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Chemical Properties in Macroaggregates of a Humic Dystrudept Cultivated with Onion under No-Till and Conventional Tillage Systems

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ABSTRACT: Nutrients present in soil aggregates are essential for maintaining the productive capacity of agroecosystems and environmental quality. The aim of this study was to evaluate the chemical properties of macroaggregates of a Humic Dystrudept cultivated with onions under a no-till vegetable system (NTVS) compared to the conventional tillage system (CTS) and a forest area in Ituporanga, SC, Brazil. The treatments consisted of the following single and mixed cover crops with onion under the NTVS: spontaneous vegetation, 100 % black oats, 100 % rye, 100 % oilseed radish, intercropped oilseed radish (14 %) + rye (86 %), and intercropped oilseed radish (14 %) + black oat (86 %). Additionally, we evaluated two areas, one with onion grown under the CTS for ±37 years and an area under forest for ±30 years, both adjacent to the experiment. Five years after implementation of the treatments with cover crops, we collected undisturbed soil samples at depths of 0.00-0.05, 0.05-0.10, and 0.10-0.20 m, and we obtained macroaggregates (8.00 mm > Ø ≥ 2.0 mm). We analyzed total organic carbon (TOC), pH in water, Ca^{2+}, Mg^{2+}, Al^{3+}, H+Al, K^+, and P in the macroaggregates. The conversion of onion-growing areas from the CTS to the NTVS after five years increases TOC, pH, Ca, Mg, and K in soil macroaggregates at the depth of 0.00-0.05 m. There is increased K content in the macroaggregates of soil under the NTVS at all depths evaluated in this study compared to the CTS. The use of millet in the CTS increases P content at depth (0.05-0.10 and 0.10-0.20 m). Intercropping black oat + oilseed radish increases Ca content at the 0.10-0.20 m depth in comparison to the black oat, rye + oilseed radish, and control treatments, and increases Mg content as well, compared to the other cover crops at the depths of 0.05-0.10 and 0.10-0.20 m.

Keywords: sustainable agriculture, nutrients, soil structure, *Alliun cepa* L., organic carbon in aggregates.

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INTRODUCTION

The state of Santa Catarina (SC) is prominent in Brazil in onion cultivation, and has been the largest producer of this vegetable of socioeconomic importance in the country since 1992 (Freitas, 2012; IBGE, 2015). The crop has mainly been cultivated under a conventional tillage system (CTS) with intensive use of pesticides and highly soluble fertilizers (Gonçalves et al., 2008). At the time of planting, soil plowed (once), followed by disking (once or twice) (Kurtz et al., 2013), causing soil aggregates breakdown, which, along with the lack of plant cover in this system, favors erosive processes and potentiates losses of soil, water, and nutrients (Panachuki et al., 2011; Loss et al., 2015). Therefore, in addition to environmental impacts, the use of these techniques causes imbalances in the agroecosystem, impairing the productive capacity of the soil and increasing the demand for external inputs, such as mineral fertilizers.

Reduction of the environmental impact of onion cultivation under CTS can be achieved using conservation techniques such as the no-till system (NTS), and the no-till vegetable system (NTVS) in the case of onion (Kurtz et al., 2013). Soil disturbance in this system is restricted to the planting rows, and cover crops are used for the production of phytomass, which is rolled down and left on the soil surface during the flowering period with the use of a knife-roller. NTVS differs from the conventional NTS by not using herbicides or any other pesticide, thus maintaining the soil protected from erosive factors for a longer period and not offering risks to the quality of food and to workers and consumers. The species used for soil cover also has dynamic and differentiated root systems capable of absorbing nutrients at deeper soil depths, accumulating them in their phytomass and later making them available in the surface most layers of the soil as their residues decompose, thus contributing to nutrient cycling and improvement in edaphic properties (Souza et al., 2013; Loss et al., 2015).

In a Humic Dystrudept in SC cultivated with onion under the NTVS, Souza et al. (2013) found that the cultivation and deposition of cover crops in the NTVS modified soil chemical properties at the 0.00-0.10 m depth, indicating changes in exchangeable K, available P, and base saturation, depending on the species of cover crops used. The data presented by the authors showed that the control treatment (spontaneous vegetation) had higher levels of P and K in comparison to the rye, oilseed radish, oilseed radish + rye, and oilseed radish + barley treatments in the first year of study (2011) after the cover crops were left on the soil surface. However, the average production and the total yield of onion were higher in treatments with cover crops in both crop seasons analyzed in the study (2011 and 2012) compared to the control treatment. In another study conducted in the same experimental area with the NTVS and CTS, Loss et al. (2015) evaluated total organic carbon (TOC) and soil aggregation indexes. These authors verified that the CTS disaggregates the soil and impairs the accumulation and protection of TOC compared to the NTVS, which, in contrast, improved soil aggregation, favoring the formation of stable macroaggregates in water and increasing TOC contents at the depth of 0.00-0.05 m.

Studies related to TOC content and other soil chemical properties should not be restricted to disturbed soil samples only. These elements should also be evaluated in soil aggregates because, according to Loss et al. (2015), there are significant differences in soil aggregation in soils managed under the CTS and NTVS, especially in the macroaggregate (8.00 mm > Ø ≥ 2.0 mm) class. During the process of soil aggregate formation, part of the soil organic matter (SOM) becomes physically protected within these aggregates, causing a decrease in mineralization due to decreased attack by microorganisms and less diffusion of O_2 and water (Christensen, 1996). Therefore, the stability of the SOM protected within the aggregate is dependent on the formation and stability of the aggregates and their binders, whereas aggregate fragmentation will expose SOM to decomposition (Adu and Oades, 1978).

The quantification of SOM content and chemical properties present in the aggregates is therefore one possible way to study its dynamics, since the levels of hierarchy represented by the sizes of the aggregates reflects the continuity and the stability of organic matter. Therefore, because of the greater lability of organic matter present in macroaggregates, its stability is dependent on the presence of plants and a constant supply of residues to the soil. In this regard, soil under the CTS loses stability and macroaggregates are broken down (Loss et al., 2015), exposing SOM to decomposition by microorganisms (Six et al., 2000).

