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Carbon in aggregate size classes in a Rhodic Eutrudox under different cropping systems

Carbono em classes de agregados em um Latossolo Vermelho sob diferentes sistemas de cultura

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Abstract

Soil productive capacity is related to levels of carbon (C) in aggregates of different sizes. The aim of this study was to assess total organic carbon levels in different size classes of water-stable aggregates in a Rhodic Eutrudox under different production systems. The cropping systems assessed were no-tillage (NT); no-tillage scarified every three years (NTS); disk plowing (DP) and heavy disking (HD). All systems were subjected to crop succession (S) (soybean - *Glycine max* / wheat - *Triticum aestivum*) and rotation (R) (soybean, maize (*Zea mays*), wheat) and cover and green manure (*Lupinus albus*, *Raphanus sativus* and *Avena strigosa*). Intact soil samples were collected in trenches at depths of 0–0.10; 0.10-0.20; 0.20–0.30 and 0.30-0.40 m. The highest levels of carbon were found under no-tillage, irrespective of the aggregate size class. In all treatments, the top layer (0.0–0,10 m) under crop succession showed the highest carbon content for all aggregate size classes. However, at depths below 0.10 m, crop rotation exhibited the highest carbon levels (between 12 and 20 g kg^{-1}). After 29 years of trials, cropping systems with the lowest soil disturbance combined with crop rotation were found to contribute to raising the level of carbon in the soil and maintaining stable aggregates.

Key words: Aggregation. Cropping system. Production system. Structure.

Resumo

A capacidade produtiva do solo está relacionada a níveis de carbono (C) em agregados de diferentes tamanhos. O objetivo deste estudo foi avaliar os níveis totais de carbono orgânico em diferentes classes de tamanho de agregados estáveis em água em um Latossolo Vermelho eutroférrico sob diferentes sistemas de produção após 26 anos. Os sistemas de cultivo avaliados foram plantio direto (NT); Plantio direto escarificado a cada três anos (NTS); arado de disco (DP) e disco pesado (HD). Todos os sistemas foram submetidos a sucessão de culturas (S) (soja - *Glycine max* / trigo - *Triticum aestivum*)

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e rotação (R) (soja; milho (*Zea mays*); trigo) e de cobertura e adubação verde (tremoço (*Lupinus albus*), nabo forrageiro (*Raphanus sativus*) e aveia preta (*Avena strigosa*). As amostras de solo intactas foram coletadas em trincheiras em profundidades de 0 a 0,10; 0,10-0,20; 0,20-0,30 e 0,30-0,40 m. Os níveis mais elevados de carbono foram encontrados em plantio direto, independentemente da classe de tamanho agregado. Em todos os tratamentos, a camada superior (0,0-0,10 m) sob sucessão de culturas mostrou os teores de carbono mais altos para todas as classes de tamanho agregado. No entanto, nas profundidades abaixo de 0,10 m, a rotação das culturas exibiu os maiores níveis de carbono (entre 12 e 20 g kg^{-1}). Após 29 anos da implantação do experimento, os sistemas de cultivo com o menor distúrbio do solo combinados com a rotação das culturas contribuíram para elevar o nível de carbono no solo e manter agregados estáveis.

Palavras-chave: Agregação. Sistema de cultura. Sistemas de produção. Estrutura.

Organic matter is essential for ensuring the quality and productive capacity of the soil, since it affects the soil's chemical attributes (nutrient availability), physical attributes (aggregation and structure) and biological attributes (biological activity). However, in tropical regions the dynamics of organic matter are regulated by high temperatures and rainfall, resulting in a high rate of decomposition. Agricultural practices therefore directly affect additions and losses of organic matter and carbon in the soil, and therefore the formation and stability of aggregates (VEZZANI; MIELNICZUK, 2011).

The aim of this study was to assess the level of total organic carbon in different size classes of water-stable aggregate in a Rhodic Eutrudox under various cropping systems with succession and rotation after 26 years.

The experiment was set up in 1988/1989 in Londrina, state of Parana, (23º11'39" S and 51º10'40" W), in a Rhodic Eutrudox (EMBRAPA, 2013). Details of the experimental area can be found in Barreto et al. (2009).

