Original Research Article

Soil attributes related to natural succession in a PPA in Southern Brazil

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ABSTRACT

The study of physical and chemical characteristics of a soil associated to different vegetation cover is very important for understanding how the soil can influence the behavior of the forest.
Aims: This study aimed to relate soil attributes under pine cultivation and natural regeneration of vegetation in permanent preservation areas (PPA).
Methodology: For this purpose, a regenerated PPA (RA) and a non-regenerated PPA (NRA) had their vegetation and seed bank characterized, respectively. In different soil depths, chemical and physical attributes of the soil were analyzed.
Conclusion: Ca content and soil density (SD) were variables that best discriminated the soil of both areas. High soil density (SD), deficiency in soil drainage and lack of propagules of woody species determined the establishment of the herbaceous vegetation in the RA. Lower SD and better soil drainage allowed the establishment of arboreal and shrub species of the Mixed Ombrophilous Forest in the RA.

Keywords: Soil Quality Indexes. Reforestation. Recovery of Degraded Areas

1. INTRODUCTION

Latin America is home for the Guarani Aquifer System (GAS), on Paraná Sedimentary Basin. It is an important subterranean water reservoir with an area of approximately 1.1 million km^2 [1]. In Brazil, it extends for about 840.000 km^2 through São Paulo, Minas Gerais, Goiás, Mato Grosso, Mato Grosso do Sul, Rio Grande do Sul, Paraná and Santa Catarina states [2].

With the disordered increase of the Brazilian agrosilvopastoral frontier, mainly during the Green Revolution, the modernization of agriculture, silviculture and livestock and the socioeconomic development have been intensified [3]. In contrast, this led to alterations of natural environments, degrading highly diversified areas like riparian forests. Thus, many forests of Mata dos Pinhais (Atlantic Mixed Ombrophile Forest - MOF), typical vegetation of the GAS of Southern Brazil, were replaced by *Pinus* sp. Plantations, which were also stimulated by commercial exploitation of wood. This represented an increase on fragmentation and degradation of riparian forests areas and of other areas of permanent preservation [4].

Removal of natural vegetation cover and cultivation of exotic species alter characteristics of the natural environment and cause degradation of soil quality, which can contaminate water tables and both superficial and subterranean aquifers. In this way, studies on the adequacy of agricultural land use are necessary in order to analyse the vulnerability of natural resources integrated in order to subsidize environmental management on critical areas about risks of contamination of the Guarani Aquifer [5].

PPAs are of relevant importance in water dynamics. They present higher fragility and susceptibility to erosion due to its irregular topography and low soil depth. Therefore,

restoration of original vegetation is indispensable in those areas, as they allow soil recovery and biodiversity attributes that avoid contamination of water tables. Also, it serves as habitat for threatened animal and plant species [6].

Given the need to understand the reestablishment process of native vegetation on a PPA degraded by exotic forest plantations, it is crucial to develop works that involve a broad environmental analysis and that uses techniques that allow multiple relations between soil attributes and the progress of the vegetation to be stablished.

The present study aimed to relate physical and chemical indicators of the quality of soil developed on Guarani Aquifer and previously explored by *Pinus* sp. Plantation to regeneration of native vegetation in areas of permanent preservation in the city of Ponte Alta do Norte, SC.

2. MATERIAL AND METHODS

This work was carried out at Paredão Farm (belonging to Klabin S.A.), located in Ponte Alta do Norte, Planalto Sul Catarinense, under the central coordinates 27°15’38’’S and 50°20’43’’W at approximately 1,000 meters of altitude.

According to Köppen classification, the region has a mesothermic humid climate with mild summer (Cfb), well distributed rain during the year, mean annual precipitation of approximately 1,500mm and mean annual temperature of 15.5°C according to Epagri data [7].

The studied areas represent an PPA, and had vegetation described as Mixed Ombrophiles Forest (MOF) according to IBGE [8]. They are rich in species such as *Araucaria angustifolia,* the first to be economically exploited until mid- 1970s. From 1982, wood production chain started using exotic plants plantations largely represented by genera *Pinus* and *Eucalyptus*. In these areas, such activities occurred until May 2006 when recomposition of native vegetation was initiated through natural succession for compliance with environmental legislation.

Evaluation of regeneration of the natural vegetation was performed between August 2010 and May 2011. Presence of native tree and shrub species from MOF allowed distinction between PPAs in two classes: regenerated PPA (RA) and non-regenerated PPA (NRA).

Taxonomic classification of the soils was performed based on the Brazilian System of Soil Classification [9], through morphological, physical and chemical evaluation of the material. This material was described and collected in two monoliths obtained from borehole and from reconstitution of the sequence of soil horizons and layers (on RA) and in an open trench (on NRA) in February 2011. Monolith construction on NRA occurred due to the proximity of the water table with the surface and to the low effective soil depth. Soil on RA is classified as a typical distrophic Latosol, while soil on NRA is classified as a typical hydromorphic quartzarenic Neosol.

