doi: https://doi.org/10.36812/pag.2021271160-174

ORIGINAL ARTICLE

Land use and soil quality in peri-urban farms in Southern Brazil

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Abstract – Small family farms constitute a major part of land use in the surrounding regions of Brazilian cities, as these farms not only contribute to the food supply, but also help conserve rural landscapes and improve environmental services. This study evaluated agricultural impacts on soil quality in seven family farms in Porto Alegre municipality, Rio Grande do Sul state, RS. Selected production units (PUs) were managed as conventional or organic farms, producing horticultural crops, fruits and pastures, besides native forests. Soil samples were collected from representative areas for five use and management types, under disturbed and undisturbed conditions, at 0–20 cm depth. Physical and chemical attributes were analyzed, comparing the effects of types of land use. Data analysis showed that more affected attributes were soil density, macro and microporosity, phosphorus content, pH and electrical conductivity. Macroporosity, phosphorus, zinc and cooper contents are the greater threats to soil quality. Horticulture, under both agroecological and conventional production systems caused major changes compared to natural conditions.

Keywords: Family farms. Peri-urban agriculture. Agroecology.

Uso da terra e qualidade do solo em propriedades periurbanas no Sul do Brasil

Resumo - Propriedades agrícolas familiares constituem uma parte importante do uso da terra na periferia das cidades do Brasil, não só por contribuírem para o fornecimento de alimentos, como também para ajudar a conservar paisagens rurais e serviços ambientais. Este estudo teve como objetivo avaliar os impactos agrícolas na qualidade do solo em sete propriedades sob forma de produção familiar em Porto Alegre, estado do Rio Grande do Sul. As unidades de produção (PUs) selecionadas eram trabalhadas sob produção convencional ou orgânica, com culturas hortícolas, frutas e pastagens, além de floresta nativa. Amostras de solo foram coletadas em áreas representativas de cinco formas de uso e manejo do solo, em condições deformada e indeformada, na profundidade 0 a 20 cm. Atributos físicos e químicos de solo foram analisados, comparando os efeitos dos tipos de uso da terra. A análise dos dados mostrou que atributos mais afetados pela mudança no uso da terra foram densidade, microporosidade, macroporosidade, conteúdo de fósforo, pH e condutividade elétrica. Macroporosidade, teores de fósforo, zinco e cobre parecem ser as maiores ameaças à qualidade do solo. A horticultura, tanto no sistema convencional como no orgânico, causou as maiores alterações em relação à condição original.

Palavras-chave: Agricultura familiar. Agricultura peri-urbana. Agroecologia.

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ISSN: 0104-907. ISSN ONLINE: 2595-7686.
Recebido em 14 abr. 2021. Aceito em 27 ago 2021.

Introduction

Although increasing urbanization and the resulting threat of various more intensive land uses, agriculture, especially in the form of family farms, has been recognized as a relevant activity because of its economic, social, and environmental importance in Porto Alegre Metropolitan Region (PAMR). The agricultural census of 2017 identified approximately 390 farms, most of which with extension lower than 20 ha. Agriculture as practiced in these farms is diverse, notwithstanding the high proportion of horticulture and fruticulture production (IBGE, 2017), that can be related to socio-economic and environmental characteristics of the greater Porto Alegre region.

One of the major requirements for maintaining a viable farming culture centered in small family farms is the continual assessment of environmental quality, in which soil quality monitoring plays a key role. Soil quality has been defined as the capacity to sustain plant and animal productivity, to maintain or improve air and water quality, provide human health and habitat for plant, and wildlife, without exceeding the limits of physical, chemical, and biological properties of the soil (VEZZANI; MIELNICZUK, 2009). In this way, the study of changes and impacts promoted in natural resources, with emphasis on soil, is an important issue, to assess the effects of different types of land use.

Particle size and soil use and management influence physical attributes, such density and porous space (MAZURANA *et al.*, 2013). Total organic carbon (TOC), on the other hand, also has direct influence on properties such as aggregation and nutrient cycling, with impacts on soil-water relationship and protection against soil degradation processes, so it is considered an important indicator of soil quality (VEZZANI; MIELNICZUK, 2009; SEQUINATTO *et al.*, 2014). The fractionation of TOC allows to distinguish the particulate organic carbon fraction (POC), formed by organic material present in the sand particle size fraction. The levels of TOC and POC indicate the continuity of biomass addition to the ground, allowing the development of the microbiota and nutrient cycling (SEQUINATTO *et al.*, 2014).

