Comissão 3.5 - Poluição, remediação do solo e recuperação de áreas degradadas

PHYSICAL PROPERTIES AND ORGANIC CARBON CONTENT OF A RHODIC KANDIUDOX FERTILIZED WITH PIG SLURRY AND POULTRY LITTER[1]

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SUMMARY

The impact of pig slurry and poultry litter fertilization on soils depends on the conditions of use and the amounts applied. This study evaluated the effect of organic fertilizers after different application periods in different areas on the physical properties and organic carbon contents of a Rhodic Kandiudox, in Concordia, Santa Catarina, in Southern Brazil. The treatments consisted of different land uses and periods of pig and poultry litter fertilization: silage maize (M7 years), silage maize (M20 years), annual ryegrass pasture (P3 years), annual ryegrass pasture (P15 years), perennial pasture (PP20 years), yerba mate tea (Mt20 years), native forest (NF), and native pasture without manure application (P0). The 0-5, 5-10 and 10-20 cm soil layers were sampled and analyzed for total organic carbon, total nitrogen and soil physical properties such as density, porosity, aggregation, degree of flocculation, and penetration resistance. The organic carbon levels in the cultivated areas treated with organic fertilizer were even lower than in native forest soil. The organic fertilizers and studied management systems reduced the flocculation degree of the clay particles, and low macroporosity was observed in some areas. Despite these changes, a good soil physical structure was maintained, e.g., soil density and resistance to penetration were below the critical limits, whereas aggregate stability was high, which is important to reduce water erosion in these areas with rugged terrain in western Santa Catarina, used for pig and poultry farming.

Index terms: biofertilizer, soil quality, soil structure.

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RESUMO: *ATRIBUTOS FÍSICOS E TEOR DE CARBONO ORGÂNICO DE UM NITOSSOLO VERMELHO QUE RECEBEU DEJETOS DE SUÍNOS E AVES*

O impacto do uso de dejetos de suínos e cama de aves sobre o solo depende das condições de uso e das quantidades adicionadas. Neste estudo, avaliou-se o efeito da aplicação de fertilizantes orgânicos em diferentes áreas e tempos de aplicação sobre atributos físicos e teores de carbono orgânico de um Nitossolo Vermelho eutroférrico, em Concórdia, SC. Os tratamentos abrangeram diferentes usos do solo com aplicação de dejetos de suínos e cama de aves, a saber: milho para silagem (M7 anos), milho para silagem (M20 anos), pastagem de azevém (P3 anos), pastagem de azevém (P15anos), pastagem perene (PP20 anos), erva-mate (Mt20 anos), mata nativa (NF) e pastagem nativa sem aplicação de dejetos (P0 anos). As amostras de solo foram coletadas nas camadas de 0-5, 5-10 e 10-20 cm e analisadas em relação aos teores de carbono orgânico total e nitrogênio total e às propriedades físicas do solo, como densidade, porosidade, agregação, grau de floculação e resistência à penetração. Os sistemas agrícolas avaliados, mesmo recebendo aplicação de fertilizantes orgânicos, apresentaram menor teor de carbono orgânico em relação ao solo sob mata nativa. O uso de fertilizantes orgânicos e os sistemas de manejo adotados reduziram o grau de floculação das argilas e foi observada baixa macroporosidade em algumas áreas. Apesar disso, observaram-se boas condições físicas ligadas à estrutura do solo, como densidade do solo e resistência à penetração abaixo dos valores críticos e alta estabilidade de agregados, o que é importante para reduzir a erosão hídrica nessas áreas de cultivo associadas à criação de suínos e aves em regiões de relevo acidentado do oeste catarinense.

Termos de indexação: biofertilizantes, estrutura do solo, qualidade do solo.

INTRODUCTION

Pig and poultry production are agricultural activities of a number of small and medium-sized farms in Santa Catarina, especially in the western and southern regions of the state. The use of organic fertilizers such as pig slurry or poultry litter is a practice adopted by the farmers to dispose of these residues which, if used correctly, can improve the soil quality (Seganfredo, 2007).

Organic fertilizers have traditionally been used in agricultural areas, especially in view of their benefits for the soil biological and chemical properties (Queiroz et al., 2004). It is worth remembering that the addition of organic residues is fundamental for carbon (C) recycling in the soil and can improve its physical quality (Brancalião & Morais, 2008). In this case, the main physical property related to organic C dynamics is soil aggregation, indirectly influencing the density, porosity, water retention, and infiltration capacity, which are all fundamental for the productive capacity of the soil (Silva et al., 2006).