For vegetation survey and soil analysis, sampling occurred along transects inside PPAs in adequacy process.

For floristic survey on RA, the quadrant-points method was used [10]. Points were marked along two transects and allocated within a distance of five meters between each other, totalizing 20 sampling points in each transect. Four trees and four shrubs that were closer to the central point and had its height greater than or equal to 1 meter were selected. Individuals were collected, identified [11] and herborized. To verify sampling adequacy, the rarefaction curve was used based on the Mao Tau index [12] using EstimateS v.8.0 programme [13].

Given the irregularities of the vegetation recomposition on NRA, botanical families were classified based on plants developed on seed banks. They were collected randomly on the soil litter along two transects, in eight sampling points and in two depths (0-10 and 10-20

m). Plant development occurred in a climatized greenhouse with regulated temperature of minimum 18 ± 2°C and maximum 25 ± 3°C and air relative humidity between 35% and 75%.

For soil sampling, transects were allocated all over the study area through systematic disregarded method which is characterized by not having fixed distances between transects [14]. Four transects of approximately 100 meters each were established. In these transects, soil samples were collected at depths of 0–20 cm and 20-40 cm for chemical analysis and 0-10, 10-20, 20-30 and 30-40 cm for physical analysis, in 16 points for each of RA and NRA areas.

For chemical analysis, soil samples were collected with a Dutch auger, oven dried at 60ºC, rolled, milled and sieved in a 2 mm sieve. Afterwards, chemical attributes such as pH in water and SMP with a potentiometer [15], pH in KCl according to Embrapa [16], extractable P (phosphorous) and exchangeable K (potassium) and Na (sodium) through Mehlich-1 method and exchangeable Ca (calcium), Mg (magnesium) and Al (aluminium) extracted with a KCl 1 mol L^{-1} solution [15] were determined.

Physical attributes were evaluated in two stages. In the first one, for granulometry analysis, samples with altered structure that were sampled with the Dutch auger were used, and the pipette method was used for determination [17]. Analysis of particle density was also performed on those samples [18]. The high correlation values between clay and sand can result in a bad conditioned data matrix. For this reason, the sand content was excluded from the analysis to avoid problems in subsequent operations that are necessary for multivariate analysis.

In the second stage, the other attributes were analysed in samples with preserved structure, for which extraction and confinement were performed using metallic rings with cutting edges with volume corresponding to 70 cm^3. These samples were weighted with field humidity and then saturated and submitted to tensions of 1, 6 and 10 ka in a sand tension table and of 33, 100, 300, 500 and 1.500 kPa in a Richards chamber. Such procedure allowed determination of total porosity (TP) through difference between humidity of the saturated soil and the dry soil [16]. With the same procedure, it was possible to obtain soil density (SD) by drying samples at 105ºC and analysing them through the volumetric ring method [19].

In order to evaluate the association level between variables and the two studied environments, data obtained from chemical and physical analysis of the soil were submitted to canonical discriminant analysis (CDA) considering minimal significance level of 5%. (P = 0.05). For this procedure, SAS (SAS Institute, Cary, NC, EUA) and R [20] programmes were used.

3. RESULTS AND DISCUSSION

Results from floristic survey in AR showed the occurrence of 11 species of tree and shrub plants belonging to eight botanical genera and six botanical families. The family with higher species richness was Asteraceae with six species. The other families had one species each. The floristic profile of this area is typical of araucaria forests at initial regeneration stage [21]. This pattern was also observed for the same given phytophysiognomy [22]. Table 1 lists tree and shrub species and their respective botanical families for vegetation in AR.

Table 1. List of arboreal and shrub species and related botanical families of the regenerated PPA (RA).

Specie	Family
Baccharis uncinella DC.	Asteraceae
Baccharis trimera (Less) DC.	Asteraceae
Baccharis dracunculifolia DC.	Asteraceae
Baccharis semiserrata DC.	Asteraceae

Dicksonia sellowiana Hook.	Dicksoniaceae
Mimosa scabrella Bentham	Mimosaceae
Myrsine coriaceae (Sw.) R. Br.	Primulaceae
Piptocarpha angustifolia Dusén ex. Malme	Asteraceae
Sapium glandulosum (L.) Morong	Euphorbiaceae
Solanum variabille Mart.	Solanaceae
Vernonanthura discolor (Spreng.) H. Rob.	Asteraceae

As this area is in a process of natural regeneration, expressive quantities of pioneer species such as *Baccharis uncinella, Mimosa scabrella*, *Solanum variabile* and *Myrsine coriacea* were found in all transects. These species are found under full sun and produce seeds early, which present dormancy and thus need high temperatures and/or direct light to germinate. They are also characterized by their good adaptation to soil that lost their original properties [23], generating a permanent bank on the soil that, under light incidence, grow and recover the area efficiently.