Among other chemical attributes, cationic exchange capacity (CEC), base saturation (V), contents of available phosphorus and trace elements, pH and electrical conductivity values are indicators directly related to the soil-plant relationship and environmental quality. These attributes have shown great variations in different soil use and management history and may become evidence of loss of soil quality and environmental degradation. These processes, on the other hand, have their intensities influenced by soil original characteristics (TOMASI *et al.*, 2012).

In this context, we hypothesized that different types of soil use and management in family farm production units (PUs) result in changes in soil attributes that, in some cases, represent short- and medium-term degradation (decrease in soil quality). Thus, the objectives of this study were a) characterization of soil surface attributes in contrasting soil use and management in family farms of Porto Alegre municipality; b) comparative analysis of the soil quality attributes as a function of land use and management, to identify which attributes could be more affected; c) identification of soil degradation tendencies derived from land use and management as currently practiced in the study areas.

Material and methods

The study was conducted in seven PUs in Porto Alegre municipality, in the localities of Lami, Lomba do Pinheiro and Serraria (Figure 1). According to the Koppen classification system, the region's climate is humid subtropical type with hot summers - Cfa (UFSM, 2004), characterized by a mean annual precipitation between 1,400 and 1,500 mm and mean annual low and high temperatures of 15.2 ºC and 25°C, respectively (climatological normal 1981-2010), according to IRGA (2011).

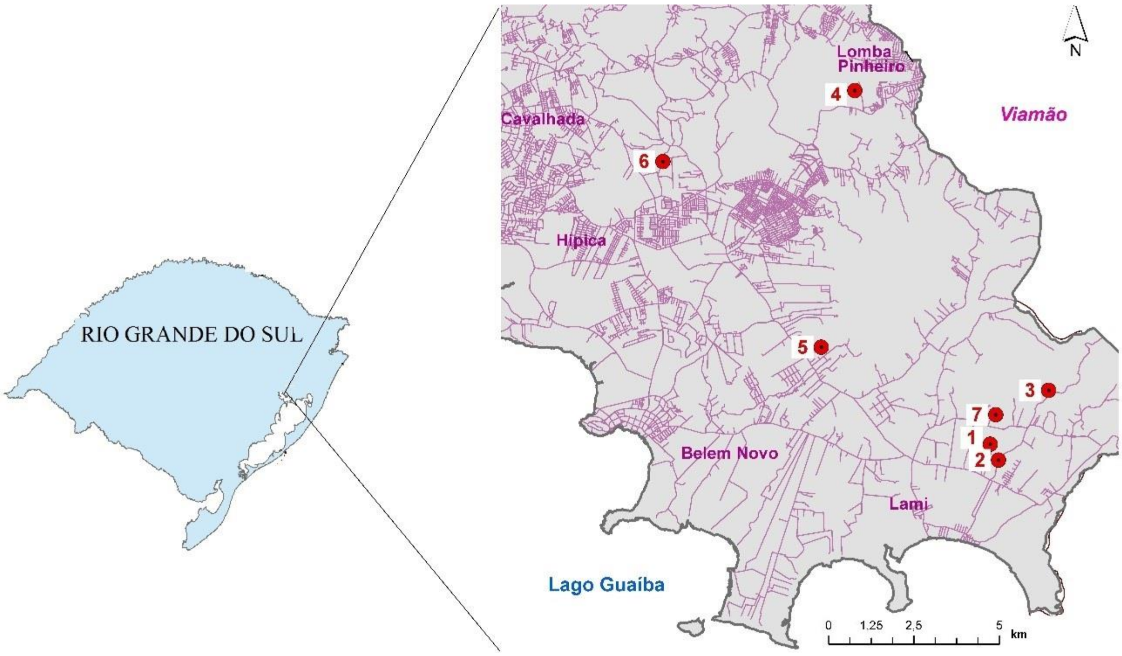

Figure 1. Localization of Porto Alegre municipality in Rio Grande do Sul State, Brazil, and production units (PUs) in the south of Porto Alegre.

Remaining natural vegetation includes fragments of seasonal semideciduous ombrophylous forests, and hygrophilous vegetation in lowlands (HASENACK *et al.*, 2008). Among several candidate farms for this project previously selected with help from local extension agents, seven were chosen based on their representativeness as family farms in the region. We evaluated the PU representativity of PAMR, based on cultivated crops, type and original soil attributes, the size of cultivated areas and main agricultural practices. Within farms, the sampled fields had between 0.2 and 2.5 ha. The soils were classified as Argissolos and Planossolos, according to "Sistema Brasileiro de Classificação de Solos" - SiBCS (SANTOS *et al.*, 2013), corresponding to Alfisols and Ultisols classes according to Soil Survey Staff (2014). Clay content of the soil surface layer (0 to 20 cm depth) ranged between 8 and 20%. Relief ranged from flat to sloping, with a slope between 1 and 10%.