The experimental design consisted of randomized blocks in a 2 x 4 factorial arrangement, with four replications, involving two production systems and four cropping systems. The two production systems assessed were: 1 - crop succession (S) and (soybean - *Glycine max* / wheat - *Triticum aestivum*) and 2 - rotation (R) (soybean, maize (*Zea mays*), wheat) and cover and green manure (*Lupinus albus*, *Raphanus sativus* and *Avena strigosa*)The four cropping systems assessed were: no-tillage (NT); no-tillage with scarification every three years (NTS) in winter; conventional preparation by disk plowing (DP) and conventional preparation with heavy disking (HD).

Soil samples were collected from the 0.00–0.10; 0.10–0.20; 0.20–0.30 and 0.30–0.40 m layers. The method described in Claessen (1997), was used to determine the aggregate size classes and the carbon was determined after oxidation by $K_2Cr_2O_7$ in sulfuric medium.

After testing the assumptions, the data were then subjected to analysis of variance and the means obtained were compared by non-orthogonal contrasts using the Scheffé test at 5 and 10 % probability, to compare the cropping systems using SISVAR software.

Tilling intensity affected carbon levels, showing that cropping systems that induce soil disaggregation also cause a drop in carbon levels by exposing organic matter to bad weather, since the carbon is no longer physically protected inside the aggregates.

Working on four farming systems Costa Júnior et al. (2012) observed that NT boosted carbon levels in macro and microaggregates compared to conventional preparation (CP) systems and pasture, and in some cases the result were better than under savanna vegetation. The accumulation of TOC in larger aggregates could be due to the higher contribution of plant waste (both shoots and roots) resulting from the plant diversity involved in the production system, especially in the 0.00-0.20 m layer with crop rotation under NT (Table 1 and 2). This build-up of carbon under NT is also due to continuous additions from plant waste, the absence of tillage and the system's consolidation time. This has also be reported by other authors (COSTA JÚNIOR et al., 2012).

In aggregates > 8 mm, the use of soil preparation implements affected the level of TOC, with lower levels compared to conservationist practices, even under NTS with scarification every three years.

Table 1. Mean values of total organic carbon (g kg^{-1}) through different screens and in different production systems (rotation and succession) and cropping systems (no-tillage; no-tillage with scarification; disk plowing and heavy disking), at four depths.

Total Organic Carbon (g kg^{-1}) (8 mm)								
Production Systems / Cropping Systems	Depths (m)							
	0.00 - 0.10		0.10 - 0.20		0.20 - 0.30		0.30 - 0.40	
	Succession	Rotation	Succession	Rotation	Succession	Rotation	Succession	Rotation
No Tillage	23.18	20.64	16.85	16.75	12.85	13.83	9.88	12.95
No Tillage, Scarified	17.14	18.31	14.8	13.71	12.07	11.27	7.72	11.93
Disk Plowing	18.31	17.92	15.58	15.19	12.71	11.88	8.96	9.15
Heavy Disking	9.25	16.07	14.41	16.94	10.9	8.76	5.66	3.4
(4 mm)								
No Tillage	22.25	19.32	14.41	15.38	11.49	12.46	9.25	13.12
No Tillage, Scarified	18.31	17.53	15.19	15.01	17.71	8.96	7.4	5.06
Disk Plowing	17.53	16.75	15.19	14.41	12.46	12.29	5.45	8.18
Heavy Disking	15.19	15.77	13.05	13.14	9.54	7.3	6.03	8.18
(2 mm)								
No Tillage	20.79	18.4	13.83	14.61	9.93	12.46	7.79	12.31
No Tillage, Scarified	17.53	16.75	14.02	14.8	11.49	9.83	5.84	6.82
Disk Plowing	16.16	16.75	14.41	12.66	11.29	10.51	5.74	6.62
Heavy Disking	16.16	15.1	13.24	11.39	4.57	8.03	6.6	5.18
(1 mm)								
No Tillage	20.69	18.45	13.93	14.61	9.93	11.68	7.6	10.55
No Tillage, Scarified	15.97	17.14	12.27	13.34	9.83	8.96	6.42	6.22
Disk Plowing	13.65	13.44	13.63	13.63	12.66	8.14	4.09	4.09
Heavy Disking	15.77	14.51	11.78	9.62	8.78	5.99	5.25	4.28
(0,5 mm)								
No Tillage	19.91	17.53	12.86	13.83	8.37	10.9	7.01	9.74
No Tillage, Scarified	15.97	16.36	12.85	13.63	9.64	9.15	6.62	6.03
Disk Plowing	13.83	12.66	12.85	12.85	11.1	7.4	6.81	2.55
Heavy Disking	15.19	14.99	12.07	8.83	5.84	4.96	4.67	3.31
(0,25 mm)								
No Tillage	19.96	17.14	12.27	13.05	8.18	10.51	5.84	9.83
No Tillage, Scarified	15.58	15.97	14.02	12.85	9.35	8.96	7.11	5.06
Disk Plowing	14.8	12.07	13.63	12.07	11.1	5.55	6.23	6.62
Heavy Disking	16.75	14.21	11.05	9.1	9.35	6.76	7.4	5.45