In rice paddy fields in Korea, an increase in organic carbon levels and an improvement in the soil physical properties were observed, evidenced by a reduction in soil density and increase in the number of large-sized aggregates after 41 years of organic compost application, in comparison with mineral fertilizer application and an unfertilized control treatment (Lee et al., 2009). The positive effect of organic material on aggregate formation and stability is noteworthy (Tisdall & Oades, 1982), particularly important in soils degraded by periodic tillage, but also on the increase of mechanical resistance in areas under no tillage, which is attenuated (Mosaddeghi et al., 2009).

The effects of organic fertilizers on soil physical properties depend on the quantity and quality of materials used and can vary according to the type of soil and management. Bhattacharyya et al. (2007) showed that the use of organic fertilizers increased the organic C levels of a sandy loam soil in the mountainous region of Northern India, which was related to a reduction in soil density and an increase in aggregate stability. These physical improvements are reflected in greater water infiltration capacity than of unfertilized or mineral-fertilized soils. On the other hand, Costa et al. (2008) observed no effect of increasing application rates of turkey litter on aggregation in a sandy loam Typic Dystrophic Red Latosol, cultivated with *Brachiaria decumbens* pasture in Uberlândia, MG. More recently, Mellek et al. (2010) analyzed the effects of increasing rates of dairy cattle slurry on a sandy clay loam Cambisol derived from sandstone, in Ponta Grossa, PR, and observed improvements in soil structure, e.g., a reduction in density and increases in macroporosity, aggregate stability and water infiltration rate.

Knowledge on alterations in physical soil properties promoted by organic fertilization is particularly interesting in the western region of Santa Catarina, due to the economic importance of animal husbandry and the need to evaluate the environmental and productive conditions of the soil (Scherer et al., 2010). This region is characterized by clayey soils, often on rough terrain, treated with high and repeated organic residue rates.

The objective of this study was to evaluate modifications in soil physical properties and organic carbon levels of a Rhodic Kandiudox under different soil use systems, resulting from the application of pig slurry and poultry litter rates.

MATERIAL AND METHODS

This study was carried out in Concordia, SC, in areas within a watershed, with soil classified as Rhodic Kandiudox, corresponding to "Nitossolo Vermelho eutroférrico" by the Brazilian Soil Taxonomy System. The climate is humid mesothermal (Cfa), according to the Köppen classification system (Embrapa, 2004).

The soil use systems consisted of areas with different crops, treated with organic fertilizer based on pig slurry and poultry litter (Table 1) in eight treatments: maize silage after 7 years of application (M7); maize silage after 20 years of application (M20); annual pasture after 3 years of application (P3); annual pasture after 15 years of application (P15); perennial pasture after 20 years of application and without grazing (PP20); yerba mate after 20 years of application (Mt20); native forest (NF) and native pasture without fertilization (P0). The surface soil layer was previously evaluated in chosen areas no more than 1,000 m away from each other, based on samples taken from holes bored into the soil. Areas with similar conditions in terms of soil depth, slope, and texture were selected, based on the moist soil color (10R 3/6) observed in all soil samples in the 0 - 20 cm layer.

Pig waste was applied in liquid form, distributed on the soil surface by tractor-driven equipment. The annual dose was 50 m^3 ha^{-1}, following the current environmental regulations (Fatma, 2000). For poultry litter, the annual application was 16 m^3 ha^{-1}.

Eight soil samples were collected systematically from each area, in two transects and spaced 10 m apart. Sampling was carried out in September 2009, in the 0-5; 5-10 and 10-20 cm layers, in 20 x 20 cm trenches.

To analyze total organic carbon (TOC) and total nitrogen (N_T), samples were taken at 10 locations (sub-

Table 1. Characteristics of a Rhodic Kandiudox under different use systems and periods of pig slurry and poultry litter applications

