the greater intake of organic matter in the most superficial layer of the forest soil. The organic matter from the vegetation has a specific mass of lower density and greater aggregation power among the mineral particles of the soil, resulting in the better structural quality of the soils and, consequently, in the greater amount of pore space and space for root growth.

The lowest soil density in areas occupied by native forests has already been found in different Brazilian Biomes [15, 17, 19, 30–37]. In the same watershed, Flores et al. [32] found in Argissolo Vermelho, that the density of native forest and native field soil was lower than in the cultivation areas, with greater differences in the layer of higher organic matter intake (0 a 0.05 m). In this layer, the native forest had the lowest density (1.06 Mg m^{-3}) while no-till was the largest (1.45 Mg m^{-3}), and after five years, no-tillage had half the organic matter of the surface layer of the native forest [32].

In the studies of different Brazilian biomes that used native forests as control of edafica quality in agricultural properties, the density was always lower in native forests compared to more intense land uses, such as annual crops of conventional management, and no-tillage and pastures. It is important to highlight that the density values of the forest soil studied, in all glebes, they had density below the appropriate critical density for plant growth. However, densities close to or above the critical boundary should probably occur on the animal tracks within forest fragments.

The pattern of the lower density of forest soils compared to other forms of landscape use, such as crops, orchards, and pastures, is a consequence of the lower or no soil revolving in these forest environments. Thus, the decompaction of forest soil is largely influenced by the intense and constant activity of edafica fauna and woody plants with a large volume of the root system. Edaphic organisms, mainly microorganisms, have an important role to decompile biomass produced in the different strata of the forest and deposited in the litter, which is incorporated into soil organic matter and promotes better conditions in physical attributes, such as aggregation, porosity, and rate of water infiltration, energy flow, as well as chemical attributes such as nutrient cycling and increased cation exchange capacity [38] in forest soils.

Since then, soil density has been an indirect environmental indicator of the degree of particulate ness. For soils of similar classes, the higher the soil density, the higher its compaction, the lower its total porosity and, consequently, the greater the restrictions on the development of the root system of young plants, water infiltration, and soil aeration [5, 17].

The total porosity of forest soils ranged from 45% to 59%. However, macroporosity and microporosity had different distributions between the relief segments and between the soil layers. The areas without grazing presented nominally higher values in macroporosity and with the statistical difference in the three parts of the relief in the surface layer of the soil (0–5 cm). The forests with cattle access presented macropores in a smaller proportion, ranging from 12–20% in the upper soil layer (0–5 cm) and close values, in the three areas of the relief, to 21.5% in the lower layer (5–10 cm). In the protected areas of grazing, the proportion of macropores was between 19–31% in the 0–5 cm layer and between 18–25% in the 5–10 cm layer. On the other hand, the micropores were more abundant in forest areas with the entry of animals, between 31 and 41% of the porosity of the samples of the 0–5 cm layer and between 22–31% for the 5–10 cm layer. In the areas without the presence of the animals, the microporosity values were lower, between 21 and 32% in the upper layer and 23–32% in the samples of the lower layer. The microporosity was different between the areas with and without the cattle, however, even with higher microporosity values, in the lowered, there was a statistical difference between the middle and upper slope in the surface layer (0–5 cm). There was no statistical difference in the lower layer (5–10 cm) in all parts of the relief. The total porosity of forest soils ranged from 45 to 59% in the upper and lower layer.

Soil porosity is the intense result of biological activity and the diameter distribution of these pores reflects the condition to determine the physical-water behavior in soils [39]. In the study of the toposequence in Pelotas, the size of the pores indicates alteration due to the presence of animals inside the fragments of protective forests. The macroporosity of the soil surface layer was the parameter that was impaired by the compaction of cattle. The trampling of the animals is indicating a reduction in soil quality, being favorable for greater compaction of the surface layer, due to the increase in soil density and the reduction of macroporosity [40].