ISSN: 0104-907. ISSN ONLINE: 2595-7686.
Recebido em 14 abr. 2021. Aceito em 27 ago 2021.

Selected farms had at least two activities concerning the plant or animal production, to provide diversity in production. The farmers and families were visited and answered a concise semi-structured interview to assess family origin, farm history and details about current production systems. Based on the criterion of greater importance to the producers, fields were selected (three to five) for soil sampling. A total of 27 fields were sampled, according to the following uses: natural forest - NF (six areas or plots), agroecological horticultural production - AH (six plots), conventional horticultural production - CH (five plots), conventional and organic fruit production - FT (six plots) and natural pastures - NP (five plots).

Agroecological horticulture (AH) production areas were cultivated at least during eight years, in a succession/rotation system using green manure with kidney beans, oat, common vetch, pigeon peas and horse radish. The areas are prepared with rotary hoe before establishing the plant beds, and this procedure is repeated every three to four crop cycles. The fields are fertilized with compost of poultry barn bedding (20 to 25 m^3 ha^{-1}) and pig slurry (16 to 20 m^3 ha^{-1}) per growth cycle. Two PUs used compounds made with local weeds and crop residues (15 to 20 m^3 ha^{-1}) or with horse manure. The main crops were garlic, lettuce, cabbage, strawberry, watermelon, pepper, eggplant, cassava and sweet potatoes.

Conventional horticultural (CH) production also used rotary hoe to prepare plant beds. Organic fertilization consists of poultry barn-bedding base in 25–30 m^3 ha^{-1}, horse manure 150–200 m^3 ha^{-1}, and fertilization with synthetic soluble fertilizers is made with 350 to 450 kg ha^{-1} of $(NH_4)_2SO_4$, $N_5P_{20}K_{20}$ or $N_{00}P_{12}K_{12}$, applied every two or three growth cycles. Liming was practiced periodically, every three years, both in conventional and agroecological systems with variable amounts (undetermined). The main crops are cassava, potato, onions, lettuce, green cabbage, eggplants, spices (parsley and basil, among others) and spinach.

Pasture areas (NP) ranged areas between 0.5 and 1.5 ha, some of which were under conventional cultivation (tobacco or vegetables) up to 4 years before this study. Soil is not tilled in most of these fields, and two plots receive between 1,000 to 2,000 L ha^{-1} yr^{-1} of liquid pig slurry. Stocking rate ranged from two to four animals in each field in continue grazing but allowing for the natural regeneration of the pasture.

Fruit production (FT) fields included a field cultivated with guava, two fields cultivated with peach, one cultivated with pecan nuts, and other with a mixed orchard with pomegranate, sugar-apple, acerola, among others. Weeds were controlled mechanically with tractor pulled mower. In this type of use, plots with organic and conventional production systems were grouped together. In the first, usual management is made with organic fertilization 2,000 to 4,000 L ha^{-1} liquid pig manure base, twice a year (after production and at the end of winter). Mineral fertilization, in areas under conventional cultivation, used 700 to 800 of $N_{12}P_{00}K_{12}$ g plant. Lime sulfur and Bordeaux mixtures were used in both systems for plant disease and insect control. The woodland plots (NF) were checked for conservation status and were sampled to establish a baseline for the soil quality attributes of interest, allowing a comparative analysis.

Soil samples were collected at 0 to 20 cm layer, considering that differences between attributes induced by agricultural practices and production system must occur mainly in this layer although some plants have

PESQ. AGROP. GAÚCHA, V.27, N.1, P. 160-174, 2021.
ISSN: 0104-907. ISSN ONLINE: 2595-7686.
Recebido em 14 abr. 2021. Aceito em 27 ago 2021.

deeper root systems. Composite samples (6 to 8 subsamples) were collected with soil sampler probe to obtain the disturbed material, in tilled plots under horticultural use, and in the projection of canopy trees under fruticulture. This sampling was made between September and December 2015. In the vegetable production field samples were collected in plant beds and in the fruit production areas, sampling was along the lines, in the projection of the canopy of trees, while in the pasture and native forest area samples were collected randomly. For the determination of physical properties (soil bulk density - SD, micro and macroporosity – MiP and MaP, and total porosity - TP), two undisturbed samples were collected in each area, through volumetric rings with 280 cm^3. Determinations were made by weighting samples respectively after saturation, equilibrium in 60 cm water column tension table, and oven dry at 110 °C after three days (DONAGEMA *et al.*, 2011).

