









Pasture recovery using *Stylosanthes* cv. Campo Grande: effect on soil quality

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ABSTRACT: The objective of this study was to study the physical attributes and the organic matter of a Red-Yellow Oxisol cultivated with *Urochloa decumbens* pasture in recovery with different introducing ways of *Stylosanthes* cv. Campo Grande. The experiment was conducted at the Agency for Agribusiness Technology of São Paulo (APTA), in the municipality of Andradina/SP, between October 2016 and September 2017. The experimental design was the randomized complete block design with four replicates and the treatments were composed of six strategies (partial desiccation, total desiccation, scarification, "rome" harrowing and plowing + harrowing.) in the no-tillage legume in the pasture, in addition to the control. Stability of aggregates, flocculation, soil porosity, organic matter and soil texture were evaluated in three layers: 0-0.10; 0.10-0.20 and 0.20-0.40 m. Soil organic matter content was higher in the topsoil layers (from 15.75 to 17.75 mg dm⁻³) and decreased with depth (from 10.50 to 11.50 mg dm⁻³). The indicated macroporosity was below the value considered ideal for the plants development. Studied treatments did not influence the organic matter content, porosity and soil density. Soil quality was influenced up to 0.20 m with the introduction of *stylosanthes*, regardless of the adopted management.

Key words: degraded area; organic matter; physical attributes

Recuperação de pastagem utilizando Estilosantes cv. Campo Grande: efeito na qualidade do solo

RESUMO: Objetivou-se estudar atributos físicos e a matéria orgânica de um Latossolo Vermelho Amarelo cultivado com pastagem de *Urochloa decumbens* em recuperação com diferentes formas de introdução de estilosantes cv. Campo Grande. O experimento foi realizado na Agência Paulista de Tecnologia dos Agronegócios (APTA), no município de Andradina/SP, entre outubro de 2016 e setembro de 2017. O delineamento experimental foi em blocos ao acaso, com quatro repetições e os tratamentos foram compostos por seis estratégias (dessecação parcial, dessecação total, escarificação, gradagem rome e aração + gradagem) em plantio direto da leguminosa na pastagem, além da testemunha. Foram avaliados a estabilidade de agregados, floculação, porosidade, matéria orgânica e textura do solo, em três camadas: 0-0,10; 0,10-0,20 e de 0,20-0,40 m. O teor de matéria orgânica no solo foi superior nas camadas superficiais (15,75 a 17,75 mg dm⁻³) e diminuiu em profundidade (10,50 a 11,50 mg dm⁻³). A macroporosidade indicada ficou abaixo do valor considerado ideal para o desenvolvimento das plantas. Os tratamentos estudados não influenciaram o teor de matéria orgânica, a porosidade e densidade do solo. A qualidade do solo foi influenciada até 0,20 m com a introdução do estilosantes, independente do manejo adotado.

Palavras-chave: área degradada; matéria orgânica; atributos físicos

Introduction

Intensive and inappropriate use of the soil-plant-animal system results in soil degradation, it being one of the main signs of a low ecosystem sustainability. Soil degradation is given by an evolutionary process composed by loss of vigor, productivity and natural resilience, which significantly alters chemical and physical attributes, increasing compaction and reducing water infiltration (Torres et al., 2018).

Among the cultivated pasture areas in Brazil, it is estimated that over 70% is in some degree of degradation, with a large proportion of these in high degradation levels. For the state of São Paulo, the estimated is that 42% of pastures are degraded (Embrapa, 2014). Recovery of these pastures will be fundamental for a greater productivity of the Brazilian livestock farming.

Soil quality and its interaction with its physical attributes is known to correlate with soil compaction and soil density that are inversely proportional and conditioned by the management. Soil moisture is also variable, being it dependent on the soil ability in retaining water (micropores) and the distribution of precipitation over time, reasons for the fluctuations during the crop cycle (Costa, 2016).

Soil physical quality, as a consequence of its use and management, is based on different physical properties related to the structural stability and shape of the soil, namely: compaction, density, penetration resistance, structure, total porosity, soil pores size distribution, water infiltration, among others (Bonini et al., 2015).

Density and porosity are the most used properties in the evaluation of soil physical quality. Density is obtained by the relation between weight and volume of the soil, i.e. the occupied volume by the soil particles in a certain volume; it also depends on the structure and management of the area, allowing variations for a same soil type (Bonini & Alves, 2012). This variable influences soil water retention and its availability to plants, aeration and penetration resistance (Rienzi et al., 2016).