Characterization of bank seed in NRA revealed occurrence of four botanical families. The family with higher richness was Cyperaceae with 43 individuals, followed by Asteraceae with 11 individuals, Melastomataceae with 4 individuals and Poaceae with 2 individuals. Seven species could not be identified. Some researches [24] registered Poaceae, Cyperaceae and Asteraceae families as the ones with the greatest species richness at Planalto Serrano wetlands; others also related abundance of these three families and also of Melastomaceae family in these areas [25].

The greatest number of individuals from Cyperaceae family in the NRA results from the high level of the water table, which provides a hydromorphic environment that enhances the development of these plants. At the lower sites of this area, several specimens of the genus *Sphagnum*, which are highly hydrophilic, were also found [26].

Tables 2 and 3 show the mean values of chemical and physical attributes, respectively, obtained at the sampled points in each analysed depth and in both RA and NRA. In order to evaluate the association level between chemical and physical variables and areas (RA and NRA), data was submitted to canonical discriminant analysis (CDA).

The number of canonical discriminant functions (CDF) in this analysis is determined by the lowest value, according to the number of analysed groups (in the present study, environments formed by combination between analysed areas and sampling depths) minus one, and the number of studied variables [27]. In this way, three CDFs were obtained or each group of variables (chemical and physical) of the soil.

Table 2. Chemical properties of soil at different depths of regenerated PPA (RA) and non-regenerated PPA (NRA)

Depth	Variables	Unit	RA		NRA	
			Average	Standard deviation	Average	Standard deviation
0-0.20 m	pH in water		4.6481	0.2189	4.2486	0.2269
	pH in KCl		3.8531	0.0865	3.8581	0.1912
	pH in SMP		4.8300	0.2568	5.3131	0.3067
	Ca	$cmol_c\ kg^{-1}$	1.0539	0.3176	2.5282	0.4840
	Mg	$cmol_c\ kg^{-1}$	1.3474	0.2849	2.1680	0.1676
	Al	$cmol_c\ kg^{-1}$	13.3000	2.6250	4.2469	3.2474
	K	$cmol_c\ kg^{-1}$	0.1259	0.0826	0.0359	0.0232

	Na	$cmol_c\ kg^{-1}$	0.0156	0.0148	0.0200	0.0087
	P	$mg\ kg^{-1}$	7.8625	4.3246	12.4346	8.1160
0.20-0.40 m	pH in water		4.6938	0.2270	4.3269	0.2517
	pH in KCl		3.8900	0.0912	4.0540	0.1548
	pH in SMP		4.9256	0.2708	5.5100	0.2751
	Ca	$cmol_c\ kg^{-1}$	0.9282	0.3641	2.5920	0.5903
	Mg	$cmol_c\ kg^{-1}$	1.9104	0.6582	1.8354	0.4189
	Al	$cmol_c\ kg^{-1}$	13.0306	2.4001	4.9686	4.1246
	K	$cmol_c\ kg^{-1}$	0.0654	0.0427	0.0312	0.0131
	Na	$cmol_c\ kg^{-1}$	0.0116	0.0068	0.0224	0.0155
	P	$mg\ kg^{-1}$	4.4244	3.1982	4.3414	4.3336

Ca: Calcium. Mg: Magnesium. Al: Aluminum. K: Potassium. Na: Sodium. P: Phosphorus.

Only the two first significative CDFs ($p<0.01$) were used, as they represent 85.15% and 9.44% of the total discrimination potential for the chemical variables and 82.99% and 12.73% for the physical variables for CDF_1 (discrimination between areas) and CDF_2 (discrimination between depths), respectively (Tables 4 and 5). CDF_1 showed a canonical correlation coefficient of 0.93 for chemical analysis and 0.71 for physical analysis, which indicates a high association level between variables and the studied areas.

Table 3. Physical properties of soil at different depths of regenerated PPA (RA) and non-regenerated PPA (NRA)

Depth	Variables	Unit	RA		NRA	
			Average	Standard deviation	Average	Standard deviation
0-0.10 m	Clay	%	27.9196	10.2291	10.8985	0.8515
	Sand	%	56.9212	14.2174	84.7866	1.0420
	Silte	%	15.1592	5.5492	4.3149	1.7324
	SD	$g\ cm^{-3}$	0.9903	0.1025	1.2567	0.1701
	PD	$g\ cm^{-3}$	2.3703	0.1058	2.4442	0.1570
	TP	m^3m^{-3}	0.5817	0.0442	0.4856	0.0654
0.10-0.20 m	Clay	%	29.0906	10.9793	11.7481	0.1034
	Sand	%	54.8304	15.9624	83.0204	1.3577
	Silte	%	16.0790	6.3673	5.2315	1.2543
	SD	$g\ cm^{-3}$	1.2005	0.1588	1.3075	0.1565
	PD	$g\ cm^{-3}$	2.3994	0.0739	2.4822	0.0831
	TP	m^3m^{-3}	0.5002	0.0603	0.4742	0.0532
0.20-0.30 m	Clay	%	29.1030	11.5055	11.1830	0.6952
	Sand	%	54.8514	15.3777	85.2626	0.8817
	Silte	%	16.0457	6.0896	3.5544	0.1935
	SD	$g\ cm^{-3}$	1.2156	0.2038	1.3438	0.1825
	PD	$g\ cm^{-3}$	2.4031	0.0452	2.5014	0.0722
	TP	m^3m^{-3}	0.4944	0.0830	0.4637	0.0649
0.30-0.40 m	Clay	%	29.7901	12.7460	9.4651	1.2882
	Sand	%	54.8921	14.8941	86.2711	1.3970