In view of the importance of the onion crop in the Brazilian economy and society, especially in the state of SC, and of the impacts of the CTS on edaphic properties and the environment, the study and improvement of technologies such as the NTVS are necessary in the pursuit of sustainable agriculture, in order to assist the agroecological transition process and provide a path towards food security. For this reason, evaluating the chemical properties of soil macroaggregates in the NTVS with the use of different cover crops allows identification of the influence of the species (isolated or in intercropping) on them and thus contributes to characterization and optimization of the use of the NTVS, aiming at sustainable production of onion.

We hypothesized that the conversion of onion cultivation areas from the CTS to the NTVS increases the chemical properties in soil macroaggregates. The objective of this study was to evaluate the chemical properties of macroaggregates of a Humic Dystrudept cultivated with onion under the NTVS compared to the CTS and a forest area in Ituporanga, SC.

MATERIALS AND METHODS

Location, history of soil use, and description of the experiment

The study was conducted at the Santa Catarina State Agricultural Research and Rural Extension Agency (*Estação Experimental da Empresa de Pesquisa Agropecuária e Extensão Rural de Santa Catarina - Epagri*) in the municipality of Ituporanga, SC, located at longitude 27° 24’ 52” S, latitude 49° 36’ 9” W, and altitude of 475 m. The climate of the region is Cfa (Köppen climate system), i.e., mesothermal humid subtropical with hot summers and infrequent frosts, without a defined dry season, with average annual temperature of 17.6 °C and average annual rainfall of 1,400 mm.

The experiment was set up in a *Cambissolo Húmico* (Santos et al., 2013) or Humic Dystrudept (Soil Survey Staff, 2006) with loamy texture in the 0.00-0.10 m layer, with 380, 200, and 420 g kg^{-1}, of clay, silt, and sand respectively, in an area with a history of onion cultivation under the CTS (plow and rotary tiller) for approximately 20 years until 1996. From that year on, lime was applied to the soil surface, with subsequent incorporation, to raise the pH in water to 6.0. Afterwards, a minimum tillage system of onion with rotation of crops and cover crops (black oat - *Avena strigosa*, velvet bean - *Mucuna aterrima*, millet - *Pennisetum glaucum*, sunn hemp - *Crotalaria juncea*, spring vetch - *Vicia sativa*) was implemented and continued from 1996 to 2007. Subsequently, sweet potato (*Ipomoea batatas* (L.) Lam) was introduced and continued until 2009. From then on, the experiment with onion under the NTVS was carried out, without the use of pesticides to desiccate cover crops.

When the experiment was set up (2009), the 0.00-0.10 m soil layer had the following properties: 23.2 g kg^{-1} TOC, pH in water 6.0, 6.2 SMP index, 26.6 mg dm^{-3} P and 145.2 mg dm^{-3} K (both extracted by Mehlich-1), 0.0 $cmol_c$ kg^{-1} Al^{3+}, 7.2 $cmol_c$ kg^{-1} Ca^{2+}, and 3.4 $cmol_c$ kg^{-1} Mg^{2+} (extracted by 1 mol L^{-1} KCl) (Tedesco et al., 1995). In the same year, at the time the experiment was set up, spontaneous vegetation was desiccated with the use of glyphosate herbicide. Thereafter, pesticide applications were no longer used.

The treatments consisted of the planting of single and mixed cover crops, as follows: (1) control with spontaneous vegetation (SV), composed of 20 botanical families, with a predominance of six families (85 %), according to Vilanova (2011) - Amaranthaceae (10 %), Asteraceae, Caryophyllaceae, Compositae (10 %), Convolvulaceae, Cruciferae, Cyperaceae (25 %), Euphorbiaceae, Fabaceae, Lamiaceae (10 %), Leguminosae, Liliaceae, Malvaceae, Oxalidaceae (10 %), Plantaginaceae, Poaceae, Polygonaceae (20 %); (2) 100 % black oat (*Avena strigosa* Schreb.) with seeding density (SD) of 120 kg ha^{-1}; (3) 100 % rye (*Secale cereale* L.) with SD of 120 kg ha^{-1}; (4) 100 % oilseed radish (*Raphanus sativus* L.) with SD of 20 kg ha^{-1}; (5) oilseed radish (14 %) and rye (86 %) intercropped, with SD of 10 and 60 kg ha^{-1}, respectively, and (6) oilseed radish (14 %) and black oat (86 %) with SD of 10 and 60 kg ha^{-1}, respectively. In April 2010, black oat was replaced by barley (*Hordeum vulgare* L.); barley was then replaced by black oats in April 2011, due to the difficulty in acquiring barley seeds. The winter species were sown by broadcasting in April of each year, and then a grain-seeding machine was used twice in the area in order to increase contact of the seeds with the soil. Seed quantities per hectare were defined based on the recommendation of Monegat (1991), with a 50 % increase in the highest amount of the recommendation. The treatments were randomized blocks with five replications. Each experimental unit was 25 m^2 (5 × 5 m). In July 2009, 2010, 2011, 2012, and 2013, all winter species were rolled down with a knife roller, model RF240 (MBO Ltd.).

Furthermore, we evaluated two additional treatments, both adjacent to the experiment. One was the original onion cultivation area kept under the CTS for 20 years until 1996, and in the subsequent years, from 1996 to 2013 (the period of collection of the soil samples), the area was maintained under the CTS, for a total of 37 years. The other additional treatment, an area under forest for ±30 years, represented the natural condition of the soil. In the CTS, as of 2007, onion was grown with millet in succession in the summer. Millet was rolled down at flowering with a knife roller and after 30-60 days, plowing (once) was carried out followed by harrowing (twice) in preparation for the onion crop. Fertilization was performed as recommended by the CQFS-RS/SC (2004) for an average yield of 45 Mg ha^{-1}. The quantities applied were 165 kg ha^{-1} of P_2O_5 (triple superphosphate), 105 kg ha^{-1} of K_2O (potassium chloride) and 192 kg ha^{-1} of N (ammonium nitrate). In the CTS, liming was carried out in 2010 to increase the pH to 6.0 through the SMP method (CQFS-RS/SC, 2004).