Soil structure is one of the most important properties to be evaluated, according to Wang et al. (2016), verification of the soil physical quality is not a complete valid measure for aggregation, since it is influenced by the soil organic cementing agents composition, considering that in the composition variability, a close relation between the soil intrinsic character and the management system adopted occurs, reflecting in response to the ecosystem effects.

According to Loss et al. (2016), the use of Brazilian Cerrado soils begins with intensive grazing, followed by annual plantations with the conventional tillage system (harrowing and plowing). With the rise of conservationist practices (crop rotation, minimum tillage and no-tillage system), the intensive soil use has been replaced by conservation systems, with the adoption of crop-livestock and crop-culture-livestock integration systems in the most recent years.

The no-tillage system (NTS) has been presented as the best tillage system due to its management advantages (soil non-tillage), plants coverage (increased yield), resulting in soil protection against external impacts of rain and air,

improving soil-water-plant relations (Rovedder & Eltz, 2008; Bertioli Junior et al., 2012; Moreira et al., 2014; Bonini et al., 2016; Torres et al., 2018). Moreira et al. (2014) state that NTS translates into specific relations of soil physical properties, such as soil porosity, adapted to the management of this system, showing satisfactory results even with the increase of the soil resistance. NTS results varies according to the soil type, weather, climate and temporal conditioning of the system, which, in the long run, provides an improvement in the physical quality of the soil.

Bertioli Junior et al. (2012) studied the compaction of a Red Oxisol under NTS for 30 years and found that optimal water range values and degree of compaction were not limiting to the crop yield after 30 years of NTS use. Possibly, there was an increase of soil organic matter and the development of a continuous and stable porous system, which attenuated the negative impacts of compaction.

Use of forages, such as the *Brachiaria* sp. genus, has mitigated the problem of pasture degradation, but over time not even them have achieved a good development in these soils, because the animal consumption of green mass, lack of nutrients replacement, soil acidification, loss of organic matter and soil compaction decrease the plants sprouting ability.

The choice of species to be used in the recovery of degraded areas is fundamental to obtain positive results. In the restoration early stages, the priority is the rehabilitation of the ecosystem function and services. This means that it is often impossible to rehabilitate the original structure of an ecosystem in the first moment, when it is urgent the mitigation of impacting agents by immediate ground covering (Rovedder & Eltz, 2008).

Developed by Embrapa Beef Cattle, the *stylosanthes* cv. Campo Grande is a hybrid *Stylosanthes* compound (80% *S. of capitata* and 20% *S. of macrocephala*), which has performed satisfactorily in sandy and medium-textured soils. These species have drought tolerance and high ability to associate with native rhizobia, presenting as an alternative to pasture recovery systems (Castagnara et al., 2013). Experiments using this hybrid compound are showing significant results, such as the increase in root weight, nutrient content and soil pH. In addition to the soil benefits, animal stocking rate increases were also verified, an important characteristic for the rural producer with direct return on investments made in the area (Costa et al., 2007; Volpe et al., 2008; Castagnara et al., 2013; Torres et al., 2018).

In this context, the present study aimed to research the recovery of the soil quality under a recovering degraded pasture of *Brachiaria decumbens* with different introduction ways of *Stylosanthes* cv. Campo Grande (*Stylosanthes capitata* and *S. macrocephala*).

Materials and Methods

Location and characteristics of the experimental area

The experiment was conducted in the experimental area from the Regional Center of Technological Development of Far

West Agribusiness, based in the municipality of Andradina-SP, located in the northwestern São Paulo State region, between October 2016 and September 2017. The climate, according to Köppen classification, is tropical hot and humid with a dry winter, having an annual mean temperature of 23 °C. The local soil was classified as a Red Yellow Oxisol (Santos et al., 2018).

The experiment was set up in December 2012 in a 3,500 m² area, on a brachiaria grass pasture (*Urochloa decumbens*) established about 12 years ago, having low production but also no large weed infestation, soil compaction, and animals trails, where was introduced the *Stylosanthes* legume Campo Grande (*Stylosanthes capitata* [80%] and *S. macrocephala* [20%]).

After four years from implementation of the management systems, a soil collection was held in the 28 experimental plots of the area, according to the following experimental design described below.

Statistical design and treatments

The employed statistical design was the complete randomized blocks, with four replicates, and treatments composed by six vegetable planting strategies in the pasture, besides the control:

1. Control: brachiaria grass (BC);
 2. brachiaria + stylosanthes with no-tillage (NT);
 3. brachiaria + stylosanthes with partial desiccation with 1.5 L ha⁻¹ of glyphosate (PD);
 4. brachiaria + stylosanthes with total desiccation with 3.0 L ha⁻¹ of glyphosate (TD);
 5. brachiaria + stylosanthes with soil scarification (S),
 6. brachiaria + stylosanthes with “rome” harrowing (H) and
 7. brachiaria + stylosanthes with plowing + harrowing (PH).
- In the treatments with H and PH, the sowing was done by hauling and the others by no-tillage means.