Disturbed samples were dried and sieved in 2 mm mesh screening to obtain thin air-dried fine earth (ADFE). On ADFE, the determination of the particle size was made by densimeter method, according to Donagema *et al.* (2011). Soil pH was determined in water in a 1:1 rate. According to Tedesco *et al.* (1995), exchangeable Al, Ca, Mg and Mn were extracted with 1mol L^{-1} KCl solution and contents determined by atomic absorption spectrophotometer (AAS); the contents of P, K, Na, Cu, Zn, and were determined by a weak acid extraction, with determination by AAS for Cu and Zn, colorimetry for Land flame photometer for K and Na. Potential acidity was determined by SMP method and electrical conductivity was determined in saturated extract by use of digital conductivimeter. Total organic carbon was determined in automatic Analyzer CHSN, after grinding the AFDE in soil mortar. For particulate organic carbon, the same procedures were made, using the sand fraction instead of the ADFE. All samples were analyzed in duplicate, and these data permitted to calculate base saturation (V) and cation exchange capacity (CEC), according to Donagema *et al.* (2011).

Analysis of variance (ANOVA) was conducted with 10% of statistical significance level to compare effects of different land use types (treatments) for each soil attribute. Because of the lack of homogeneity of variances, some data were transformed with the square root or logarithm, or, whenever a lack of normality remained, non-parametric methods (Kruskall-Wallis, followed by Mann Whitney test in case of difference between treatments) were used. Additionally, the dataset was analyzed with multivariate analysis (discriminant analysis) to determine the classification of each field according to the types of land use defined as done by Lima *et al.* (2007) and Cunha (2014). All analysis were conducted with Statistical Package for Social Sciences (SPSS)® software.

Results and Discussion

Soil bulk density (SD) showed significant differences among different types of land use. The smallest value was observed in AH, with 1.33 g cm^{-3}, without significant differences in relation to CH, NF and FT. The largest average value under NP, with 1.57 g cm^{-3} (Figure 2). These results show the trend of smaller SD values, in surface layers of areas under more intensive tillage and turnover, like AH and CH (MONTEIRO *et al.*, 2019). However, greater SD is observed in areas under pasture. All values were beneath the range defined by the value of 1.7 to 1.8 g cm^{-3}, critical to root development in sandy or loamy soils (SILVA *et al*., 2015).