In relation to forest species, soil esthesity porosity is fundamental for seed germination and plant growth. A smaller volume of aerating space in the soil restricts the full development of the root system. In this sense, data on critical values for plant growth in different studies showed a minimum limiting value of soil aeration amount (macroposority) of at least 10% [8]. The toposequence soils in Pelotas, despite the loss of aeration space and water infiltration in the unfenced areas, showed macroporosity values above minimum environmental quality values. Even the forest fragments with the presence of the animals maintained adequate soil aeration conditions for plant growth with adaptations to grazing and animal trampling, such as carne-de-vaca (*Styrax leprosus*), embira (*Daphnopsis racemosa*), pitanga (*Eugenia uniflora*), *Cestrum*

(Cestrum parquii) e mamica-de-cadela (*Zanthoxylom fagara*), spiny vines, among other dominant.

Other land uses show less adequate conditions of aerated ground space. In different management systems of agricultural property in Pelotas, CRUZ et al. [41] found in conventional systems, no-tillage and native livestock field, lower aeration values, between 8 and 13% macroporosity for Argissolo Vermelho. Already evaluating soil quality in cultivated areas a few kilometers from the study, FLORES et al. [32] found greater aerate structure in the native forest and in the no-tillage system, 19 and 14%, respectively, already in the conventional planting system and in the native field with high livestock grazing, 8% macroporosity occurred. In Argissolo Vermelho distrófico in the same geological unit of this study, SUZUKI et al. [37] evaluated pasture, production forest, and forest of anthropized native protection in relation to compaction intensity. The authors found in the pasture with more than five years the lowest macroporosity (3.6%), while in the planting of *Eucalyptus saligna* with 20 years, the best macroporosity (19.9%). An intermediate macroporosity and practically below the minimum required plants occurred in the eucalyptus saligna forest in recent formation (four years) and in the anthropized native forest and used as shelter by cattle for five years [37].

4. Conclusions

The higher porosity of esthetic and water infiltration in forest soils, compared to other uses of the landscape, such as crops, orchards, and pastures, is the result of less soil revolving and its permanent vegetation cover. Forest vegetation constantly supplies organic matter to the soil through the litter intake of the treetops, the rhizosphere relationships in the root system, and its mycorrhizae relationships. The long time without soil revolving in production forests or protective forests occurs the action of organisms, plants, and animals in the incorporation of organic matter and the structuring of soil aggregates promoting improvements in forest soil quality by the stability of the environment.

The classification of the soils presented different classes in the toposequence, with Neossolos at the top and on the slopes and Argissolos in the lowlands of the relief, in the riparian forest. The presence of cattle inside the forest fragments, regardless of the position in the relief, indicates a tendency to promote negative effects and the loss of macroporosity in the surface layer of the soil. The soils of the forest fragments with the presence of the animals presented lower significant values of macroporosity in the surface layer, contributing to a certain compaction, compromising the distribution of porosity, and generating negative effects on soil physical quality.

This study evaluated the effects of cattle grazing on the physical quality of forest soils in the extreme south of the Atlantic forest, resulting in technical-scientific subsidies for the implementation of forest fragment isolation in landscapes planned to improve soil quality in the protected forests of watersheds. Thus, conservation by the isolation of protective forests in the planning of rural property benefits the quality of forest soils. Further studies are needed in the Arroio Pelotas watershed to characterize soil physics patterns according to the type of land use, to mitigate environmental impacts of livestock, and encourage a more sustainable activity.

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Conflict of interest

The authors declare no conflict of interest.

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References

[1] Brasil. Lei n° 12.651 de 25 de maio de 2012. Código Florestal. Dispõe sobre a proteção da vegetação nativa. 2012

[2] Antoneli V, Oliveira T, Bednarz JA. A fragmentação da floresta é um indicador de compactação do solo em Sistema Faxinal. Caminhos de Geografia. 2019; **20**(72):94-106

[3] Coder KD. Soil Compaction & Trees: Causes, Symptoms & Effects. Georgia: University of Georgia Warnell School of Forest Resources Extension Publication; 2000. p. 37

[4] Lima JSS, Leite AMP. Mecanização. In: Machado CC, editor. Colheita Florestal. Vol. 3. Viçosa: UFV; 2014. pp. 42-72

[5] Silveira AR, Rocha WW, Leite ÂMP, Santos JJ, Dias Júnior MS. Capacidade de suporte de cargas de um Latossolo submetido a duas alternativas de uso do solo e sob Floresta Nativa. Scientia Forestalis. 2022;**50**:1-9

[6] Suzuki LEA, Reichert JM, Reinet DJ. Degree of compactness, soil physical properties and yield of soybean in six soils under no-tillage. Soil Research. 2013;**51**:311-321