Use and management systems	Description/History
Maize - 7 years (M7)	Area: 4ha; silage maize (2 annual crops), after 7 years of bimonthly pig slurry applications; poultry litter application (once a year); no mineral fertilizer application; no tillage and winter fallow.
Maize - 20 years (M20)	Area: 3 ha; silage maize (2 annual crops), with 20 years of bimonthly pig slurry applications; poultry litter application (once a year); no mineral fertilizer applications; conventional soil tillage; winter ryegrass; 5 Mg ha^{-1} lime application in 2008.
Annual pasture - 3 years (P3)	Area: 1 ha; pig slurry applications for 3 years, every 3 months; poultry litter applications (once a year); no mineral fertilizer applications; winter oat and ryegrass and summer millet and Sudan grass; one annual chisel plowing; Stocking rate: 35-40 dairy cows/ha.
Annual pasture - 15 years (P15)	Area: 2 ha; fertilized with pig slurry for 15 years, every 3 months; poultry litter application (once a year); no mineral fertilizer application; winter oat and ryegrass and summer millet and Sudan grass; one annual chisel plowing; Stocking rate: 35-40 dairy cows/ha.
Perennial pasture - 20 years (PP20)	Perennial pasture of ryegrass, oats and fodder radish without grazing, with one annual mowing; slurry applications for 20 years; poultry litter application (once a year) in the first 10 years of soil use; no mineral fertilizer applications.
Yerba mate - 20 years (Mt20)	Yerba mate (*Ilex paraguariensis* St.Hill) intercropped with ryegrass, without grazing; pig slurry applications between the rows for 20 years; poultry litter application (once a year) in the first 10 years of soil use.
Native forest (NF)	Native forest without human interference.
Native pasture without slurry (P0)	Area: 2 ha; Native pasture, with grazing; without organic fertilizer applications. Stocking rate: 35-40 cattle/ha.

samples) near the ring sampling points using a soil auger so that, for each soil layer, the soil was homogenized to form a composite sample. The chemical composition was determined by the methods described by Tedesco et al. (1995), and TOC determined by titration after wet combustion with potassium dichromate. The N_T was extracted by sample digestion and distillation and then determined by titration with 0.025 mol L^{-1} H_2SO_4. The carbon/nitrogen (C/N) relationship was calculated as the ratio between total organic C and total N.

Undisturbed soil was sampled in steel cylinders (diameter 5 cm, length 2.5 cm for the two superior layers and 5 cm for the inferior layer). Around these, soil clods were sampled using a spatula and stored in plastic bags to evaluate aggregate stability.

Aggregate stability was determined by the wet sieving procedure, using aggregates between 4.76 and 8.35 mm, following the Kemper & Chepil (1965) method, using an equipment consisting of four sieves (4.76; 2.00; 1.00 and 0.25 mm). Aggregate stability was represented by the mean weight diameter (MWD).

Particle size was analyzed by the pipette method, determining total clay with NaOH dispersant, and natural clay, dispersed in water. The degree of flocculation (DF) was calculated using the total and natural clay quantities. Soil bulk density (Db) was measured by the volumetric ring method. Particle density (Dp) was determined by the volumetric flask method. The volume of biopores and micropores was determined on a sand tension table with suction of 1 and 6 kPa, respectivley. Total porosity (P_T) was calculated by the ratio between soil bulk density and particle density (Db/Dp). Macroporosity was obtained using the difference between P_T and microporosity (Embrapa, 1997).

Soil resistance to penetration was evaluated in volumetric rings, measured at -6 kPa soil tension, using an electronic penetrometer, model Marconi MA-933 (diameter cone 3.9 mm, penetration angle 45º and penetration rate 1mm s^{-1}). The value of each sample corresponded to the average of 40 values determined between 6 and 45 mm for the 5 cm rings, and an average of 15 values determined between 6 and 20 mm for the 2.5 cm rings.

The results were subjected to variance analysis by the F test in a completely random design, evaluating the variation factors soil use system (application of pig slurry, poultry litter and soil use) and layer, with comparison of means by the "t" test ($p<0.05$). Pearson correlations were estimated between the variables studied, considering the three sampled layers together.

RESULTS AND DISCUSSION

Based on variance analysis (Table 2), the results of the interaction (use system x layer) for the variables: total organic C, C/N ratio, mean weight diameter, degree of flocculation, soil density, total porosity, macroporosity, and penetration resistance are presented. For the biopores and microporosity variables, only the effect of use system is presented.

Native forest demonstrated the highest levels of total organic carbon (TOC), with values of 63.1 g kg^{-1}, 49.3 g kg^{-1} and 36.6 g kg^{-1} for the 0-5, 5-10 and 10-20 cm layers, respectively (Table 3). This shows that the level of organic C is reduced in the cultivated areas, despite the application of organic fertilizers, compared to the natural condition of the soil, which can affect its quality. This fact was also shown by Arruda et al. (2010), in a study of the effects of increasing application rates of pig slurry to a Red Dystroferric Latosol, in Campos Novos, SC.