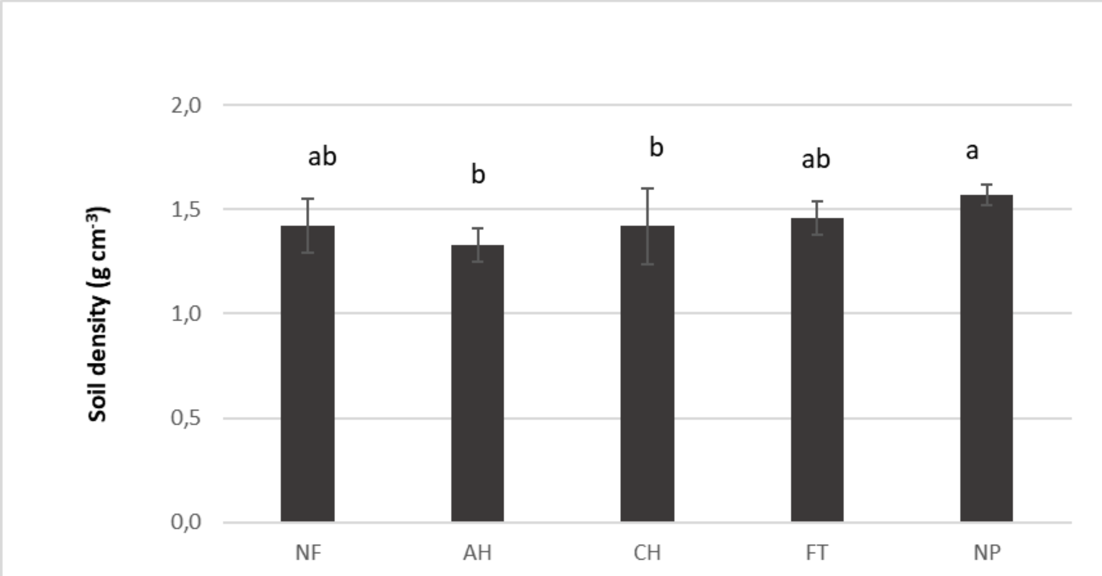

Figure 2. Soil density values among land uses in PUs from Port Alegre municipality, Rio Grande do Sul State, Brazil. Bars indicate means values, and vertical lines indicate largeness of ± one standard deviation. Letters represent significant differences from Tukey (p<0,1). NF: native forest; AH: agroecological horticulture; CH: conventional horticulture; FT: fruit production; NP: natural pasture.

These values directly reflected in total porosity (TP), since there were the same significant differences between AH and NP (Table 1). The smallest mean value of TP found in pasture areas was associated with soil compaction, caused by animal pressure in intensive grazing, in relation to other systems of use and management.

Microporosity (Mip), on the other hand, was higher in NP, indicating the effect of decrease in total porous space through animal load pressure, while in CH values remained lower, probably due the low contents of aggregation agents like organic matter (Table 1). Concerning macroporosity (Map), all land uses had values above 0.10 m^3 m^{-3}, revealing a condition of good quality related to soil aeration, except for pastures, when these values may constitute an alteration with reflections in soil physical quality (ARAÚJO *et al.*, 2012).

The values of TOC and POC had similar behaviors. Results showed a tendency of higher contents in NF, indicating that, even in less intensive use and management, decreased in TOC content occurs in relation to this type of soil cover (ROSSETTI; CENTURION, 2015). Use of green manure and crop rotation, as well the maintenance of crop residues in surface soil, probably contributed to high values in AH. Although differences among land uses, the variability within each land use led to the absence of significance. The more recent changes in land use in some areas under study (four years) indicate the need for stabilization of a use for consolidation changes. It may be emphasized in the lower carbon content, both particulate and total fractions, in relation to

PESQ. AGROP. GAÚCHA, V.27, N.1, P. 160-174, 2021.
ISSN: 0104-907. ISSN ONLINE: 2595-7686.
Recebido em 14 abr. 2021. Aceito em 27 ago 2021.

clayey soils, reflecting more interactions between organic and mineral fractions in the last (REIS *et al.* 2014).

Table 1. Mean and standard deviation values for some physical and chemical attributes in different land uses.

	TP		Ma		Mi		TOC		POC		EC	
	md	sd	md	sd	md	sd	md	sd	Md	sd	md	sd
	------------------------ cm^3 cm^{-3} --------------------------						------------dag kg^{-1} ------------				---dS m^{-1}---	
NF	0.42 ab	0.04	0.15 ab	0.08	0.27 ab	0.05	1.33 ns	0.58	0.29 ns	0.20	0.49 ab	0.20
AH	0.45 a	0.04	0.16 ab	0.03	0.30 ab	0.05	1.41	0.85	0.47	0.44	0.69 a	0.30
CH	0.43 ab	0.04	0.22 a	0.03	0.20 b	0.03	0.97	0.40	0.30	0.14	0.55 ab	0.07
FT	0.42 ab	0.02	0.13 ab	0.05	0.28 ab	0.04	0.89	0.31	0.22	0.06	0.29 b	0.07
NP	0.39 b	0.02	0.08 b	0.02	0.31 a	0.05	1.19	0.13	0.21	0.04	0.37 ab	0.13

Different letters after values indicate significant differences, by Tukey ($p < 0,1$). TP: total porosity; Ma: macroporosity; Mi: microporosity; SD: soil density; TOC: total organic carbon; POC: particulate organic carbon; EC: electrical conductivity. md: mean; sd: standard deviation. NF: native forest; AH: agroecological horticulture; CH: conventional horticulture; FT: fruit production; NP: natural pasture. md: mean value; sd : standard deviation.

Electrical conductivity (EC) values were directly influenced by land use, showing higher values of EC in AH, with significant differences in relation to FT. It was evaluated that the differences between PUs management and use, and probably the position of the fruticulture fields, in more effective drainage areas, have contributed to the lower EC in this land use. Also, manures like poultry bed and pig slurry had a great effect on increasing EC, due higher contents of cations like potassium (MORAL *et al.*, 2005). These manures also contributed to the greatest average value of pH occurred on soils under AH, in addition to the correction of soil (Table 2). This management also improved base saturation (V) in AH, CH and, in minor scale, FT with a significant difference between the first in relation to NP and NF. (Table 2).