[7] Leite SP, Silva CR, Henriques LC. Impactos ambientais ocasionados pela agropecuária no Complexo Aluízio Campos. Revista Brasileira de Informações Científicas. 2011;**2**(2):59-64

[8] Reichert JM, Suzuki LEAS, Reinert DJ. Compactação do solo em sistemas agropecuários e florestais: identificação, efeitos, limites críticos e mitigação. Tópicos Ciência do Solo. 2007;**5**:49-134

[9] Sampietro JA, Lopes ES, Reichert JM. Compactação causada pelo tráfego de Feller Buncher e Skidder em um Neossolo Regolítico sob distintas umidades. Ciência Florestal. 2015;**25**(1): 239-248

[10] Gubiani PI, Reichert JM, Reinert DJ. Indicadores hídrico-mecânicos de compactação do solo e crescimento de plantas. Revista Brasileira de Ciência do Solo. 2013;**37**(1):1-10

[11] Broersma K, Krzic M, Newman R, Bomke A. Effects of grazing on soil compaction and water infiltration in Forest plantations in the Interior of British Columbia. In: Hollstedt C, Sutherland K, Innes T, editors. Proceedings, from science to management and back: a science forum for southern interior ecosystems of British Columbia. Kamloops: Southern Interior Forest Extension and Research Partnership; 2000. pp. 89-92

[12] Greacen EL, Sands R. Compaction of forest soils. A review. Soil Research. 1980;**18**(2):163-189

[13] Fernandes HC, Souza AP. Compactação de um latossolo vermelho causada pelo tráfego do "Forwarder". Revista Árvore. 2003;**27**(3):279-284

[14] Szymczak DA, Brin EJ, Reinert DJ. Frigotto T, Mazzalira CC, Dal'com A, MARAFINAS J. Compactação do solo causada por tratores florestais na colheita de *Pinus taeda* L. na região sudoeste do Paraná. Revista Árvore. 2014;**38**(4): 641-648

[15] Spera ST, Santos HP, Fontaneli RS, Tomm GO. Efeito de integração entre lavoura e pecuária, sob plantio direto, em alguns atributos físicos do solo após dez anos. Bragantia. 2010;**69**(3): 695-704

[16] Hickmann C, Costa LM, Schaefer CEGR, Fernandes RBA. Morfologia e estabilidade de agregados superficiais de um argissolo vermelhoamarelo sob diferentes manejos de longa duração e Mata Atlântica secundária. Revista Brasileira Ciência do Solo. 2011;**35**:2191-2198

[17] Castro MA, Cunha FF, Lima SF, Paiva-Neto VB, Leite AP, Magalhães F, et al. Atributos físico-hídricos do solo ocupado com pastagem degradada e floresta nativa no Cerrado Sul-Mato-Grossense. Brazilian Geographical Journal: Geosciences and Humanities research medium. 2012;**3**(2):498-512

[18] Vásquez-Velásquez G. Headwaters deforestation for cattle pastures in the Andes of Colombia and its implications for soils properties and hydrological dynamic. Open Journal of Forestry. 2016;**6**:337-347

[19] Lima HV, Lima CLR, Leão PL, Cooper M, Silva AP, Romero RE. Tráfego de máquinas agrícolas e alterações de bioporos em área sob pomar de laranja. Revista Brasileira Ciência do Solo. 2005; **29**:677-684

[20] Han E et al. Quantification of soil biopore density after perennial fodder cropping. Plant and Soil. 2015;**394**(1–2): 73-85

[21] Parron LM et al. Serviços Ambientais em Sistemas Agrícolas no Bioma Mata Atlantica. Brasília: EMBRAPA Florestas; 2015. p. 34

[22] IBGE. Instituto Brasileiro de Geografia e Estatística. Vegetação: as regiões fitoecológicas, sua natureza e seus recursos econômicos: estudo fitogeográfico. In: IBGE, Levantamento de recursos naturais. Vol. 3. Rio de Janeiro; 1986. pp. 541-632

[23] Klein RM. Aspectos predominantes da vegetação sul-brasileira. In: CONGRESSO DA SOC. BOTÂNICA DO BRASIL. Porto Alegre; 1964