After rolling down the winter cover crops and spontaneous vegetation in the month of July of each year, we applied 96 kg ha^{-1} of P_2O_5 in the form of ground natural Gafsa rock phosphate, 175 kg ha^{-1} of P_2O_5, 125 kg ha^{-1} of K_2O, and 160 kg ha^{-1} of N in the form of poultry manure to the soil surface, half of which was applied at the planting of onion seedlings and the other half 30 days later. As of the 2011 crop season, no natural phosphate was applied, since the levels were interpreted as high (CQFS-RS/SC, 2004). Afterwards, we opened the planting furrows with a machine adapted for planting no-till onion, and then we manually transplanted seedlings of cv. 'Empasc 352' - Bola Precoce. The spacing used was 0.40 m between rows and 0.10 m between plants, with 10 onion rows per plot. Weeding was carried out at 60 and 90 days after the planting of the onion seedlings. After the second weeding in October of each year, except for the first year, we planted velvet bean (*Mucuna aterrima* Piper and Tracy) in summer throughout the cultivated area at a SD of 120 kg ha^{-1}. The velvet bean is rolled down in April, followed by the sowing of cover crops.

The mean values of cover crop dry matter production, onion yield, and soil aggregate stability indexes in the areas evaluated for the year 2013 (the year of collection of soil samples) are presented in Loss et al. (2015).

Soil sample collection and obtaining the macroaggregates

In September 2013, five years after the experiment was set up, we collected undisturbed soil samples at the depths of 0.00-0.05, 0.05-0.10, and 0.10-0.20 m by opening mini-trenches of 0.40 × 0.40 × 0.40 m in each plot, using a cutting blade. The samples were placed in plastic bags and sent to the Laboratory of Soil Management and Classification of the Federal University of Santa Catarina (UFSC), where they were air dried and then manually broken down, following cracks or weak points, and passed through 8.00 and 4.00 mm mesh sieves to obtain the soil aggregates, according to Claessen (1997). In general, each undisturbed sample weighed approximately 900-1,000 g. On average, in the NTVS and in the forest area, the aggregates between 8.00 mm > Ø ≥ 4.0 mm, which were used for evaluation of the chemical properties in this study, represented ±60 % of the total soil weight. In the CTS, however, the aggregates did not exceed ±30 to 35 % of the total soil weight. The amounts related to aggregate stability and aggregation indexes (mean weight diameter) are described in Loss et al. (2015).

Evaluation of chemical properties

For chemical analysis, the aggregates retained in the 4.00 mm mesh sieve were manually broken down and passed through a 2.00 mm mesh sieve to obtain the fine air-dried soil of the aggregates. We determined the following properties in this material: TOC, pH in water, exchangeable contents of Ca^{2+}, Mg^{2+}, Al^{3+}, and H+Al, in addition to available K and P contents, according to methods described by Claessen (1997).

Statistical analyses

The results were analyzed for normality and homogeneity of data through Lilliefors and Bartlett tests, respectively, and subsequently analyzed in a randomized complete block design with six treatments (black oat, rye, oilseed radish, oilseed radish + rye, oilseed radish + black oat, spontaneous vegetation) and five replicates. The results were subjected to analysis of variance by the F test, and the mean values, when significant, were compared by the Scott-Knott test at 5 % probability. For the adjacent areas of the CTS and forest, the confidence intervals were estimated by the t test at 5 % probability.

RESULTS AND DISCUSSION

Total organic carbon content in the macroaggregates

The highest TOC contents were observed in the forest area at the three depths evaluated in this study. The NTVS had higher TOC content at the depth of 0.00-0.05 m compared to the CTS. No differences were found among the treatments in the NTVS (Figure 1).

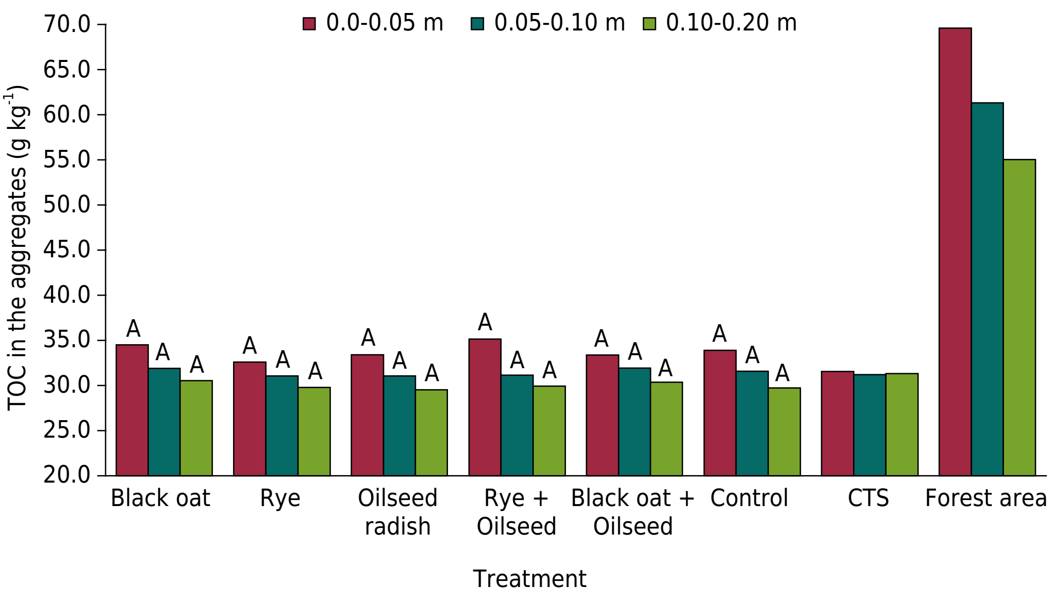

Figure 1. Total organic carbon (TOC) content in the macroaggregates of a Humic Dystrudept cultivated with onion under no-till compared to conventional tillage and forest area. Different letters, at each depth, indicate statistical differences by the Scott-Knott test at 5 %. CI (m ± 95 %) = 0.38, 0.48, and 0.19 for 0.00-0.05, 0.05-0.10, and 0.10-0.20 m, respectively, in the CTS. CI (m ± 95 %) = 2.42, 1.71, and 1.86 for 0.00-0.05, 0.05-0.10, and 0.10-0.20 m, respectively, in the forest area.

The TOC contents are the result of the production, alteration, and decomposition rates of organic residues, which are dependent on a number of factors, such as temperature, moisture, aeration, pH, and the availability of water and nutrients. These factors are naturally conditioned by pedogenetic processes, but they can also be influenced by anthropic action, such as land use and management (Nascimento et al., 2010). Therefore, the higher TOC content in the forest area is the result of the deposition of organic material, especially from litter, which promotes the accumulation of C on the soil surface as the residues are being humified (Mafra et al., 2008).