Cation exchange capacity (CEC) had average values between 7.4 and 10.2 $cmol_c$ dm^{-3}. There were no significant differences among treatments ($p < 0.1$), despite high amplitude difference (Table 2). These data emphasized the medium to long-term effect of land use and management in some attributes. Almost all soil use systems and management had values of CEC below 10 $cmol_c$ dm^{-3}, which can be associated with low content of soil organic carbon and low clay content in the soil, indicating great dependence of these soil attributes in CEC values, mainly in tropical regions (PETER *et al.*, 2017).

Sulfur (S), zinc (Zn) and copper (Cu) showed similar behavior, with the absence of significant differences among the land uses (Table 2). There is, however, some variation between types of use, with higher values, in general, for FT, AH and CH, with the latter especially for S content. LOURENZI *et al.* (2016), working in fruticulture areas of different cultivation periods, found high levels of Zn and Cu, with significant differences, in many cases, compared to levels found in reference areas.

Table 2. Mean and standard deviation values for some chemical attribute in different land uses.

	pH		CEC		V		S		Zn		Cu	
	md	sd	md	sd	Md	sd	Md	Sd	Md	sd	md	sd
			cmolc kg^{-1}		%		------------------------mg kg^{-1}-------------------					
NF	4.7 b	0.27	8.8 ns	1.7	40.0 c	13.6	8.9 ns	2.9	10.0 ns	16.9	3.4 ns	5.8
AH	6.3 a	0.24	10.2	1.6	83.1 a	5.0	12.2	4.4	18.1	10.1	1.4	0.5
CH	5.4 ab	0.4	8.4	1.5	66.0 ab	8.2	13.9	9.7	16.9	13.8	4.3	4.1
FT	5.4 ab	0.75	8.0	2.8	59.4 ab	22.8	7.3	1.9	18.7	11.4	8.4	7.7
NP	5.2 b	0.48	7.4	1.4	46.6 c	17.9	8.4	1.4	7.2	6.7	2.7	4.1

Different letters after values indicate significant differences, by Tukey (p , 0,1). CEC: cation exchange capacity; V: base saturation; S: sulfur; Zn: zinc; Cu: cooper. NF: native forest; AH: agroecological horticulture; CH: conventional horticulture; FT; fruit production; NP: natural pasture. md: mean value; sd: standard deviation.

It is important to emphasize that these elements contents were higher than in this study, by the effect of soil characteristics, like differences in clay content, for example (FERREIRA *et al.*, 2018). In this work, very high contents of Cu e Zn were observed (SBCS-NRS, 2016), and we evaluated this is promoted by use of Bordeaux mixtures and lime sulphur. These data, associated with low contents of clay and organic matter, can induce to contaminating and leaching of these elements, with regional reflections in these localities' environments (MATTIAS *et al.*, 2010).

The average values of P ranged between approximately 20 and 353 mg dm^{-3}. There were significant differences ($p < 0.1$) among the treatments (Figure 3). Largest value of P occurred in soils under AH, followed by CH, without significant differences between them. Besides this, some areas had P levels above the indication by Gebrim *et al.* (2010) as "critical level". According to the authors, from approximately 100 and 150 mg kg^{-1} of P in soil, for sandy and clay soils, respectively, percolation of P had increased sharply, both in organic and inorganic forms, indicating the potential of phosphorus contamination in nearby water bodies, for example. The authors highlighted that the high levels of phosphorus, obtained by extraction method Mehlich, indicate the predominant form of inorganic P, which is a result of the easy mineralization of organic compounds added to the soil (GAGNON *et al.*, 2012).

This tendency also occurred in this work. Gatiboni *et al.* (2015) showed that soils have a "change point value" of phosphorus content and greater values can induce a rapid increase in P removed by water, in a leaching process. For soils with approximately 20 percent of clay this value was about 75 mg dm^{-3}, lower than values obtained in our work. Lopes *et al.* (2007), evaluating the susceptibility of phosphorus losses to water bodies, found the element content in soil as one of the most important factors. In our work, this problem may occur in areas with higher slopes and intensive soil tillage (specially AH and CH).