Silte	%	15.3178	4.1495	4.2637	1.5375
SD	g cm^{-3}	1.3061	0.1166	1.3499	0.1647
PD	g cm^{-3}	2.4232	0.0768	2.4778	0.1224
TP	m^3 m^{-3}	0.4604	0.0515	0.4559	0.0559

SD: Soil density. PD: Particle Density. TP: Total Porosity.

Table 4. Linear correlation coefficients (*r*), standardized canonical coefficients (SCC) and parallel discrimination rate (PDR) in the first two canonical axes, for the chemical properties of soil at different depths in the regenerated PPA (RA) and non-regenerated PPA (NRA).

Variables	Canonical Discriminating Function 1			Canonical Discriminating Function 2		
	r	**SCC**	**PDR**	***r***	**SCC**	**PDR**
pH in water	-0.6808	-0.3790	0.2580	0.1395	0.1039	0.0145
pH in KCl	0.2371	-0.0479	-0.0114	0.6280	0.6436	0.4042
pH in SMP	0.7120	0.1333	0.0950	0.3058	0.1202	0.0368
Ca	0.9214	1.3322	1.2275	0.1399	1.0976	0.1536
Mg	0.4253	0.3737	0.1590	-0.3470	-0.4409	0.1530
Al	-0.8819	-0.9637	0.8499	0.0125	0.8568	0.0107
K	-0.5775	-0.5417	0.3128	-0.0480	0.2535	-0.0122
Na	0.3960	0.1233	0.0488	0.1336	0.0976	0.0130
P	0.1492	0.0674	0.0100	-0.6668	-0.8567	0.5713
Eigenvalues		8.16			0.90	
% Acum Var		85.15%			94.58%	

Table 5. Linear correlation coefficients (*r*). standardized canonical coefficients (SCC) and parallel discrimination rate (PDR) in the first two canonical axes, for the physical properties of soil at different depths, in the regenerated PPA (RA) and non-regenerated PPA (NRA).

Variables	Canonical Discriminating Function 1			Canonical Discriminating Function 2		
	r	**SCC**	**PDR**	***r***	**SCC**	**PDR**
Clay	0.8947	0.3384	0.3028	-0.0202	0.1445	-0.0029
Silte	0.9710	0.7595	0.7375	-0.0675	0.0909	-0.0061
SD	-0.3983	-4.2710	1.7012	0.8858	-7.0057	-6.2053
PD	-0.4370	1.0805	-0.4722	0.3028	2.2830	0.6914
TP	0.3021	-4.0539	-1.2245	-0.9072	-7.4419	6.7516
Eigenvalues		2.48			0.38	
% Acum Var		82.99			12.73	

Standard canonical coefficient (SCC) indicates the relative influence of each variable for separation of the environments in the presence of other variables, thus representing a measure of multivariate behaviour. The *r* value expresses the influence of each variable independent of the others, that is, it reveals a view of the univariate behaviour [28]. The parallel discrimination rate (PDR) is the result of the product between the SCC value and the *r* value. Higher and positive values of PDR indicate more weight on environment separation, while negative values indicate the presence of supressing variables that mask their effect.

In the evaluation of the soils in the present study, there was a significant difference ($p<0.001$) of the mean vectors of chemical and physical attributes between groups (combination of areas *vs.* depth), tested by Wilks' lambda and Pillai's trace statistics. Such behaviour can be seen in figures 1 (chemical attributes) and 2 (physical attributes). It was possible to verify the separation between areas and sampling depths for both attributes. However, the discrimination is more evident between the areas.