With the introduction of agricultural systems in areas of native vegetation, there is an imbalance in the SOM dynamics and, consequently, a rapid decrease in TOC content (Scholes and Breemen, 1997). However, changes in soil properties vary according to the characteristics of the management system adopted (Coutinho et al., 2010; Machado et al., 2014). In the Vale do Itajaí region (SC), which is considered a production hub of the onion crop in the state of SC, the use of the CTS in onion cultivation has effectively contributed to environmental degradation, mainly due to intensive use of plowing and harrowing to prepare the soil, which in addition to causing surface losses of up to 0.20 m of the most fertile soil layer (Gonçalves et al., 2008; Madeira, 2009), also favors increased mineralization of SOM due to the increased oxidation that occurs in this system. These results were found in the 0.00-0.05 m layer for TOC, which showed lower values in the CTS compared to the NTVS.

In spite of the conservation practices and the amount of dry matter deposited on soils under the NTVS (Loss et al., 2015), the TOC levels of the aggregates of this system did not reach the level of the forest area. However, the TOC levels under the NTVS showed a significant increase in the 0.00-0.05 m layer compared to the TOC levels under the CTS. Additionally, considering that in the CTS there is a greater annual supply of millet dry matter (Loss et al., 2015), the negative impact of soil plowed and disking on soil C accumulation and maintenance is manifest.

Nevertheless, the fact that TOC levels in the NTVS remain distant from the levels found in the forest area may be related to the time period since adoption of the NTVS, which in this study was five years. Pereira Neto et al. (2007), who conducted a study on the period of consolidation of the NTS in corn crops over 2 to 14 years, found that the NTS is consolidated as of the 9th and 10th year after its implementation. These authors measured the area of the structures present in the soil crop profile through a geographic information system (GIS) and evaluated them by the statistical method of principal component analysis. They found that the structures where the NTS was implemented less than 8 years resembled those of the CTS. When the NTS was implemented for more than 9 years, the structures resembled those of the forest profile.

In the NTVS and CTS, the TOC levels depend on the amount of dry matter (shoot and root) produced by cover crops and on soil management, among other factors. Thus, the systems which promote the production and maintenance of dry matter on the soil surface provide the highest levels and accumulation of TOC in the soil. This pattern was observed in the NTVS compared to the CTS for the depth of 0.00-0.05 m. In this soil depth, the smaller TOC values in the CTS are due to increased mineralization of TOC caused by soil disturbance, which promotes the fragmentation of plant residues and consequently favors attack by microorganisms. These results corroborate the studies of Lovato et al. (2004) and Loss et al. (2009), who reported TOC losses in soils with intense disturbance, mainly due to increased microbial activity and increased exposure of plant residues to microorganisms and their enzymes. In the CTS, even with the higher supply of dry matter (Loss et al., 2015), the practices of soil tillage (plowing and harrowing) cause the rupture of the aggregates, with subsequent exposure of the TOC that was physically protected inside them, consequently resulting in lower TOC contents in the topsoil. The lower TOC levels in the CTS are directly related to the lower soil aggregation rates observed in the CTS compared to the NTVS at 0.00-0.05 m (Loss et al., 2015).

The absence of differences at depths of 0.05-0.10 and 0.10-0.20 m between treatments in the NTVS and CTS indicates the similarity of the cover crops used in the NTVS in adding TOC. However, in the CTS, the similarity of TOC contents in depth may be related to the incorporation of the plant residues of millet into deeper layers, homogenizing the TOC contents in these layers. The same pattern of similarity of TOC levels in the CTS and the NTVS was also described by Assis et al. (2006) in aggregates of a *Latossolo Vermelho* managed under the NTS (for 4 years) and the CTS (for 30 years). The authors verified that the C contents are reduced by cultivation of the soil compared to the native forest (subdeciduous forest). However, they also observed that aggregates under the NTS showed no increase in C content compared to aggregates under the CTS.

Soil chemical properties in the macroaggregates

The treatments under the NTVS and CTS had higher values of soil pH compared to the forest area, which had the highest levels of Al^{3+} and H+Al at the three depths evaluated in this study. In relation to treatments under the NTVS and CTS at the depth of 0.00-0.05 m, the pH values were higher in the NTVS, whereas at 0.05-0.10, the NTVS and CTS did not differ, nor at 0.10-0.20 m; the NTVS with the use of spontaneous vegetation (control) for soil cover showed the highest pH value of all the treatments (Table 1).

Table 1. Chemical properties of the macroaggregates of a Humic Dystrudept cultivated with onion under no-till compared to conventional tillage