The fact that the application of pig and poultry litter did not increase organic C levels in the soil was probably due to the increased microbial activity resulting from the addition of easily decomposing organic materials, consequently intensifying organic material mineralization in the soil (Gerzabek et al., 1997). Whereas Giacomini et al. (2008), did not observed higher C release in the form of CO_2 from oat straw with pig slurry and pig litter bedding, applied to a sandy Red Hapludalf soil.

On the other hand, in a study of Hati et al. (2006) on the combined effect of mineral fertilizer and animal manure on a Vertisol, it was observed that the application of 10 Mg ha^{-1} pig slurry did increase the organic C in the 0-15 cm layer, after three years of application.

The TOC levels were lowest in the pasture area under intensive use (P15) in all layers. This fact could be associated to the partial tillage by the annual chisel plowing, exposing the soil to higher temperature and oxygen levels and, consequently, increasing microbial activity, causing a gradual decline in soil C levels (Silva & Mendonça, 2007), regardless of the long period of animal litter applications. It must also be taken into consideration that this area was intensively grazed, which probably resulted in less plant biomass on the soil surface, reducing the contribution of organic material to the soil.

The pastures, with the exception of P15, as previously commented, had higher levels of C in the 0-5 cm layer than the maize production areas (M7 and M20), proving that the intensive phytomass removal for silage, combined with conventional soil tillage (in M20), are unfavorable factors in maintaining organic C in the soil.

In relation to the variation in organic C between layers, a reduction was observed in the 0-5 and 5-10 cm layers compared to the 10-20 cm layer, in areas receiving slurry applications, with the exception of yerba mate (Mt20). This was shown by the combined effect of periodic soil tillage (M20, P3 and P15), phytomass removal (silage and pasture) and organic fertilizer application. These, despite being C sources, serve to stimulate the mineralization of soil organic matter.

Leite et al. (2010) studied the influence of tillage system on a sandy clay Latosol in the Cerrado region of Piauí and observed that the reserves of TOC in soils under conventional tillage were lower in the surface layer and increased with depth, compared to no-tilled areas. This was related to the distribution of organic residues in the tilled soil layer as well as to effects linked to greater mineralization and possible C losses from the surface layer, intensified by erosion.

Lower C/N ratios were observed in agricultural areas, compared to the area under native forest (Table 3), indicating greater N availability, due to the slurry applications as well as to the fertilizers of the crops

Table 2. Variance analysis results, with values P>F, for the use system effect, layer and interaction (use system x layer), in areas under different use systems and application periods of pig and poultry organic fertilizers on a Rhodic Kandiudox

Source of variation	TOC	C/N	MWD	DF	Db	P_T	Bio	Macro	Micro	PR
Use systems	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Layer	<0.001	<0.001	<0.001	0.021	<0.001	<0.001	0.051	0.623	0.001	<0.001
Interaction	<0.001	<0.001	0.067	<0.001	<0.001	<0.001	0.112	<0.001	0.671	<0.001

TOC: total organic carbon; C/N: carbon/nitrogen ratio; MWD: mean weight diameter; DF: degree of flocculation; Db: bulk density; P_T: total porosity; Bio: biopores; Macro: macroporosity; Micro: microporosity; PR: penetration resistance.

Table 3. Total organic carbon levels (TOC) and carbon/nitrogen ratio (C/N) in areas under different soil use systems, and pig and poultry organic fertilizer application periods on a Rhodic Kandiudox

Use systems	Layer			*LSD* *(layer)*	*CV* *(layer)*
	0-5 cm	5-10 cm	10-20 cm		
		Total organic carbon, g kg^{-}			%
M7	18.1 Bc	15.3 Ccd	21.7 Ad	1.36	7.1
M20	18.8 Bc	16.6 Bcd	22.1 Ad	2.48	12.4
P3	22.5 Bb	20.1 Bb	28.7 Ab	3.44	13.8
P15	15.0 Bd	14.1 Bd	21.5 Ad	1.37	7.8
PP20	23.7 Bb	18.2 Cbc	25.6 Ac	1.64	7.0
Mt20	24.8 Ab	16.1 Ccd	21.4 Bd	2.59	12.0
NF	63.1 Aa	49.3 Ba	36.6 Ca	4.63	8.9
P0	23.8 Ab	15.6 Bcd	23.3 Acd	3.28	15.0
LSD (system)	2.8	2.9	2.3		
CV (system), %	10.7	2.9	9.4		
		C/N ratio			%
M7	9.7 Abc	7.9 Ac	10.3 Ac	2.88	29.6
M20	12.6 Ab	8.3 Ac	13.0 Ab	4.70	39.8
P3	7.8 Bc	7.4 Bc	12.3 Ab	1.71	17.9
P15	9.3 Abc	7.9 Ac	10.2 Ac	3.54	37.0
PP20	7.8 Bc	7.3 Bc	11.4 Abc	1.15	12.5
Mt20	7.0 Bc	7.1 Bc	10.5 Ac	0.79	9.2
NF	21.0 Aa	19.9 ABa	18.7 Ba	1.88	9.0
P0	12.6 Bb	10.8 Cb	18.0 Aa	1.55	10.8
LSD (system)	3.46	1.98	1.67		
CV (system), %	31.4	20.5	12.7		