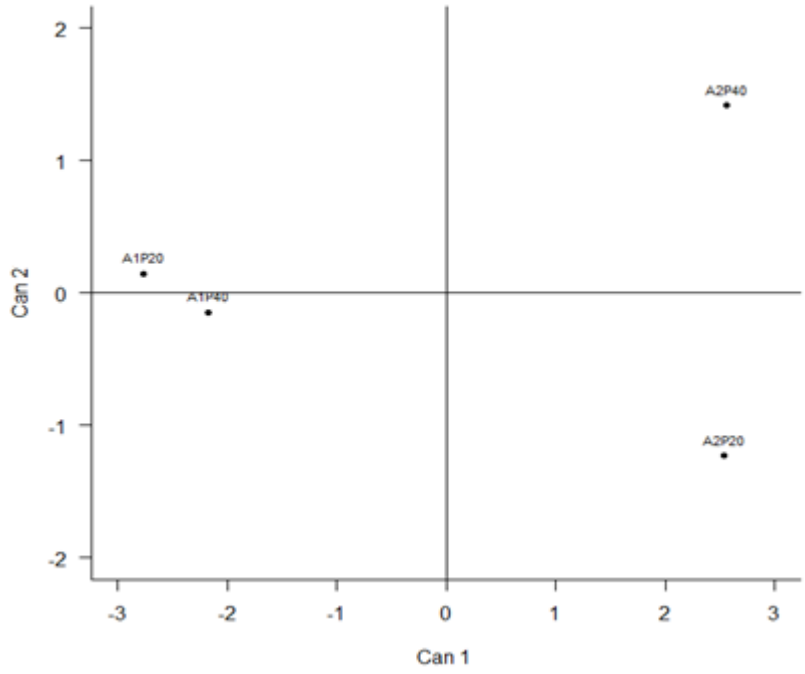

Figure 1. Average values of the canonical discriminant function 1 (Can 1) and canonical discriminant function 2 (Can 2) in relation to chemical properties of soil at the depths of 0-20 cm (P20) and 20-40 cm (P40) in the RA (A1) and NRA (A2).

The chemical attributes with more weight on CDF_1 were Ca (*PDR=1.2275*) and Al (*PDR=0.8499*) contents. For CDF_2. the greatest weights were observed for P (*TDP=0.5713*) and pH in KCl (*TDP=0.4042*) attributes (Table 4).

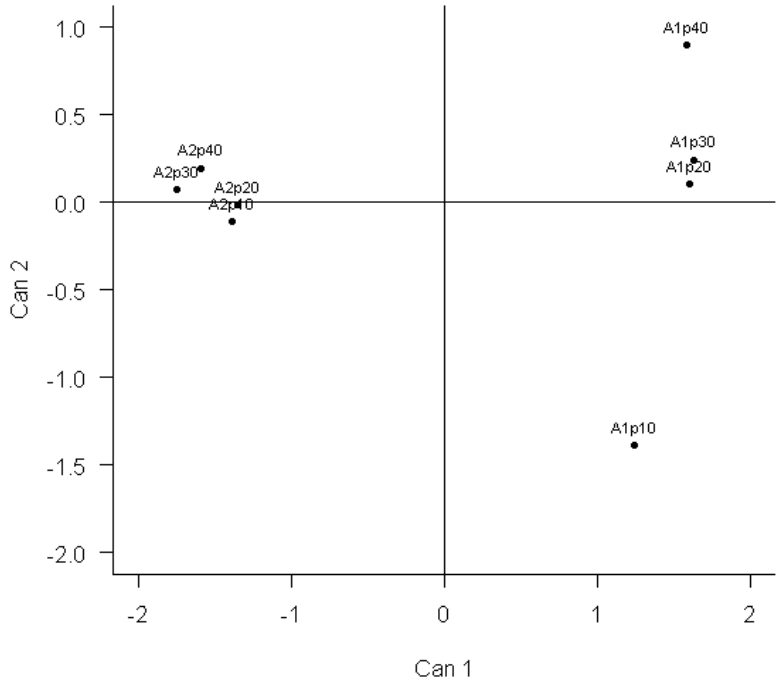

Figure 2. Average values of the canonical discriminant function 1 (Can 1) and canonical discriminant function 2 (Can 2) in relation to physical properties of soil at the depths of 0-0.10 m (p10), 0.10-0.20 m (p20), 0.20-0.30 m (p30) and 0.30-0.40 m (p40) in the RA (A1) and NRA (A2).

Discrimination of areas related to Ca and its high contents in NRA (Table 2) for both depths can be explained based on distinct processes. In this area, soil saturation with water is recurrent and can remain for prolonged periods of time. It favours the reduction of compounds that have oxygen in their molecule by anaerobic or facultative anaerobic organisms. Such reduction causes release of hydroxyls and consequent increase in pH in a phenomenon called auto-liming [29]. As a result of the dissolution of Fe oxides and Fe^{+2} ions competition for exchange sites, Ca^{+2} is released to the soil solution.

Increase in pH caused by soil saturation by water can also increase the thickness of the double electric layer on the external surfaces of the solid components of the soil. In this way, there is greater diffusion of the basic cations towards the soil solution including Ca [30].

As Ca, exchangeable Al also explains great part of the variation between areas due to chemical processes in the soil. Lower values found in ANR (Table 2) are due to lower clay and organic material content. which contributes to lower soil ability to exchange cations (AEC) and thus to the capacity of fixing exchangeable Al under the RA soil [30]. This can also be explained by the increase in pH due to the auto-liming caused by periodic saturation of the soil with water. which can increase Al precipitated with hydroxyls ($Al(OH)_3$) and diminish exchangeable Al.