Treatment	$pH(H_2O)$	P	K	Ca^{2+}	Mg^{2+}	Al^{3+}	H+Al
		mg dm^{-3}		cmol$_c$ dm^{-3}			
				0.00-0.05 m			
Black oat	5.22 a	67.44 a	534.38 a	8.27 a	2.73 b	0.03 b	4.97 a
Rye	5.38 a	67.39 a	565.61 a	7.46 a	3.01 a	0.00 b	4.62 a
Oilseed radish	5.26 a	70.79 a	509.17 a	8.23 a	2.31 b	0.10 b	4.97 a
Rye + Oilseed radish	5.30 a	72.89 a	462.94 a	8.06 a	2.63 b	0.09 b	4.91 a
Black oat + Oilseed radish	5.39 a	77.95 a	547.46 a	8.03 a	3.25 a	0.05 b	4.77 a
Control	5.50 a	71.36 a	462.95 a	8.25 a	3.09 a	0.22 a	4.67 a
CV (%)	3.98	9.61	17.89	6.90	13.59	29.94	15.56
CTS (m±CI 95 %)	4.98±0.17	79.02±8.32	143.94±19.57	4.80±0.31	2.26±0.07	0.34±0.16	6.10±0.61
Forest area (m±CI 95 %)	3.94±0.06	16.36±1.33	124.38±12.51	2.84±0.05	1.40±0.08	4.99±0.42	19.42±1.45
				0.05-0.10 m			
Black oat	5.10 a	64.09 a	272.17 a	6.94 a	1.94 b	0.11 a	6.19 a
Rye	5.07 a	39.07 a	305.74 a	6.37 a	2.08 b	0.17 a	5.95 a
Oilseed radish	5.05 a	56.67 a	295.63 a	5.88 b	2.13 b	0.18 a	6.53 a
Rye + Oilseed radish	5.08 a	49.31 a	276.19 a	6.48 a	2.08 b	0.17 a	6.21 a
Black oat + Oilseed radish	5.13 a	54.46 a	280.34 a	5.91 b	2.56 a	0.14 a	6.18 a
Control	5.26 a	50.89 a	324.62 a	5.06 b	2.26 b	0.13 a	5.65 a
CV (%)	3.26	22.76	20.96	4.80	12.61	18.34	13.66
CTS	5.00±0.09	99.55±11.9	62.29±3.78	5.91±0.29	2.47±0.33	0.21±0.08	5.11±0.36
Forest area	3.72±0.05	13.31±1.27	70.03±10.92	0.22±0.03	0.94±0.27	6.51a±0.45	20.80±1.85
				0.10-0.20 m			
Black oat	5.05 b	22.55 a	160.37 a	5.14 b	1.80 b	0.40 a	6.71 a
Rye	5.01 b	12.56 a	165.74 a	5.52 a	1.82 b	0.47 a	6.71 a
Oilseed radish	4.95 b	31.38 a	135.54 a	5.53 a	1.54 c	0.47 a	7.14 a
Rye + Oilseed radish	4.92 b	24.20 a	178.75 a	4.84 b	1.55 c	0.64 a	7.10 a
Black oat + Oilseed radish	5.13 b	18.33 a	141.92 a	5.62 a	2.13 a	0.21 a	6.21 a
Control	5.32 a	14.01 a	180.71 a	5.26 b	1.87 b	0.24 a	6.12 a
CV (%)	3.33	54.97	20.55	6.12	8.60	29.04	13.26
CTS	5.03±0.15	69.74±10.05	55.06±3.35	5.83±0.39	2.39±0.26	0.29±0.13	4.89±0.26
Forest area	3.96±0.15	5.45±0.17	43.34±5.30	0.20±0.03	0.58±0.05	5.98±0.36	17.28±2.59

Means followed by the same letter in the column do not differ from each other by the Scott-Knott test at 5 %. CV: coefficient of variation. Values of the CTS and forest area expressed by the means and confidence interval (m ± CI 95 %).

Most Brazilian soils are acidic (pH <5.5) and may manifest problems caused by Al toxicity, which in the Al^{3+} form is harmful to plants, affecting the development of their root system and, consequently, their yield (Comin et al., 2006; Meurer, 2012). In this respect, we observed that only the treatment with spontaneous vegetation, which did not differ from the other treatments under the NTVS at 0.00-0.05 m, had a pH value of 5.5, while we observed lower values in the other treatments. The pattern shown by the spontaneous vegetation may be related to the diversity of families and species of this treatment, which have different root systems and phytochemical composition, resulting in more complex relationships with microorganisms and greater hardiness and adaptation in relation to the other species of cover crops.

Overall, the higher pH values in the NTVS compared to other treatments, mainly at 0.00-0.05 m, are due to the use and maintenance of cover crops, which through their dynamic and active root systems at various soil depths, as well as production of biomass, favor the release and exudation of low molecular weight organic acids. This results in an increase in negative charges in the soil and thus promotes the complexation of H and Al ions, causing an increase in pH and leaving the Ca, Mg, and K cations free in the soil solution (Franchini et al., 1999; Amaral et al., 2004; Pavinato and Rosolem, 2008). In a study on the ion dynamics in an acidic soil leached with extracts of cover crop residues, Franchini et al. (1999) observed that the application of extracts of black oat and oilseed radish in the soil column increased soil pH from 4.1 to 5.1 and 5.9, respectively, for the 0.00-0.05 m layer, with gradually smaller effects at greater depths.

Plowing and harrowing in the CTS favored the mineralization of millet plant residues at the depth of 0.00-0.05 m, resulting in decreased release of organic acids of low molecular weight and thus less complexation of H and Al, which is corroborated by the lower pH values and higher Al values, except for the control treatment (Table 1). However, the lower pH values and, consequently, the higher Al^{3+} contents in the forest area are due to the fact that this system represents the natural condition of the soil, where there was no liming.

Treatments under the NTVS and CTS had higher P levels than those of the forest area at the first two depths (0.00-0.05 and 0.05-0.10 m). The NTVS and CTS did not differ in P content at the depth of 0.00-0.05 m. However, the CTS showed higher P content at 0.05-0.10 m, while the NTVS was similar to the forest area at 0.10-0.20 m, with lower levels of P compared to the CTS. For K, we found that the use of single or mixed cover crops, as well as spontaneous vegetation for onion cultivation in the NTVS, showed higher levels at the three depths evaluated in this study. Furthermore, the CTS and forest area did not differ and had lower values (Table 1).

Extractable P and exchangeable K contents in treatments under the NTVS and the P content under the CTS were interpreted as very high at the three depths, whereas the forest area had P levels considered high at the depths of 0.00-0.05 and 0.05-0.10 m, and levels considered low at 0.10-0.20 m (CQFS-RS/SC, 2004). These results of the cultivation systems are due to the fertilization conducted in the areas, in addition to the effect of the cover crops. We observed that the different soil management systems (NTVS and CTS) did not affect the P values of the surface layer (0.00-0.05 m), but they showed statistical differences at the depths of 0.05-0.10 and 0.10-0.20 m. The higher P values in the CTS may be related to the additions of P and associated with the higher C contents of the fulvic acid fraction (C-FAF) in this system compared to the NTVS for the depths of 0.05-0.10 and 0.10-0.20 m (Santos, 2016). Fulvic acids and organic acids of low molecular weight may also compete for the adsorption sites of phosphate anions, thus favoring the availability of P to plants (Andrade et al. 2003; Pavinato and Rosolem 2008).

Phosphorus adsorbed by the colloids is very important for the replacement of P taken up by plants (Gatiboni et al., 2007). Additionally, the P bound to the SOM sites has greater lability compared to the P bound to the mineral fractions, such as clay. With the soil turnover in the CTS, the SOM (TOC) of the surface layer is incorporated into greater depths (0.05-0.10 and 0.10-0.20 m) and is mineralized more quickly, providing labile P to microorganisms. Moreover, negative charges can be generated by the deprotonation of exposed hydroxyls in clays and SOM, resulting in repulsion between the phosphate and the adsorbent surface (McBride, 1994). This may have resulted in increased P concentration in depth in the CTS, in addition to differences in phosphate fertilization, i.e., triple superphosphate in the CTS (165 kg ha^{-1} applied annually) and natural Gafsa rock phosphate in the NTVS (175 kg ha^{-1} applied up to 2011).