Soil physical and chemical characteristics evaluation

Deformed and undeformed samples were collected in the layers: 0-0.10; 0.10-0.20 and 0.20-0.40 m and after preparation, the following soil analyzes were performed:

a) Degree of flocculation: in accordance to the methodology presented by Teixeira et al. (2017) and calculated by the expression (total clay - clay dispersed in water)/total clay;

b) Porosity and soil density: total porosity was obtained by soil saturation (total soil pore volume occupied by water), microporosity by the tension table method of 0.060 kPa water column, and the macroporosity calculated by the difference between total porosity and microporosity, according to Teixeira et al. (2017). Soil density was calculated by the volumetric ring method, also according to Teixeira et al. (2017).

c) Organic matter (O.M.): determined by the colorimetric method, according to the methodology described by Rajj & Quaggio (1983).

d) Stability of aggregate: distribution and stability of aggregates in water represented by the weighted mean diameter of the aggregates were determined by the Angers et al. (2007) method.

Statistical analysis

Analysis of variance and comparison of the treatment means by Tukey test ($p = 0.05$) were performed using the Sisvar 5.6 software (Ferreira, 2011).

Results and Discussion

No significant differences were observed between the treatments and soil layers in the texture analysis (Table 1), with the soil classified as having sandy texture.

For degree of flocculation and weighted mean diameter (WMD) there was a statistical difference between the treatments studied, while for organic matter there was no statistical difference between the treatments and soil layers (Table 2).

Moreover, no differences were observed for macroporosity, microporosity, total porosity and soil density (Table 3) between treatments and soil layers.

According to the results obtained for soil texture (Table 1), it is observed higher proportions of soil sand in all evaluated layers, a characteristic noted in Oxisols that show textural uniformity in relation to the depths, with no textural gradient

Table 1. Soil particle size distribution (sand, silt and clay) (g kg⁻¹) of a Red Yellow Oxisol recovering from pasture and styling, Andradina-SP. 2016/17.

Treatment	0-0.10 m	0.10-0.20 m	0.20-0.40 m
Sand (g kg ⁻¹)			
BC	875	803	798
NT	856	828	804
PD	841	831	820
TD	850	840	821
S	856	847	834
H	842	867	841
PH	843	871	842
F (5%)	1.392 ^{ns}	2.704 ^{ns}	1.018 ^{ns}
CV (%)	2.44	3.43	4.22
Silt (g kg ⁻¹)			
BC	55	40	37
NT	62	45	38
PD	62	45	52
TD	54	53	62
S	42	57	69
H	59	63	57
PH	68	64	88
F (5%)	0.378 ^{ns}	0.405 ^{ns}	2.260 ^{ns}
CV (%)	17.11	56.81	44.98
Clay (g kg ⁻¹)			
BC	70	76	96
NT	80	89	106
PD	96	107	109
TD	95	108	111
S	102	109	116
H	99	124	128
PH	89	133	142
F (5%)	1.397 ^{ns}	1.376 ^{ns}	1.780 ^{ns}
CV (%)	11.84	31	19.61

BC = brachiaria control; PD = partial desiccation with glyphosate; TD = total desiccation with glyphosate; NT = no-tillage; S = soil scarification; H = “rome” harrowing; PH = plowing + gradation. ^{ns} = not significant by the F test ($p \geq 0.05$).

Table 2. Degree of flocculation (%), organic matter content (mg dm⁻³) and weighted mean aggregate diameter (mm) of a recovering pasture and styling Red Yellow Oxisol, Andradina-SP. 2016/17.

Treatment	0-0.10 m	0.10-0.20 m	0.20-0.40 m
Degree of flocculation (%)			
BC	65.07b	69.16b	81.25a
PD	80.86a	80.36ab	72.30a
TD	76.85ab	83.82 a	81.05a
NT	78.40ab	80.24ab	55.60b
S	78.31ab	80.63ab	74.09a
H	73.19ab	76.48ab	81.77a
PH	77.67ab	79.89ab	67.65ab
F (5%)	2.74*	2.83*	8.14 *
CV (%)	8.36	7.09	9.07
OM (mg dm ⁻³)			
BC	17.75	13.75	11.50
PD	17.25	13.25	11.25
TD	17.00	13.50	11.00
NT	16.75	14.75	11.50
S	16.50	13.25	10.75
H	16.25	13.00	10.50
PH	15.75	13.50	11.25
F (5%)	1.11 ^{NS}	1.02 ^{NS}	0.61 ^{NS}
CV (%)	7.49	8.33	8.71
DMP (mm)			
BC	3.78 a	3.89 ab	3.27 a
PD	2.40 b	3.78 ab	0.99 c
TD	2.77 ab	3.44 b	3.43 a
NT	0.45 c	2.48 c	3.31 a
S	3.74 a	2.26 c	3.69 a
H	3.42 ab	3.45 b	3.13 a
PH	2.23 b	4.02 a	2.37 b
F (5%)	280.99*	16.37*	31.36*
CV (%)	5.16	10.30	11.52