Regarding the association between soil depths and evaluated variables, P presents relative importance. For both areas, soil litter deposition during *Pinus* cultivation period and low mobility of P in the soil contributed to its accumulation in its organic form on the superficial layer. NRA presented higher levels of P than RA in this layer (Table 2), as saturation by water occur in this area, which allows dissociation of Fe oxides through

reductive organisms and thus releasing P from these minerals [29], pH in KCl also contributes to variation between soil depths specially in NRA, setting a pH-dependent charge gradient between the analysed depths (Table 2).

Soil litter supply, its decomposition and incorporation to nutrients are part of a dynamic process that gives a distinct character for the soils under vegetal cover: nutrients are rapidly released and can be transported to lower layers where roots can recover them [31]. Therefore, native plant species in forests usually do not have limitations about nutritional deficiencies as cycling in the soil-plant system tend to ease the effects of low nutrients concentration in the soil. Thus, it is not surprising that the low content of Ca, K and P and the high content of exchangeable Al (Table 2) (element whose toxic effect can cause reduction of root growth) were not limiting for the development of tree and shrub species in RA.

Higher values of Ca content and lower values of exchangeable Al at depths of 0-20 and 20-40 cm, as well as higher Mg, K and P contents at depth of 0-20 cm in NRA (Table 2) are an indicative that the effectiveness of the regeneration of the native vegetation can be related to other variables other than soil chemistry.

The physical attributes with higher weight on CDF_1 were SD (*TDP=1.7012*), silt content (*TDP=0.7375*), while for CDF_2 the highest weights were observed for TP (*TDP=6.7516*) and PD (*TDP=0.6914*) (Table 5).

The high contents of silt and clay on the typical distrophic Latosol in RA (Table 3) indicates its characterization as sandy-clay loam texture, while the hydromorphic quartzarenic Neosol typical of NRA fits in sandy loam texture, as the silt and clay fractions are less representative comparing to the previous soil. Both attributes showed relative importance in discrimination of areas since they affect, both directly and indirectly, the soil texture, density and porosity. The texture classification fits all evaluated depths since silt and clay contents did not reveal significative variation between depths in each area.

A gradual reduction of TP according to depth was observed in both areas due to the action of compacting forces in the soil. However, the main discriminant between areas was SD, with higher values in the NRA (Table 3), according to the literature [32], sandy soils of forests present maximum density of 1.25 mg m^{-3}, which is lower than the values in all depths in NRA.

Although both areas have sandy soil, reduction in TP according to soil depth occurred more intensively in NRA once the effect of compaction is potentialized under high water content [33] and low soil depth conditions. [34] also observed reduction of total porosity in depth after eucalyptus harvest, suggesting that machine traffic in reforestation areas causes decrease in pore volume due to soil compaction. This effect is evidenced when the entrance of these machines in the area do not respect the soil humidity conditions, as some similar results have shown for the Red Yellow Latosol after the eucalyptus harvest [35].

High values of soil density and reduction of total porosity influenced the water retention capacity and thus hindered the establishment of the vegetation, even though the soil presents good chemical conditions such as observed in NRA (Tables 2 and 3).

Soil density can be altered by its use and management as long as the arrangement of soil particles is altered and, therefore, monitoring values over time can provide important information about the influence of soil use and management on exploitation sustainability to which the soil is submitted [36].

DS value reflects characteristics of the soil porous system. As roots develop on those pores, any significative alteration on this system can result in interference on root development and on water availability for the plants [37]. With higher retention of water, water percolation in the soil profile is reduces drastically [38]. The presence of a water table next to the surface and the high soil density hinders soil drainage in the NRA, providing high humidity conditions.

Therefore, even though NRA offers better conditions of soil fertility than AR, the natural situation of hydromorphism associated with high DS impair soil aeration, reducing seed germination rates and root growth of forest species [39]. A presumable low quantity of propagules, indicated by the seed bank survey, also contributes to the inefficiency of the spontaneous regeneration of these species in the area.

On the other hand, species that have root system that develop on the superficial layers of the soil and that are adapted to conditions of low oxygen concentration and DS gain importance in floristics from periodically flooded environments. Herb species include Cyperaceae, Asteraceae, Melastomataceae and Poaceae families, which are predominant in the NAR.

Lower SD values, allied to better drainage and low level of the water table help to avoid restrictions of the root development in woody species in the NRA soil. In this way, tree and shrub species at the Mixed Ombrophilous Forest are predominant in the area.

4. CONCLUSION

The attributes that better describe soils in the RA and NRA are Ca content and total porosity. High soil density values. bad drainage and lack of propagules from tree and shrub species favoured the establishment of herbaceous vegetation in the NRA.

Low soil density values and good drainage conditions of the soil were sufficient for establishment of tree and shrub species at the Mixed Ombrophilous Forest in the RA.