Due to limited soil turnover, in the NTVS the P added by decomposition of the plant residues remains on the surface layer and slowly increases at the other depths through decomposition of roots and the rhizosphere. Plants exude organic acids via the root system, which is capable of promoting an ion exchange with P adsorbed to soil colloids, increasing the P concentration available in the rhizosphere of these plants (Lynch, 1990). Furthermore, the constant presence of roots in the NTVS can also induce high activity of acid phosphatases in the rhizosphere, which also increases P availability to plants (Gahoonia and Nielsen, 2004).

The high P and K levels found in the NTVS and CTS are associated with fertilization, but also demonstrate the capacity of cover crops to contribute to nutrient cycling. Their roots act dynamically in the soil, exploiting different depths, taking up nutrients from deeper layers, accumulating them in their phytomass, and depositing them on the surface as they are decomposed, thereby contributing to maintaining and/or increasing fertility in the soil aggregates (Melo et al., 2011).

In the CTS, although millet was used as a cover crop and incorporated into the soil, the use of plowing and harrowing in this system causes aggregate breakdown, resulting in lower rates of aggregation (Loss et al., 2015) and, consequently, higher losses of K^+ by leaching. With the rupture of the aggregates, the K^+ that was physically protected inside the aggregates is readily available because, according to Rosolem et al. (2003) and Costa et al. (2005), K is not a structural component of any plant compound and its mineralization is not a prerequisite for its release. However, it is found in the form of K circulating in plants in large quantities and is of immediate use. Therefore, when the plant is decomposed, it is completely released to the soil and can be quickly used by other plants, but losses by leaching may also occur, especially in sandy or unstructured soils.

Higher K^+ levels in the NTVS compared to the CTS are associated with greater protection (aggregation) of this element in the macroaggregates, in addition to the differences in the amounts of potassium chloride applied (105 and 125 kg ha^{-1} for the CTS and NTVS, respectively). Potassium is also benefited by this system possibly because the NTVS increases the supply of TOC (Figure 1, 0.00-0.05 m) and, consequently, causes chemical, physical, and biological improvements in the soil. Therefore, we observe larger amounts of K^+ in the NTVS since the SOM is mineralized more quickly in the CTS, which has a smaller number of sites that bind with K^+, resulting in a smaller amount of K^+ in this system.

The NTVS and CTS had higher Ca^{2+} and Mg^{2+} contents levels in comparison to the forest area at the three depths evaluated in this study. For Ca^{2+}, all the treatments under the NTVS at 0.00-0.05 m, and the black oat, rye, and rye + oilseed radish treatments at 0.05-0.10 m had higher levels. At the depth of 0.10-0.20 m, rye, oilseed radish, and black oat + oilseed radish treatments and the CTS had higher averages than the other treatments. For Mg^{2+}, rye, black oats + oilseed radish, and control treatments showed the highest levels at a depth of 0.00-0.05 m under the NTVS. At the depth of 0.05-0.10 m, the black oat + oilseed radish treatment and the CTS had higher Mg^{2+} contents. For the depth of 0.10-0.20 m, the CTS had higher Mg^{2+} contents, and for the NTVS, the black oat + oilseed radish treatment stood out with the highest Mg^{2+} values.

Among the single and mixed cover crops, in general, the black oat + oilseed radish treatment stood out, because it had higher levels of Ca^{2+} at 0.10-0.20 m in comparison to the black oat, rye + oilseed radish, and control treatments, as well as higher Mg contents compared to the other cover crops at 0.05-0.10 and 0.10-0.20 m. Oilseed radish favors soil aggregation (Loss et al., 2015) because it presents a physical effect of soil compression as it develops its pivoting root system, while black oat is distinguished by its chemical effects resulting from its fasciculate and dense root system, which promotes a better distribution of root exudates (Liu et al., 2005; Casali, 2012). Therefore, intercropping these cover crops increases the cycling and accumulation of Ca^{2+} and Mg^{2+} in soil of the macroaggregates.

In addition to the effect of the liming performed in 1996, the NTVS also has benefits attributed to the cover crops, which favor plant residues at the surface and in depth, increasing nutrient cycling and contributing to maintaining or increasing soil fertility. Maintaining the cover crop residues on the soil surface (as is done in the NTVS), in contrast with the CTS, diminishes microbial action due to less contact of residues with the soil and their lower fragmentation for they do not undergo the mechanical effect of incorporation into the soil and so have slower decomposition. Thus, in the NTVS, which constantly has a supply of plant residues (shoot and root), there may be continuous production of organic compounds of low molecular weight, and their effect on the fertility of the macroaggregates is continuous, not only during the decomposition period which follows incorporation, as is the case of the CTS, as reported by Pavinato and Rosolem (2008).

In the CTS and NTVS, the soil pH was adjusted to 6.0 by liming (in 2010 in the CTS and in 1996 in the area where the NTVS was later implemented in 2009). One would therefore expect higher Ca^{2+} and Mg^{2+} in the CTS, which was not observed in the surface layer of the soil. Consequently, differences in the contents of these bases are due to soil tillage in the CTS, which causes the breakdown of aggregates and promotes the loss of exchangeable bases, and this pattern is visible mainly in the topsoil (0.00-0.05 m), in which higher values of Ca^{2+} and Mg^{2+} (Table 1) are found in the NTVS. In the CTS, the results found [high levels of P and exchangeable bases according to CQFS-RS/SC (2004)] are related to fertilization and liming and the use of millet as a cover crop, which according to Teixeira et al. (2011), is a species that produces high amounts of dry matter and has a high C/N ratio with slower degradation of biomass; in addition, it gradually accumulates and releases all macronutrients (N, P, K, Ca, and Mg).

In comparing the treatments under the NTVS with the CTS, especially at a depth of 0.00-0.05 m the use of single and mixed cover crops contributed to an increase in K^{+}, Ca^{2+}, and Mg^{2+}, as well as to higher pH and lower Al^{3+} values (except for the control treatment) in the soil macroaggregates. Soil macroaggregates under the NTVS were favored by no soil turnover and the intense activity of the root systems of the cover crops, together with nutrient release and cycling of plant biomass. These results are corroborated by higher aggregation indexes (mean weight diameter - MWD and geometric mean diameter - GMD) in the NTVS compared to the CTS at the three depths evaluated in this study, and by higher values of the GMD in the NTVS at the depths of 0.00-0.05 and 0.05-0.10 m compared to the forest area (Loss et al., 2015).