BC = brachiaria control; PD = partial desiccation with glyphosate; TD = total desiccation with glyphosate; NT = no-tillage; S = soil scarification; H = "rome" harrowing; PH = plowing + gradation. * significant by the F test (p < 0.05). Means followed by the same letters do not differ from each other by Tukey (p ≥ 0.05).

(Santos et al., 2018). In sandy soils, clay content is low and directly influences water availability, nutrient adsorption and soil CEC.

In relation to the degree of flocculation (DF) and organic matter content (OM), a reduction in depth (Table 2) is noticeable, demonstrating the relation between these two variables. This behavior is due to the cementing function of organic matter, which is more pronounced the higher the moisture level is, having a much more considerate effect than the dispersion due to the increase in net load. In the topsoil layers (0-0.10 and 0.10-0.20 m), all treatments with the introduction of stylosanthes showed a higher degree of flocculation, differing statistically from the brachiaria-only cultivated control. In the two aforementioned layers, there was higher DF due to the presence of stylosanthes, but its way of introduction did not differ between the layers. In the 0.20-0.40 m layer, this effect of the stylosanthes introduction was not verified. Data from this study differ from Prado & Centarion (2001) and Camilotti et al. (2010), who found DF around 20-50% in Red Oxisol, but the decrease in the

Table 3. Macroporosity (MA), microporosity (MI), total porosity (TP) and soil density (SD) of a recovering pasture and styling Red Yellow Oxisol, Andradina-SP. 2016/17.

Treat.	Macroporosity			Microporosity		
	0-0.10	0.10-0.20	0.20-0.40	0-0.10	0.10-0.20	0.20-0.40
(m)						
BC	0.03	0.04	0.04	0.24	0.24	0.24
PD	0.03	0.03	0.05	0.26	0.22	0.25
TD	0.03	0.06	0.05	0.26	0.24	0.24
NT	0.03	0.04	0.06	0.27	0.22	0.23
S	0.04	0.06	0.05	0.24	0.24	0.24
H	0.03	0.03	0.05	0.25	0.24	0.24
PH	0.03	0.04	0.05	0.23	0.24	0.24
F (5%)	0.327 ^{ns}	1.679 ^{ns}	0.352 ^{ns}	1.298 ^{ns}	1.094 ^{ns}	0.328 ^{ns}
CV (%)	33.26	37.77	27.17	9.65	6.94	5.88
Total porosity						
Soil density						
(m)						
BC	0.29	0.28	0.28	1.60	1.59	1.60
PD	0.29	0.25	0.30	1.53	1.63	1.55
TD	0.29	0.30	0.29	1.61	1.57	1.59
NT	0.31	0.26	0.29	1.57	1.60	1.59
S	0.28	0.30	0.29	1.59	1.56	1.58
H	0.29	0.27	0.29	1.56	1.62	1.54
PH	0.25	0.28	0.30	1.64	1.60	1.57
F (5%)	0.944 ^{ns}	1.708 ^{ns}	0.237 ^{ns}	1.122 ^{ns}	0.505 ^{ns}	0.496 ^{ns}
CV (%)	12.97	9.46	7.83	4.26	4.36	3.95

BC = brachiaria grass control; PD = partial desiccation with glyphosate; TD = total desiccation with glyphosate; NT = no-tillage; S = soil scarification; H = "rome" harrowing; PH = plowing + gradation. ns = not significant by the F test (p ≥ 0.05).

degree of flocculation in depth was also confirmed in these same studies. Maio et al. (2011), while studying the effect of fertilization and sewage sludge verified a similar effect to this study, and the organic matter source positively influenced only the degree of flocculation, with the other studied soil physical properties not influenced. DF indicates the degree of stability of soil aggregates, in which values closer to 100% indicate a greater stability.