NT: no-tillage; NTS: no-tillage, scarified; DP: conventional preparation with disk plowing; HD: conventional preparation with heavy disking.

As the soil is tilled, superficial carbon can be redistributed at depth, which can increase C levels in aggregates < 8 mm, but according to Sarkhot et al. (2015), in the long term there is a drop in C as intensive tilling practices continue. However, using different plant species that accumulate higher quantities of dry matter in the soil, carbon tends to increase in aggregates in layers below 0.10 m.

The explanation for the higher level of TOC is due to an increment on the surface from crop waste and the greater concentration of roots at depth, especial in the crop rotation system because of the diversity of plant species that exploit deeper soil layers, as well as the soluble organic compounds excreted by plants and microorganisms.

Table 2. Values of *p* in non-orthogonal contrasts through different screens and with different production systems (rotation and succession) and cropping systems (no-tillage; no-tillage, scarified; disk plowing and heavy disking) at four depths

Total Organic Carbon (g kg^{-1}) (8 mm)								
Production Systems / Cropping Systems	Depths (m)							
	0.00 - 0.10		0.10 - 0.20		0.20 - 0.30		0.30 - 0.40	
	Succession	Rotation	Succession	Rotation	Succession	Rotation	Succession	Rotation
Contrasts	$p > F$ (Scheffé)							
NT x DP	0.002*	0.031*	0.2	0.124	0.821	0.014*	0.317	0.002*
NT x HD	0.000*	0.002*	0.028*	0.835	0.014*	0.000*	0.001*	0.000*
NT x NTS	0.000*	0.056*	0.054*	0.010*	0.247	0.003*	0.042*	0.27
DP x HD	0.000*	0.115	0.233	0.089**	0.020*	0.001*	0.005*	0.000*
NTS x HD	0.000*	0.065**	0.679	0.007*	0.098**	0.004*	0.039*	0.000*
NTS x DP	0.297	0.719	0.415	0.141	0.34	0.361	0.213	0.012*
CV %	5.95		5.84		5.29		9.91	
(4 mm)								
NT x DP	0.007*	0.082**	0.516	0.42	0.301	0.222	0.16	0.075**
NT x HD	0.001*	0.025*	0.256	0.079**	0.058**	0.000*	0.229	0.075**
NT x NTS	0.016*	0.202	0.516	0.755	0.000*	0.004*	0.48	0.008*
DP x HD	0.109	0.477	0.091**	0.299	0.011*	0.002*	0.822	1.000
NTS x HD	0.043*	0.213	0.091**	0.135	0.000*	0.097**	0.601	0.243
NTS x DP	0.564	0.564	1.000	0.615	0.000*	0.029*	0.458	0.243
CV %	7.26		5.97		7.73		32.39	
(2 mm)								
NT x DP	0.032*	0.402	0.599	0.097**	0.582	0.435	0.366	0.022*
NT x HD	0.032*	0.108	0.599	0.012*	0.046*	0.091**	0.594	0.007*
NT x NTS	0.113	0.402	0.86	0.86	0.53	0.297	0.388	0.027*
DP x HD	1.000	0.403	0.301	0.264	0.016*	0.323	0.701	0.521
NTS x HD	0.488	0.403	0.485	0.008*	0.014*	0.469	0.733	0.466
NTS x DP	0.488	1.000	0.725	0.071**	0.937	0.783	0.966	0.928
CV %	11.07		7.93		24.69		30.55	