The NTVS is a useful tool with potential for the agroecological transition process since it contributes to improvement of the chemical properties of the soil aggregates and, consequently, can reduce the need for use of highly soluble fertilizers, thus contributing to improvement and maintenance of edaphic and environmental quality over the years.

CONCLUSIONS

The conversion of onion cultivation areas from the CTS to the NTVS increases organic carbon, pH, Ca^{2+}, Mg^{2+}, and K^{+} contents in the soil macroaggregates at a depth of 0.00-0.05 m after five years.

In the NTVS, there is an increase in K^{+} content in the macroaggregates at all evaluated depths in comparison to the CTS.

The use of millet in the CTS increases the P content at greater depths (0.05-0.10 and 0.10-0.20 m).

Intercropping of black oat + oilseed radish increases Ca^{2+} content at the 0.10-0.20 m depth compared to the black oat, rye + oilseed radish, and control treatments. Additionally, there is increased Mg^{2+} content in comparison to the other cover crops at the depths of 0.05-0.10 and 0.10-0.20 m.

REFERENCES

Adu JK, Oades JM. Physical factors influencing decomposition of organic materials in soil aggregates. Soil Biol Biochem. 1978;10:109-15. https://doi.org/10.1016/0038-0717(78)90080-9

Amaral AS, Anghinoni I, Deschamps FC. Resíduos de plantas de cobertura e mobilidade dos produtos da dissolução do calcário aplicado na superfície do solo. Rev Bras Cienc Solo. 2004;28:115-23. https://doi.org/10.1590/S0100-06832004000100012

Andrade FV, Mendonça ES, Alvarez V VH, Novais RF. Adição de ácidos orgânicos e húmicos em Latossolos e adsorção de fosfato. Rev Bras Cienc Solo. 2003;27:1003-11. https://doi.org/10.1590/S0100-06832003000600004

Assis CP, Jucksch I, Mendonça ES, Neves JCL. Carbono e nitrogênio em agregados de Latossolo submetido a diferentes sistemas de uso e manejo. Pesq Agropec Bras. 2006;41:1541-50. https://doi.org/10.1590/S0100-204X2006001000012

Casali CA. Sistemas de culturas sob diferentes manejos por longa duração alteram as formas de fósforo do solo? [tese]. Santa Maria: Universidade Federal de Santa Maria; 2012.

Christensen BT. Carbon in primary and secondary organo-mineral complexes. In: Carter MR, Stewart BA, editors. Structure and organic matter storage in agricultural soils. Boca Raton: CRC Press; 1996. p.97-165.

Claessen MEC, organizador. Manual de métodos de análise de solo. 2a ed. Rio de Janeiro: Centro Nacional de Pesquisa de Solos; 1997.

Comin JJ, Barloy J, Hallaire V, Zanette F, Miller PRM. Effects of aluminium on the adventitious root system, aerial biomass and grain yield of maize grown in the field and in a rhizotron. Exp Agric. 2006;42:351-66. https://doi.org/10.1017/S0014479706003620

Comissão de Química e Fertilidade do Solo - CQFS-RS/SC. Manual de adubação e calagem para os estados do Rio Grande do Sul e Santa Catarina. 10a ed. Porto Alegre: Sociedade Brasileira de Ciência do Solo; 2004.

Costa GS, Gama-Rodrigues AC, Cunha GM. Decomposição e liberação de nutrientes da serapilheira foliar em povoamentos de *Eucalyptus grandis* no norte fluminense. Rev Árvore. 2005;29:563-70. https://doi.org/10.1590/S0100-67622005000400008

Coutinho FS, Loss A, Pereira MG, Rodrigues Junior DJ, Torres JLR. Estabilidade de agregados e distribuição do carbono em Latossolo sob sistema plantio direto em Uberaba, Minas Gerais. Commun Sci. 2010;1:100-5.

Franchini JC, Miyazawa M, Pavan MA, Malavolta E. Dinâmica de íons em solo ácido lixiviado com extratos de resíduos de adubos verdes e soluções puras de ácidos orgânicos. Pesq Agropec Bras. 1999;34:2267-76. https://doi.org/10.1590/S0100-204X1999001200014

Freitas AC. Cebola Catarinense no topo. Rev Agropec Catarinense. 2012;25:20-5.

Gahoonia TS, Nielsen NE. Root traits as tools for creating phosphorus efficient crop varieties. Plant Soil. 2004;260:47-57. https://doi.org/10.1023/B:PLSO.0000030168.53340.bc

Gatiboni LC, Kaminski J, Rheinheimer DS, Flores JPC. Biodisponibilidade de formas de fósforo acumuladas em solo sob sistema plantio direto. Rev Bras Cienc Solo. 2007;31:691-9. https://doi.org/10.1590/S0100-06832007000400010

Gonçalves PAS, Boff P, Rowe E. Referências tecnológicas para a produção de cebola em sistemas orgânicos. Florianópolis: Epagri; 2008. (Boletim técnico, 142).

Instituto Brasileiro de Geografia e Estatística - IBGE. Levantamento Sistemático da Produção Agrícola. Rio de Janeiro: 2015 [acesso: 3 Set 2015]. Disponível em: ftp://ftp.ibge.gov.br/Producao_Agricola/Levantamento_Sistematico_da_Producao_Agricola_[mensal]/Fasciculo/lspa_201506.pdf.