Study areas: M7: maize after 7 years of organic fertilizer application; M20: maize after 20 years of application; P3: annual pasture after 3 years of application; P15: annual pasture after 15 years of application; PP20: perennial pasture after 20 years of application; Mt20: yerba mate after 20 years of application; NF: native forest; P0: native pasture. Capital letters, in the rows, compare layers and small letters, in the columns, compare use systems, by the t test (p <0.05). LSD: least significant difference; CV: coefficient of variation.

and forage species. The greater N availability stimulates the microbial activity, favoring the decomposition of residues and soil organic matter.

The MWD values varied between 4.8 and 6,1 mm in the three layers (Table 4). In the 0-5 cm layer, the areas treated with organic fertilizers, except for M7, did not differ from the native pasture and forest areas. This behavior was also observed in the 5-10 and 10-20 cm layers, however, apart from NF, the areas fertilized with slurry were not different from the pasture areas without slurry applications. It is presumed that this could be influenced by the fibrous roots of the grass species on these areas which help to aggregate the soil by mechanical action and by the release of exudates with cementing properties, and because the soil contained high clay levels which, together with the level of organic C, led to the high stability of aggregates.

The high MWD was also observed by Arruda et al. (2010) in a study with increasing pig slurry rates applied to a Red Latosol in Campos Novos, SC. The high aggregate stability is linked to the presence of a large quantity of organic radicals in the soil organic matter, which interact with the mineral surface (Tisdall & Oades, 1982).

The degree of clay flocculation (DF) remained between 35 and 71 %. The DF values were highest in the native forest in all three layers, followed by P0 and P3. Pasture areas (P15 and PP20), maize (M7 and M20) and yerba mate, did not differ from each other (Table 4). There was a positive correlation between DF and total organic carbon (r = 0.51; Table 5). In this soil, the nature of the possible factors regulating flocculation is chemical and mineral, influenced by organic compounds present in the organic material originating from the pig slurry and poultry litter fertilizer, influencing the charges on the colloid surfaces (Siqueira et al., 1990).

Soil bulk density (Db) varied between 0.81 and 1.34 g cm^{-3} (Table 6). The Db levels were highest in maize after 7 and 20 years of pig slurry and poultry litter application in all three layers, as well as in P15. This could be related to the soil tillage, as in the case of maize after 20 years of organic fertilization, under

Table 4. Mean weight diameter (MWD) and degree of flocculation (DF) in a Rhodic Kandiudox, under different land use systems and pig and poultry organic fertilizer application periods

Use systems	Layer			$LSD^{(layer)}$	$CV^{(layer)}$
	0-5 cm	5-10 cm	10-20 cm		
		Mean weight diameter, mm			%
M7	5.28 Ac	5.17 Ac	5.06 Abc	0.58	10.9
M20	5.78 Ab	5.75 Aab	5.58 Aa	0.27	4.6
P3	6.08 Aa	5.76 Bab	5.78 Ba	0.20	3.3
P15	5.78 ABb	5.88 Aa	5.61 Ba	0.17	2.9
PP20	5.88 Ab	5.62 ABab	5.50 Bab	0.36	6.1
Mt20	5.90 Ab	5.46 Abc	4.83 Bc	0.50	8.9
NF	5.80 Aab	5.82 Aa	5.68 Aa	0.23	3.8
P0	5.72 Ab	5.82 Aa	5.42 Aab	0.51	8.7
$LSD^{(system)}$	0.33	0.31	0.45		
$CV^{(system)}$, %	5.7	5.5	8.3		
		Degree of flocculation, %			
M7	45 Bc	45 Bcd	50 Ab	2.4	4.9
M20	46 Ac	42 Acd	40 Ac	8.3	18.4
P3	57 Bb	60 Aba	63 Aa	4.9	7.8
P15	38 Ad	38 Ad	42 Ac	5.7	13.7
PP20	45 Ac	41 Acd	43 Ac	7.4	16.3
Mt20	35 Bd	47 Ac	53 Ab	10.9	23.1
NF	69 ABa	71 Aa	64 Ba	7.1	9.9
P0	58 Bb	63 ABb	67 Aa	8.2	12.5
$LSD^{(system)}$	6.8	7.2	7.0		
$CV^{(system)}$, %	13.6	13.9	13.1		