REFERENCES

[1] Organization of American States - OAS. Aquifer Guarani: strategic program of action. Guaraní aquifer: strategic program of action. Bilingual edition. Brazil. Argentina. Paraguay. Uruguay: OAS; 2009.

[2] Facetti JF. The Guarani aquifer: a regional environmental service. In: Galindo-Leal C. Câmara IG. editors. Atlantic Forest: biodiversity. threats and prospects. Belo Horizonte: Conservation International; 2005.

[3] Simioni FJ. Hoff DN. The Forestry Sector in the Serra Catarinense. Lages: Uniplac; 2007.

[4] Reis A. Three DR. Scariot EC. Restoration in the Mixed Ombrophilous Forest through natural succession. Brazilian Forest Research. 2007; 55: 67-73. Available in: https://pfb.cnpf.embrapa.br/pfb/index.php/pfb/article/view/120/79

[5] Hamada E. Lopes-Assad ML. Pereira DA. Agricultural aptitude in the area of recharge of the Guarani aquifer: case of the hydrographic microbasin of the Espraiado stream. Ribeirão Preto. SP. Environmental Engineering Journal. 2006; 3 (1): 62-71. Available in: https://ainfo.cnptia.embrapa.br/digital/bitstream/item/127924/1/2006AP-046.pdf

[6] Jordan WR. Peters RL. Allen EB. Ecological restoration as a strategy for conserving biological diversity. Environmental Management. 1988; 12 (1): 55-72. Available in: https://link.springer.com/content/pdf/10.1007%2FBF01867377.pdf

[7] Pandolfo C. Braga HJ. Silva Jr. VP. Massignan AM. Investments Thomé VMR et al. Climatological Atlas of the State of Santa Catarina [CD-ROM]; 2002; Florianópolis. Florianopolis: Epagri.

[8] Brazilian Institute of Geography and Statistics - IBGE. Technical Manual of the Brazilian vegetation. 2 ed. Magazine and expanded. Rio de Janeiro: IBGE; 2012. Available in: https://biblioteca.ibge.gov.br/visualizacao/livros/liv63011.pdf

[9] Brazilian Agricultural Research Corporation - Embrapa. Brazilian system of soil classification. 3 ed. Magazine and expanded. Brasília: Embrapa; 2013.

[10] Cottam G. Curtis JT. The use of distance measures in phytosociological sampling. Ecology. 1956; 37 (3): 451-460. Available in: https://doi.org/10.2307/1930167

[11] Angiosperm Phylogeny Group. An update of the Angiosperm Phylogeny Group classification for the orders and families of flowering plants: APG III. Botanical Journal of the Linnean Society. 2009; 161: 105-121.

[12] Colwell RK. Mao CX. Chang J. Interpolating, extrapolating and comparing incidence-based species accumulation curves. Ecology. 2004; 85: 2717-2727. Available in: https://doi.org/10.1890/03-0557

[13] Colwell RK. EstimateS: Statistical estimation of species richness and shared species from samples. Version 8.0. [cited 2011 Apr. 18]. Available in: http://purl.oclc.org/estimates

[14] Quenouille MH. Problems in plane sampling. *Annals of Mathematical Statistics*. 1949; 20: 355-375. Available in: doi:10.1214/aoms/1177729989

[15] Tedesco MJ. Gianello C. Bissani CA. Soil analysis. plants and other materials. Technical Bulletin nº5. Porto Alegre: Federal University of Rio Grande do Sul; 1995.

[16] Brazilian Agricultural Research Corporation - Embrapa. Manual of methods of soil analysis. 2.ed. Rio de Janeiro: National Soil Research Center; 1997. Available in: https://www.agencia.cnptia.embrapa.br/Repositorio/Manual+de+Metodos_000fzvhotqk02wx5ok0q43a0ram31wtr.pdf

[17] Gee GW. Bauder JW. Particle-size analysis. In: Klute A. editor. Methods of soil analysis. Part 1 - Physical and Mineralogical Methods. 2nd ed. Madison: American Society of Agronomy; 1986.

[18] Gubiani PI. Reinert DJ. Reichert JM. Alternative method for the determination of soil particle density - accuracy, precision and processing time. Rural Science. Santa Maria. 2006; 36 (2): 664-668. Available in: http://dx.doi.org/10.1590/S0103-84782006000200049

[19] Blake GR. Hartge KH. Bulk density. In: Klute A. editor. Methods of soil analysis: physical and mineralogical methods. 2 ed. Madison: American Society of Agronomy; 1986.

[20] R Core Team (2013). A: A language and environment for statistical computing. R Foundation for Statistical Computing. Vienna. Austria. ISBN 3-900051-07-0. URL http://www.R-project.org/.