When there is an increase in OM and soil aggregation, the physical attributes can be positively altered. With the data obtained for the OM, it was verified a reduction of the mean values with the depth increase, showing that the stylosanthes introduction influenced the topsoil layer (0-0.20m). This relation is coherent since the OM is composed of vegetal and animal remains that integrate the topsoil layer. One way to increase the soil OM content is to grow legumes, aiming improvements in soil quality such as decreased density, increased macroporosity and water infiltration (Bonini Neto et al., 2017). In this study, it was verified increase of organic wood content in the soil, due to the stylosanthes introduction, up to 0.20 m and a consequently higher DF.

WMD values above 2 mm (Table 2) may indicate soil structure quality. According to Bonini et al. (2015), a high stability alone does not characterize a good soil structure because it may be compacted and the cohesive forces of solid soil particles may be acting, however, if the soil stability is high and organic matter is present, it is possible to say that the soil has quality in its structure.

In the 0-0.10 and 0.10-0.20 m layers, the organic matter contents are close to 20 g dm^{-3} , which are average values for this (sandy) soil class (Bonini et al., 2016), thus confirming a satisfactory structure quality up to 0.20 m depth. Treatments BC and S (0-0.10 m), BC and PH (0.10-0.20 m) and PD and S (0.20-0.40 m) stood out. It can be stated that the stylosanthes introduction did not directly influence the WMD, but indirectly contributed to the increase of soil OM.

In the recovery of degraded areas, it is important studying the soil structure, due to the size, shape and arrangement of the aggregates, which vary according to changes made by management, so it is recommended to add organic matter and revolve the soil (mechanical strength) to begin the genesis process of the soil structure. According to Wang et al. (2016), soil structure is an attribute of soil quality, since changes in soil stability may influence its water storage, aeration, as well as erosion processes and biological activities, which ultimately interfere with the crop growth.

Regarding soil porosity and density (Table 3), it is worth pointing out that for all treatments, macroporosity values were below $0.10 \text{ m}^3 \text{ m}^{-3}$, which are considered ideal for proper plant growth and development (Bonini et al., 2015). Results in accordance to the previously mentioned researches were found by Mateus et al. (2018), when studying porosity and soil density in forested areas of different ages. The same authors verified that at the beginning of the implantation, the soil had lower macroporosity and over time it was observed a positive evolution of its attributes, resulting in higher macroporosity.

With reduced macroporosity values, micropore and density values increase, consequently resulting in increased soil compaction. In this study, no recovery of pore quality was verified, agreeing with Resende et al. (2015), who state that variations in soil density values indicate effects of the adopted management, which can be beneficial or harmful to the soil. The authors also reported that the intensive use of pasture promoted greater value in compaction when compared to other management forms, which resulted in reduced soil water infiltration.

Total porosity does not allow evaluating the soil quality, since its distribution is not known. Studying macro and microporosity allows evaluating that, with the increase of macroporosity, there was a reduction of microporosity and indicative of structure degradation. On the other hand, when the opposite happens, the soil reflects a better pore quality and distribution. This evolution of pore size distribution is due to conservationist use of the soil as well as the best tillage system due to its management advantages (non-tillage), plant cover (increased productivity), resulting in soil protection in relation to external impacts of rain and air, improving the soil-water-plant ratio.

Data from this study show that four years implementing the conservation systems were not sufficient to modify soil porosity and density, in agreement with Moreira et al. (2014), who indicated a specific relation of soil physical properties and NTS as the constitution of soil porosity, which varies according

to soil type, weather, climate and temporal conditioning of the system.

Given that the density of the soil is obtained by its weight-volume relation, that is, volume occupied by the particles of the soil in a certain volume; it depends on the structure and management of the area, allowing variations for the same soil type (Bonini & Alves, 2012). Data from this study are above of what is considered ideal (Bonini et al., 2015; Rienzi et al., 2016), hindering the plants development due to its lower aeration, and is accordance with Maio et al. (2011), who studying some soil properties verified the influence of treatments only on the degree of flocculation, the other soil characteristics not being influenced positively or negatively. These results indicate that legume treatments are not yet contributing to improve soil physical quality, but have already improved the soil organic matter content, which is of utmost importance for its structure recovery.

Conclusions

Studied treatments did not influence the porosity and soil density. The macroporosity and soil density are lower and higher than what is considered ideal, respectively.

Organic matter content increased with the introduction of stylosanthes in the area, in the topsoil, regardless of the adopted management strategy.

Degree of flocculation and the WMD obtained high values, indicating improvement in soil quality, with high stability of soil aggregates influenced by the introduction of stylosanthes.

Analysis of organic matter indicated that the layers closer to the soil surface show higher concentrations than the deeper layers, influenced by the legume cultivation.

Soil quality was influenced up to 0.20 m with the introduction of stylosanthes, regardless of the adopted management.

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