Areas studied: M7: maize after 7 years of organic fertilizer applications; M20: maize after 20 years of application; P3: annual pasture after 3 years of application; P15: annual pasture after 15 years of application; PP20: perennial pasture after 20 years of application; Mt20: yerba mate with 20 years of application; NF: native forest; P0: native pasture. Capital letters, in the rows, compare layers and small letters, in the columns, compare use systems, by the t test ($p < 0.05$). LSD: least significant difference; CV: coefficient of variation.

Table 5. Pearson correlation coefficients between soil properties, in areas under different systems of use and application periods of organic fertilizers on a Rhodic Kandiudox

Variable	DF	TOC	Db	Macro	P_T	Bio	C/N
Db		- 0.29		- 0.82	- 0.72	- 0.66	
PR			0.61	- 0.51	- 0.32	- 0.32	
Micro				- 0.30	0.74		
TOC	0.51						0.72
P_T				0.54			

DF: degree of flocculation; TOC: total organic carbon; Macro: macroporosity; Micro: microporosity; P_T: total porosity; Db: soil bulk density; PR: penetration resistance; C/N: carbon/nitrogen. Only significant coefficients were presented ($p < 0.05$).

Table 6. Soil bulk density (Db), total porosity (PT) and macroporosity (Macro), in areas under different land use systems and different application periods of pig and poultry organic fertilizers on a Rhodic Kandiudox

Use systems	Layer			*LSD* $^{(layer)}$	*CV* $^{(layer)}$
	0-5 cm	5-10 cm	10-20 cm		
		Soil density, g cm^{-3}			
M7	1.27 Aab	1.23 Abc	1.22 Aa	0.12	9.3
M20	1.24 ABbc	1.28 Aab	1.20 Bab	0.04	3.6
P3	1.18 Acd	1.22 Abc	1.14 Abc	0.10	8.1
P15	1.34 Aa	1.34 Aa	1.25 Ba	0.07	5.7
PP20	0.99 Be	1.11 Ad	1.14 Abc	0.06	5.6
Mt20	1.15 Bd	1.28 Aab	1.21 Bab	0.06	5.2
NF	0.81 Af	0.97 Ae	1.02 Ad	0.09	10.1
P0	1.20 Abcd	1.18 Acd	1.10 Bc	0.06	5.3
LSD $^{(system)}$	0.33	0.31	0.45		
CV $^{(system)}$, %	5.7	5.5	8.3		
		Total porosity, m^3 m^{-3}			
M7	0.52 Ac	0.52 Abc	0.53 Ab	0.04	8.7
M20	0.50 Bc	0.49 Bc	0.53 Ab	0.02	4.1
P3	0.56 Ab	0.55 Aab	0.58 Aa	0.03	6.6
P15	0.35 Be	0.34 Be	0.39 Ad	0.04	11.6
PP20	0.62 Aa	0.58 Ba	0.57 Ba	0.02	3.5
Mt20	0.41 Ad	0.37 Be	0.41 Ad	0.03	8.2
NF	0.59 Aab	0.52 Bbc	0.51 Bb	0.09	8.5
P0	0.40 Bd	0.42 Bd	0.46 Ac	0.03	8.0
LSD $^{(system)}$	0.03	0.03	0.03		
CV $^{(system)}$, %	7.9	7.3	6.9		
		Macroporosity, m^3 m^{-3}			
M7	0.097 Ac	0.090 Abc	0.078 Ab	0.040	43.5
M20	0.050 Ad	0.058 Ac	0.062 Ab	0.020	32.9
P3	0.090 Ac	0.085 Abc	0.095 Ab	0.036	38.6
P15	0.058 Acd	0.068 Ac	0.070 Ab	0.034	50.2
PP20	0.137 Ab	0.107 ABb	0.080 Ab	0.045	39.9
Mt20	0.086 Acd	0.072 Aa	0.087 Ab	0.033	38.4
NF	0.261 Aa	0.221 Aba	0.182 Ba	0.061	26.2
P0	0.075 Ccd	0.108 Bb	0.155 Aa	0.027	22.9
LSD $^{(system)}$	0.039	0.034	0.039		
CV $^{(system)}$, %	36.3	33.6	37.8		