Kurtz C, Schmitt DR, Sgrott EZ, Wamser GH, Santos IA, Costa JV, Gonçalves PAS, Lannes SD, Carre-Missio V. Sistema de produção para a cebola: Santa Catarina. 4a ed rev. Florianópolis: Epagri; 2013

Liu A, Ma BL, Bomke AA. Effects of cover crops on soil aggregate stability, total organic carbon, and polysaccharides. Soil Sci Soc Am J. 2005;69:2041-8. https://doi.org/10.2136/sssaj2005.0032

Loss A, Basso A, Oliveira BS, Koucher LP, Oliveira RA, Kurtz C, Lovato PE, Curmi P, Brunetto G, Comin JJ. Carbono orgânico total e agregação do solo em sistema de plantio direto agroecológico e convencional de cebola. Rev Bras Cienc Solo. 2015;39:1212-24. https://doi.org/10.1590/01000683rbcs20140718

Loss A, Pereira MG, Schultz N, Anjos LHC, Silva EMR. Carbono e frações granulométricas da matéria orgânica do solo sob sistemas de produção. Cienc Rural. 2009;39:1067-72. https://dx.doi.org/10.1590/S0103-84782009005000036

Lovato T, Mielniczuk J, Bayer C, Vezzani F. Adição de carbono e nitrogênio e sua relação com os estoques no solo e com o rendimento do milho em sistemas de manejo. Rev Bras Cienc Solo. 2004;28:175-87. https://doi.org/10.1590/S0100-06832004000100017

Lynch JM. Introduction: Some consequences of microbial rhizosphere competence for plant and soil. In: Lynch JM, editor. The rhizosphere. Chichester: Wiley-Interscience Publication; 1990. p.1-10.

Machado LV, Rangel OJP, Mendonça ES, Machado RV, Ferrari JL. Fertilidade e compartimentos da matéria orgânica do solo sob diferentes sistemas de manejo. Coffee Sci. 2014;9:289-99.

Madeira NR. Avanços tecnológicos no cultivo de hortaliças em sistema de plantio direto. In: Anais do 49º Congresso Brasileiro de Olericultura [CD-ROM]; 2009; Águas de Lindóia. Brasília, DF: Horticultura Brasileira; 2009. p.4024-32.

Mafra AL, Guedes SFF, Klauberg Filho O, Santos JCP, Almeida JA, Rosa JD. Carbono orgânico e atributos químicos do solo em áreas florestais. Rev Árvore. 2008;32:217-24. https://doi.org/10.1590/S0100-67622008000200004

Mcbride MB. Environmental chemistry of soils. New York: Oxford University Press; 1994.

Melo AV, Galvão JCC, Braun H, Santos MM, Coimbra RR, Silva RR, Reis WF. Extração de nutrientes e produção de biomassa de aveia-preta cultivada em solo submetido a dezoito anos de adubação orgânica e mineral. Semina: Cienc Agrár. 2011;32:411-20. https://doi.org/10.5433/1679-0359.2011v32n2p411

Meurer EJ. Fundamentos de química do solo. 5a ed. Porto Alegre: Evangraf; 2012.

Monegat C. Manejo de plantas de cobertura do solo em pequenas propriedades. In: Monegat C, editor. Plantas de cobertura do solo: características e manejo em pequenas propriedades. Chapecó: Edição do Autor; 1991. p.146-239.

Nascimento PC, Lani JL, Mendonça ES, Zoffoli HJO, Peixoto HTM. Teores e características da matéria orgânica de solos hidromórficos do Espírito Santo. Rev Bras Cienc Solo. 2010;34:339-48. https://doi.org/10.1590/S0100-06832010000200007

Panachuki E, Bertol I, Alves Sobrinho T, Oliveira PTS, Rodrigues DBB. Perdas de solo e de água e infiltração de água em Latossolo Vermelho sob sistemas de manejo. Rev Bras Cienc Solo. 2011;35:1777-85. https://doi.org/10.1590/S0100-06832011000500032

Pavinato PS, Rosolem CA. Disponibilidade de nutrientes no solo - decomposição e liberação de compostos orgânicos de resíduos vegetais. Rev Bras Cienc Solo. 2008;32:911-20. https://doi.org/10.1590/S0100-06832008000300001

Pereira Neto OC, Guimarães MF, Ralisch R, Fonseca ICB. Análise do tempo de consolidação do sistema de plantio direto. Rev Bras Eng Agríc Amb. 2007;11:489-96. https://doi.org/10.1590/S1415-43662007000500007

Rosolem CA, Calonego JC, Foloni JSS. Lixiviação de potássio da palhada de espécies de cobertura de solo de acordo com a quantidade de chuva aplicada. Rev Bras Cienc Solo. 2003;27:355-62. https://doi.org/10.1590/S0100-06832003000200015

Santos HG, Jacomine P KT, Anjos LHC, Oliveira VAVL, Francisco J, Coelho MR, Almeida JA, Cunha TJF, Oliveira JB, coordenadores. Sistema brasileiro de classificação de solos. 3a ed. Brasília, DF: Embrapa Solos; 2013.

Santos LH. Frações orgânicas e atributos químicos em agregados do solo sob sistemas de plantio direto e convencional de cebola [dissertação]. Florianópolis: Universidade Federal de Santa Catarina; 2016.

Scholes RJ, van Breemen N. The effects of global change on tropical ecosystems. Geoderma. 1997;79:9-24. https://doi.org/10.1016/S0016-7061(97)00036-0

Six J, Paustian K, Elliott ET, Combrink C. Soil structure and soil organic matter: I. Distribution of aggregate size classes and aggregate associated carbon. Soil Sci Soc Am J. 2000;64:681-9. https://doi.org/10.2136/sssaj2000.642681x

Soil Survey Staff. Soil Taxonomy: a basic system of soil classification for making and interpreting soil surveys. 2nd ed. Washington, DC: US Government Printing Office; 2006.

Souza M, Comin JJ, Leguizamón ES, Kurtz C, Brunetto G, Müller Júnior V, Ventura B, Camargo AP. Matéria seca de plantas de cobertura, produção de cebola e atributos químicos do solo em sistema plantio direto agroecológico. Cienc Rural. 2013;43:21-7. https://dx.doi.org/10.1590/S0103-84782012005000150

Tedesco MJ, Volkweiss SJ, Bohnen H, Gianello C, Bissani CAA. Análise de solos, plantas e outros materiais. 2a ed. Porto Alegre: Universidade Federal do Rio Grande do Sul; 1995. (Boletim técnico, 5).

Teixeira MB, Loss A, Pereira MG, Pimentel C. Decomposição e liberação de nutrientes da parte aérea de plantas de milheto e sorgo. Rev Bras Cienc Solo. 2011;35:867-76. https://doi.org/10.1590/S0100-06832011000300021

Vilanova CC. Sistema de plantio direto de cebola: contribuições das plantas de cobertura no manejo ecológico de plantas espontâneas [dissertação]. Florianópolis: Universidade Federal de Santa Catarina; 2011.