[21] Salami G. Campos.ML. Gomes JP. Batista F. Mantovani A. Pitz MM et al. Evaluation of the floristic and structural aspects of a fragment of Mixed Ombrophylous Forest influenced by successive rotations of exotic forest species. Journal of Agroveterinary Sciences. 2015;

14 (1): 7-14. Available in: http://revistas.udesc.br/index.php/agroveterinaria/article/viewFile/5774/4229

[22] Batista F. Floristic diagnosis and mapping of critical sites in permanent preservation areas according to the diversity index of Shannon [Dissertation]. Lages. SC: State University of Santa Catarina; 2012. Available in: http://www.cav.udesc.br/arquivos/id_submenu/724/dissertacaofelipebatista.pdf

[23] Kulchetscki L. Carvalho PE. Kulchetscki SS. Ribas LLF. Gardingo JR. Urban arborization with native essences: a proposal for the Brazilian Center-South region. Publicatio UEPG - Exact and Earth Sciences. Agrarian and Engineering. 2006; 12 (3): 25-32. Available in: http://dx.doi.org/10.5212/publicatio.v12i03.871

[24] Silva KM. Bortoluzzi RLC. Gomes JP. Mantovani A. Bioactive species in wetlands of the Santa Catarina Plateau. Brazilian Journal of Medicinal Plants. 2013; 15 (4): 483-493. Available in: http://dx.doi.org/10.1590/S1516-05722013000400003.

[25] Zanin A. Longhi-Wagner HM. Souza MLR. Rieper M. Phytophysiognomy of the camp formations of the Campo dos Padres. Santa Catarina. Brazil. Insula. 2009; 38: 42-57. Available in: https://periodicos.ufsc.br/index.php/insula/article/viewFile/2178-4574.2009v38p42/17367

[26] Tomotsugu Y. Shin-Ichi U. Kazuo Y. Water balance and water movement in unsaturated zones of *Sphagnum* hummocks in Fuhrengawa Mire. Hokkaido. Japan. *Journal of Hydrolog*y. 2006; 319(1-4): 312-327. Available in: https://doi.org/10.1016/j.jhydrol.2005.06.037

[27] Johnson RA. Wichern DW. *Applied multivariate statistical analysis*. 6th ed. New Jersey: Prentice Hall; 2007.

[28] Hair Jr. JF. Anderson RE. Tatham RL. Black WC. Multivariate Data Analysis. 6 ed. São Paulo: Bookman; 2009.

[29] Scivittaro WB. Machado MO. Fertilization and liming for irrigated rice cultivation. In: Gomes AS. Magalhães Jr AM. editors. Irrigated rice in southern Brazil. Brasília: Embrapa Technology Information; 2004.

[30] Ernani PR. Soil chemistry and nutrient availability. Lages: The author; 2008.

[31] Townsend CR. Begon M. Harper JP. Fundamentals in Ecology. 2nd ed. Porto Alegre: Artmed; 2006.

[32] Torres E. Saraiva OF. Soils of mechanical soil impedance in agricultural systems with soybean. Technical Circular No. 23. Londrina: Embrapa Soja; 1999. Available in: https://www.infoteca.cnptia.embrapa.br/bitstream/doc/461800/1/circTec23.pdf

[33] Szymczak DA; Brun EJ. Reinert DJ. Frigotto T. Mazzalira CC. Lucio AD. Marafiga J. Soil compaction caused by forest tractors in the Pinus taeda l. In the southwestern region of Paraná. Tree magazine. 2014; 38: 641-648. Available in: http://www.scielo.br/pdf/rarv/v38n4/07.pdf

[34] Pelissari AL. RSS Feed Jordani SA. Guimarães PP. Physical-water attributes and carbon stock in Quartzarenic soil under Eucalyptus urograndis planting. Native. 2013; 01 (1): 24-28. Available in: http://dx.doi.org/10.14583/2318-7670.v01n01a05

[35] Silva SR. Barros. NF. Costa LM. Milk FP. Soil compaction and eucalyptus growth in response to forwarder traffic intensity and load. Brazilian Journal of Soil Science. 2008; 32 (3): 921-932. Available in: http://dx.doi.org/10.1590/S0100-06832008000300002

[36] Stumpf L. Physical and mechanical attributes of a soil built in a coal mining area in Candiota-RS. cultivated with different plant species [Dissertation]. Pelotas. RS: Federal University of Pelotas; 2011. Available in: http://repositorio.ufpel.edu.br/handle/ri/2432

[37] Santos LNS. Steps RR. Cardoso LCM. Santos L. Garcia GO. Cecílio RA. Evaluation of physical attributes of an Oxisol under different vegetation cover in Alegre (ES). Environmental engineering. 2009; 6 (2): 140-149. Available in: http://ferramentas.unipinhal.edu.br/engenhariaambiental/include/getdoc.php?id=616&article=226&mode=pdf.

[38] Kiehl EJ. Manual of soil science. São Paulo: Agronomic Ceres; 1979.

[39] Floriano EP. Germination and Nullity of Forest Seeds. Didactic book nº2. Santa Rosa: ANORGS; 2004.