The 27 fields used in the study had an initial classification (CIN) according to uses observed and history reported by farmers. However, results obtained allowed the framing or reclassification (REC) in a particular land use, which in some cases was different from the initially defined. Therefore, we used discriminant analysis of Fischer (CUNHA, 2014). Some attributes were removed from the set of attributes evaluated, because the absence of normal distribution of the data, or great correlation coefficient with other attributes that were used in this analysis. This analysis generated two discriminant functions or two "dimensions" explained approximately 82% of variability of samples analyzed. With these functions, scores were determined for each sample, and average scores for each land use, determined by centroids (Figure 4). Phosphorus, basis saturation, soil density and electrical conductivity had the highest correlation with F1, while microporosity and total organic carbon were those of greater correlation with F2.

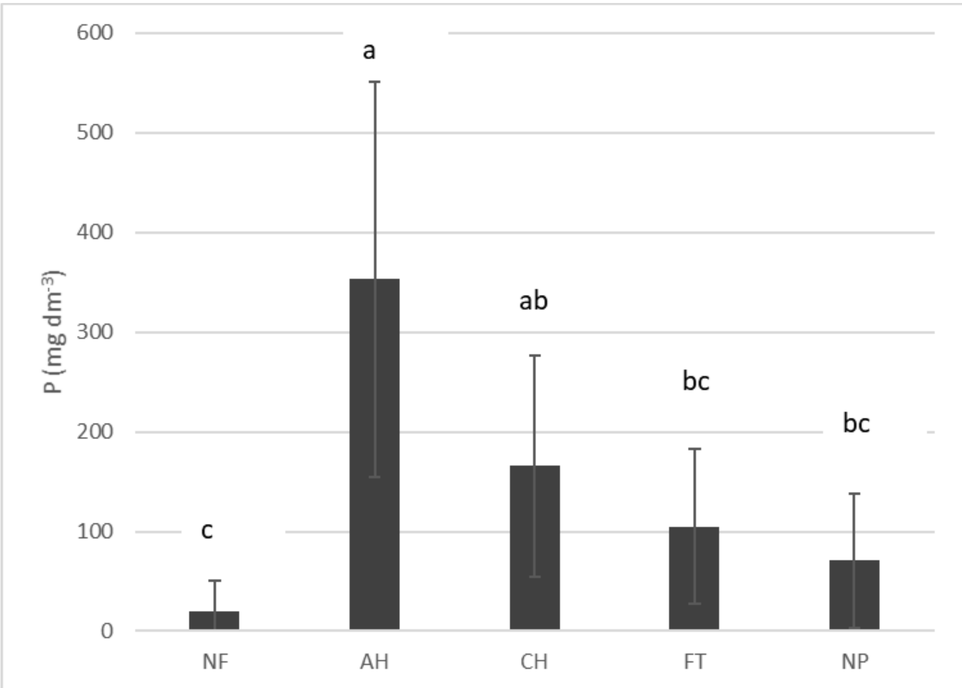

Figure 3. Phosphorus content values among land uses in PUs from Porto Alegre municipality, Rio Grande do Sul State, Brazil. Bars indicate means values, and vertical lines indicate the largeness of ± one standard deviation. Letters represent significant differences from Tukey (p<0,1). Axis y: mg dm-3. NF: native forest; AH: agroecological horticulture; CH: conventional horticulture; FT: fruit production; NP: natural pasture.

The reclassification (REC) in a usage type indicated that only three areas were reclassified on different uses from the initially defined (not showed). It was observed that one area initially defined as AH and other as

ISSN: 0104-907. ISSN ONLINE: 2595-7686.
Recebido em 14 abr. 2021. Aceito em 27 ago 2021.

FT were reclassified in CH land use, while one area of FT was reclassified in NP land use. We evaluated that the time of adoption of specifics uses and management influenced soil characteristics in some areas; as well some changes in these practices are related with a strategy in family farm, improving sustainability to their production system (LIMA *et al.*, 2007). In the case of FT, it is probable that the different production systems (organic and conventional), included in the same treatment, resulted in some dispersion of area characteristics.

Euclidean distances between land use centroids formed by the two discriminant functions allow observing the formation of groupings (Figure 4). The smaller centroid distances involved NF, NP and FT. Then, there seems to be a group first involving fewer intensive uses. FT was included, probably due different production systems (organic or conventional) and even by the diversity in purposes or emphasis of cultivation (commercial, family consumption, rural tourism activity). The positions of CH and AH centroids showed a relatively small distance between them, although did not show the same proximity involving the others three land uses.