continue

continuation

(1 mm)								
NT x DP	0.021*	0.084**	0.856	0.55	0.161	0.076**	0.162	0.018*
NT x HD	0.090**	0.164	0.2	0.008*	0.539	0.009*	0.339	0.021*
NT x NTS	0.101	0.63	0.316	0.44	0.957	0.161	0.626	0.091**
DP x HD	0.441	0.694	0.265	0.026*	0.055*	0.261	0.629	0.936
NTS x HD	0.943	0.342	0.762	0.037*	0.574	0.129	0.629	0.427
NTS x DP	0.401	0.189	0.406	0.857	0.147	0.661	0.341	0.928
CV %	16.41		12.33		19.21		38.86	
(0.5 mm)								
NT x DP	0.030*	0.073**	0.997	0.53	0.242	0.14	0.934	0.009*
NT x HD	0.081**	0.327	0.613	0.006*	0.276	0.020*	0.328	0.016*
NT x NTS	0.137	0.646	0.998	0.899	0.578	0.444	0.868	0.132
DP x HD	0.592	0.364	0.615	0.021*	0.035*	0.294	0.368	0.748
NTS x HD	0.759	0.592	0.615	0.008*	0.112	0.083**	0.412	0.257
NTS x DP	0.404	0.161	1.000	0.615	0.522	0.444	0.934	0.928
CV %	15.68		12.09		26.32		39.2	
(0.25 mm)								
NT x DP	0.057**	0.061**	0.429	0.57	0.027*	0.004*	0.729	0.013*
NT x HD	0.214	0.256	0.479	0.036	0.419	0.020*	0.181	0.002*
NT x NTS	0.099**	0.642	0.314	0.909	0.419	0.286	0.269	0.001*
DP x HD	0.442	0.399	0.147	0.100**	0.12	0.4	0.308	0.308
NTS x HD	0.642	0.488	0.100**	0.044*	1.000	0.142	0.8	0.729
NTS x DP	0.756	0.138	0.819	0.648	0.12	0.031*	0.436	0.928
CV %	15.49		13.59		15.87		16.39	

*Scheffé test at 5 %; ** Scheffé test at 10 %. NT: no-tillage; NTS: no-tillage, scarified; DP: conventional preparation with disk plowing; HD: conventional preparation with heavy disking.

In many cases, this response is not merely related to the quantity of organic matter deposited on the soil, but also to the volume and distribution of roots along the profile, and the system adopted, whether succession or rotation (QIAO et al., 2015). Planting different crops causes a build-up of carbon and enhances aggregate stability. Santos et al. (2012) observed that the different crops studied raised average C levels in the 0.00 – 0.10 m layer, in line with our findings.

Increasing organic C levels results in an increase in soil aggregation indices by decreasing classes of lower diameter (< 0.25 mm) (ASSIS et al., 2006; BATISTA et al., 2013). The TOC levels in microaggregates can be explained by the build-up of humic fractions, and in macroaggregates by free organic matter (particulate carbon). The accumulation of free organic matter is therefore linked to the formation of larger aggregates, and association with iron oxides helps form larger aggregates of larger diameter, enhancing carbon protection since the aggregation also depends on oxides (FERREIRA et al., 2007).

NT and NTS increased total organic carbon, irrespective of aggregate size, and especially in the 0.0–0.20 m layer. The highest carbon accumulations were observed at a depth of 0.0–0.10 m, and crop succession resulted in the highest average carbon level for all aggregate sizes. At lower depths, the highest average carbon levels were found under crop rotation. Heavy disking (HD) resulted in lower carbon levels, especially in aggregates < 8 mm in layers below 0.20 m.

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