[24] Streck EV, Kämpf N, Dalmolin RSD, Klamt E, Nascimento PCD, Schneider P, et al. Solos do Rio Grande do Sul. 3ª ed. rev. e ampl. EMATER/RS-ASCAR: Porto Alegre; 2018. p. 252

[25] Santos RD, Santos HG, Ker JC, Anjos HC, Shimzu SH. Manual de descrição e coleta de solo no campo. 7th ed2015

[26] Teixeira PC, Donagemma GK, Fontana A, Teixeira WG. Manual de Métodos de Análise de Solo 3ª edição revista e ampliada. 2017

[27] Santos HG, Jacomine P, Anjos L, Oliveira V, et al. Sistema brasileiro de classificação de solos, 2018

[28] IUSS Working Group WRB. World reference base for soil resources 2014: International Soil Classification System for Naming Soils and Creating Legends for Soil Maps. Rome: World Soil Resources; 2015

[29] Tedesco MJ, Gianello G, Bissani CA, Bohnen H, Volkweiss SJ. Análises de solo, plantas e outros materiais. 2ª ed. rev. e ampliada. Porto Alegre: Boteltim Técnico n°5, Departamento de Solos, Universidade Federal do Rio Grande do Sul - UFRGS, 1995. 174

[30] Cruz DLS, Vale Junior JF, Cruz PLS, Cruz ABS, Nascimento PPRR. Atributos físico-hídricos de um Argissolo Amarelo sob floresta e savana naturais convertidas para pastagem em Roraima. Revista Brasileira Ciência do Solo. 2014; **38**:307-314

[31] Fernandes KL, Ribon AA, Tavares Filgi T, Custodio GD. Barros LR

Influence of time management in modeling of curve resistance to the penetration of a latosol under different uses and management of pastures and native woodland. Revista Árvore. 2016; **40**(3):519-527

[32] Flores CAF, Reinert DJ, Reichert JM, Albuquerque JA, Auletto EA. Recuperação da qualidade estrutural, pelo sistema plantio direto, de um Argissolo Vermelho. Ciência Rural. 2008;**38**(8):2164-2172

[33] Melloni R, Melloni EGP, Alvarenga MIN, Vieira FBM. Avaliação da qualidade de solos sob diferentes coberturas florestais e de pastagem no sul de Minas Gerais. Revista Brasileira Ciência do Solo. 2008;**32**:2461-2470

[34] Domingos MMM, Gasparetto NVL, Nakashima P, Ralisch R, Tavares FJ. Estrutura de um Nitossolo Vermelho Latossólico eutroférrico sob sistema plantio direto, preparo convencional e floresta. Revista Brasileira Ciência do Solo. 2009;**33**: 1517-1524

[35] Santos GG, Marchão RL, Silva EM, Silveira PM, Becquer T. Qualidade física do solo sob sistemas de integração lavoura-pecuaria. Pesquisa Agropecuária Brasileira. 2011;**46**(10):1339-1348

[36] Viana ET, Batista MA, Tormena CA, Costa ACS, Inoue TT. Atributos físicos e carbono orgânico em Latossolo Vermelho sob diferentes sistemas de uso e manejo. Revista Brasileira de Ciência do Solo. 2011;**35**:2105-2114

[37] Suzuki LEAS, Lima CLR, Reinert DJ, Reichert JM, Pillon CN. Condição estrutural de um argissolo no Rio Grande do Sul, em floresta nativa, em pastagem cultivada e em povoamento com eucalipto. Ciência Florestal. 2012;**22**(4): 833-843

[38] Kubiak KL et al. Fauna epiedáfica associada a fragmentos florestais de Araucaria angustifolia em diferentes condições edafoclimáticas no estado do Paraná. Revista Brasileira de Geografia Física. 2021;**14**(02):1070-1080

[39] Klein M. Física do Solo. 3ª ed. Brazil: Passo Fundo; 2014. p. 263

[40] Santos JT et al. Atributos físicos e químicos do solo de Áreas sob Pastejo na Micro Região do Brejo Paraibano. Ciência Rural. 2010;**40**:2486-2492

[41] Cruz ACR, Pauletto EA, Flores CA, Silva JB. Atributos físicos e carbono orgânico de um Argissolo Vermelho sob sistemas de manejo. Revista Brasileira Ciência do Solo. 2003;**27**:1105-1112