Areas studied: M7: maize after 7 years of organic fertilizer applications; M20: maize after 20 years of application; P3: annual pasture after 3 years of application; P15: annual pasture after 15 years of application; PP20: perennial pasture after 20 years of application; Mt20: yerba mate with 20 years of application; NF: native forest; P0: native pasture. Capital letters in the rows compare layers and small letters in the columns compare use systems, by the t test ($p<0.05$). LSD: least significant difference; CV: coefficient of variation.

conventional tillage, which degrades and deforms the soil structure. Similarly to the effects of soil tillage, machine traffic reduces soil porosity with a consequent increase in Db, as in the maize area after 20 years of fertilization. In P15, the greater Db can be attributed to animal trampling, due to grazing in this area.

For M7, under no tillage, greater surface density was observed which can be attributed to compaction caused by machine and equipment traffic. Greater soil density in no-tillage areas compared to conventionally tilled areas was also observed by Bertol et al. (2000), evaluating a Haplumbrept soil under different management systems.

In the treatments which received slurry applications P3, PP20 and Mt20, Db was lowest in the 0-5 cm layer. In well-managed pastures, there can be an increase in organic C levels of the soil, as well as a favorable influence on the soil structure by the growth of fibrous grass roots.

Mellek et al. (2010) applied 180 m^{-3} ha^{-1} of cattle manure to a Cambisol and observed a density reduction (1.32 to 1.17 Mg m^{-3}) in the 0-5 cm layer and an increase in macroporosity and in aggregate size. The application of mineral and organic fertilizer to a Vertisol in India reduced the soil density in the 0-7.5 cm layer from 1.30 Mg m^{-3} in the control, to 1.18 Mg m^{-3} in a treatment with increasing pig slurry rates (Hati et al., 2006). According to the same authors, the reduction in soil density could be related to organic material influencing soil porosity in the treatments with higher rates of organic residues.

The P_T varied between 0.37 and 0.62 m^3 m^{-3} in the three areas evaluated (Table 6) and PP20 was the treatment with the greatest P_T value of the three layers analyzed. In the underlying layers (5-10 and 10-20 cm), P3 was superior to the other areas studied. Pagliai et al. (1983) observed that pig slurry application of 300 m^3 ha^{-1} increased the total porosity from 0.10 to 0.31 m^3 m^{-3}, mainly because of a significant proportion of pores with diameter > 30 μ in the surface layer of a silty clay soil in northern Italy.

Macroporosity varied between 0.05 and 0.26 m^3 m^{-3}, in the three layers (Table 6). It was observed that the macropore values found in M7, P3, P15 and NF were above the critical level of 0.10 m^3 m^{-3}, necessary for adequate gas and water flow in the soil, ensuring root oxygenation and the capacity of water infiltration and redistribution in the soil profile (Reichert et al., 2003). In the perennial pasture soil after 20 years of fertilization, macroporosity was highest in the 0-5 and 5-10 cm layers.

The greatest values of biopores were detected the three layers of the native forest, whereas the other areas did not differ from each other in the 0-5 and 5-10 cm layers (Table 7). It must be considered that other factors apart from the fertilizer type and quantity can affect the soil physical quality, e.g., reduced soil disturbance in the no tillage system, as well as the effects of plant root systems and fauna activity.

The microporosity values were between 0.30 and 0.49 m^3 m^{-3} (Table 7) in the three layers and there was no significant interaction between treatment and layer for this variable (Table 2). Maize after 20 years and perennial pasture after 20 years of slurry applications did not differ from each other, and microporosity was greatest in the 0-5 cm layer and also in the 5-10 and 10-20 cm, for PP20. In NF, P0, P15 and Mt20, the micropore values were lower in all three layers than in the other areas.

Soil resistance to penetration (PR) varied from 267 kPa to 2,580 kPa (Table 8) and was positively correlated with Db (r = 0.61), indicating that the PR values are directly proportional to Db, as also observed by Collares et al. (2006) when analyzing physical properties of an Alfisol. Barbosa et al. (2007) tested doses of urban sewage sludge applied to a clayey Eutrophic Red Latosol and noted that the annual application of 12 Mg ha^{-1} over two years reduced PR and Db and increased the PT of the soil.