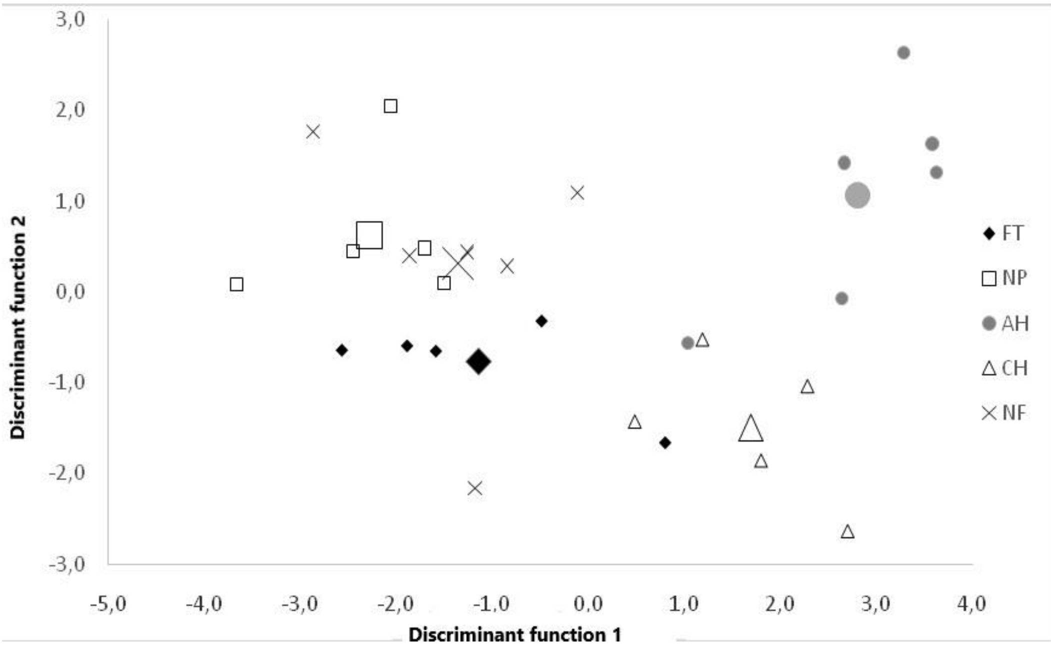

Figure 4. Scores of areas sampled from two main discriminant functions. Small plots represent unit areas or samples, and larger plots represent land uses centroids. NF: native forest; AH: agroecological horticulture; CH: conventional horticulture; FT: fruit production; NP: natural pasture.

It denotes peculiar characteristics of horticulture system production, like more intensive uses and management, regardless in conventional or agroecological system. Emphasis is in fertilizers use (mineral and/or organic) and soil tillage. Also, it was possible to detect some PUs that are defined like having "agroecological system production", but in fact have a transitional situation, persisting some technical and conductional threats (GLIESSMANN, 2000). It can be cited, for example, the high pH values, base saturation and phosphorous

Recebido em 14 abr. 2021. Aceito em 27 ago 2021.

content, in AH and CH systems. On the other hand, physical attributes with major changes (density and macroporosity) are present in native pasture, showing some indicators of soil degradation

Generally, results obtained indicate that changes in soil characteristics, according to the land use, affected some attributes in the short term. Soil density, macroporosity, total porosity, pH, electrical conductivity, and levels of phosphorus, are the more affected attributes. The high values of soil bulk density and low values of macroporosity as well as high levels of phosphorus (mostly), zinc and copper were the most impactful in terms of soil degradation, deserving a more frequent monitoring, to prevent degradation and contamination of soil and other natural resources.

Horticulture, both in AH and CH systems, appeared as the land use type which presented major changes in relation to land use with zero impact, such as the NF. These results confirm the influence of intensive management systems of fertilization, crop and soil tillage.

The reclassification of three areas (about 12% of the set) by using discriminant analysis shows that, although different forms of crop conduction among PUs, each land use is related to consolidated effects in soil attributes of representative PUs of family farming in PAMR.

Acknowledgment

We would like to thank to “Ministry of Education” of Brazilian government, through the program titled “Programa de Apoio a Extensão Universitária” 2016 edition; to “Empresa de Assistência Técnica e Extensão Rural” (EMATER), Porto Alegre’s Office, for research support; to producers and families of PUs, for the opportunity to have a time together and to learn with them.

Conflict of interest

The authors declare that the research was conducted in the absence of any potential conflicts of interest.

Ethical statements

The authors confirm that the ethical guidelines adopted by the journal were followed by this work, and all authors agree with the submission, content and transfer of the publication rights of the article to the journal.
They also declare that the work has not been previously published nor is it being considered for publication in another journal.
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