In the native forest area, unaffected by human interference, the resistance to penetration was lowest in all three layers. Among the management systems with the highest PR values in the 0-5 cm layer were maize after 7 and 20 years of fertilization, but with lowest values of macro and biopores, due to the negative correlation (Table 5) of PR with these variables (r = -0.51 and -0.32 respectively). According to Taylor & Gardner (1963), who considered the value of 2,000 kPa as critical to plant root development, none of the areas under agricultural management or fertilizer applications reached this value.

The high PR value in the maize area after 7 years of slurry applications to the surface layer could be related to the removal of the greater part of the maize biomass for silage, and to the area lying fallow in the winter, with less soil cover, favoring an increase in soil density.

In the pasture areas (P3, P15 and P0), the higher PR values could be due to animal trampling and also influenced by the lower levels of organic C, which increases the cohesion between particles and aggregates by establishing a lower organic cement concentration around and between them.

In the yerba mate area, the greater PR values in the underlying layers can be explained by machine traffic, which always occurs in the same place, between the rows of the mate trees, in the 20 years of fertilization.

Maintenance of good physical soil conditions is fundamental in agricultural areas in the west of Santa Catarina State, especially as they are situated in a rough terrain, which favors surface runoff, intensifying water erosion. Soil cover must be a priority, by the addition of large amounts of biomass to the soil and plant species efficient in aggregating

Table 7. Biopore and micropore volume ($m^3 m^{-3}$), in areas under different land use systems and application periods of pig and poultry organic fertilizers in a Rhodic Kandiudox

Variable	M7	M20	P3	P15	PP20	Mt20	NF	P0	LSD	CV %
Biopores	0.040 c	0.031 c	0.040 bc	0.034 bc	0.047 b	0.040 bc	0.078 a	0.041 bc	0.015	60.1
Micropores	0.440 b	0.455 b	0.476 a	0.300 d	0.487 a	0.318 cd	0.324 c	0.314 dc	0.019	8.8

Areas studied: M7: maize, 7 years of organic fertilizer applications; M20: maize, 20 years of application; P3: annual pasture, 3 years of application; P15: annual pasture, 15 years of application; PP20: perennial pasture, 20 years of application; Mt20: yerba mate, 20 years of application; NF: native forest; P0: native pasture. Capital letters, in the rows, compare layers and small letters, in the columns, compare use systems, by the t test ($p<0.05$). LSDS: least significant difference; CV: coefficient of variation.

Table 8. Soil resistance to penetration at -6kPa matric potential of a Rhodic Kandiudox, in areas under different land use systems and application periods of pig and poultry organic fertilizers

Use systems	Layer			*LSD* $^{(layer)}$	*CV* $^{(layer)}$
	0-5 cm	5-10 cm	10-20 cm		
	Resistance to penetration, kPa				%
M7	2020 Aa	1903 Abc	1732 Abc	301	15.3
M20	2064 Aa	2224 Aabc	1772 Ab	653	30.2
P3	1074 Bb	1803 Acd	1393 Bcd	371	25.0
P15	1243 Cb	2236 Aab	1659 Bbc	329	18.5
PP20	1009 Bb	1442 Ad	1699 Abc	303	21.0
Mt20	998 Bb	2214 Aabc	2580 Aa	535	26.8
NF	267 Cc	729 Be	1054 Ad	242	34.0
P0	1406 Cb	2599 Aa	2008 Ab	448	21.5
LSD $^{(system)}$	409	426	361		
CV $^{(system)}$, %	32.9	22.4	20.7		

Areas studied: M7: maize, 7 years of organic fertilizer applications; M20: maize, 20 years of application; P3: annual pasture, 3 years of application; P15: annual pasture, 15 years of application; PP20: perennial pasture, 20 years of application; Mt20: yerba mate, 20 years of application; NF: native forest; P0: native pasture. Capital letters, in the rows, compare layers and small letters, in the columns, compare use systems, by the t test ($p<0.05$). LSD: least significant difference; CV: coefficient of variation.

the soil, to ensure good water infiltration capacity (Volk & Cogo, 2008).

CONCLUSIONS

In the agricultural systems studied, the organic carbon levels of those fertilized with organic litter were lower than of soil under the natural vegetation of native forest, and the levels of organic carbon were highest in the 10-20 cm layer.

The use of organic fertilizers and the tested management systems reduced the degree of clay flocculation and low macroporosity was observed in some of the areas.

Nevertheless, favorable physical conditions were observed in soil structure, such as soil density, resistance to penetration below critical values, and high aggregate stability.

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