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PHYSICAL PROPERTIES OF A RHODIC HAPLUSTOX UNDER TWO SUGARCANE HARVESTING SYSTEMS⁽¹⁾

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SUMMARY

This study had the purpose of evaluating the effects of two management types of sugarcane: harvesting of burnt cane (BCH) and mechanized harvesting of unburnt green cane (MCH), on some soil physical properties of a dystrophic Rhodic Haplustox. The data were then compared with results for the same soil type under native forest. A completely randomized design was used, with three treatments and 20 replications. The following characteristics were determined: organic matter, aggregate stability, soil bulk density, and porosity at depths of 0–0.20 m and soil penetration resistance. After 15 years of cultivation, there were some alterations in the soil under cane burnt before harvesting, evidenced by a drop in the weighted average diameter of stable aggregates in water and increased soil bulk density. Significant changes were also detected in total porosity and pore distribution under both harvesting systems. Critical values for penetration resistance were observed in the area under mechanized sugar cane harvesting, with a value of 4.5 MPa in the 40–55 cm layer. This value is considered high and could indicate compaction and restriction of root growth. Soil properties under the green cane (unburned) management system were closest to those of the soil under native forest.

Index terms: *Saccharum officinarum*, soil bulk density, porosity, soil penetration resistance, soil aggregate stability.

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RESUMO: *PROPRIEDADES FÍSICAS DE LATOSSOLO VERMELHO SOB DOIS SISTEMAS DE COLHEITA DE CANA-DE-AÇÚCAR*

Este trabalho foi conduzido em Latossolo-Vermelho distrófico, sob cultivo de cana-de-açúcar, com o objetivo de avaliar o efeito de dois sistemas de manejo, com (CCQ – corte manual de cana queimada com carregamento mecânico) e sem queima (CSQ – colheita mecânica de cana picada, crua), sobre propriedades físicas do solo. Os dados foram comparados com os resultados do mesmo solo sob mata nativa. O delineamento utilizado foi o inteiramente casualizado, com três tratamentos e 20 repetições. Foram determinadas a matéria orgânica, estabilidade de agregados, densidade e porosidade do solo, na profundidade de 0–0,20 m, e a resistência do solo à penetração. Após 15 anos de cultivo, constatou-se alteração do solo no sistema CCQ, evidenciada pela diminuição do diâmetro médio ponderado dos agregados estáveis em água e pelo aumento da densidade do solo. Foram também detectadas alterações significativas na porosidade total e distribuição de poros, devido às práticas de manejo nos dois sistemas de colheita. Valores críticos de resistência à penetração foram observados na área de cana mecanizada (CSQ), a 0,40–0,55 m de profundidade, sendo o valor (4,5 MPa) classificado como alto, podendo indicar compactação e restrição ao crescimento radicular. O manejo mecanizado foi o sistema que apresentou características do solo mais próximas às da área de mata nativa.

Termos de indexação: *Saccharum officinarum, densidade do solo, porosidade, resistência do solo à penetração, estabilidade dos agregados.*

INTRODUCTION

Agricultural activities can affect the physical, chemical and biological properties of soil and environment (Lal, 2000; Souza et al., 2005) and inadequate management can lead to degradation and a drop in productivity (Bronick & Lal, 2005).

In the State of São Paulo, areas covered by native forest were gradually replaced by coffee plantations and later by sugarcane in monoculture over lengthy periods (Oliveira et al., 1995). This substitution, along with continuous, prolonged, intensive cultivation and the applied management practices, is changing the natural conditions of the soil (Amézqueta, 1999; Abiven et al., 2009).

On sugarcane plantations, the crop is usually burnt before harvesting, causing environmental problems such as emission of C monoxide (CO) and other atmospheric pollutants, ash deposits in urban areas, physical exposure of the soil and loss of chemical fertility (Allen et al., 2004; Marques et al., 2009). To mitigate these problems, a mechanized system of green cane harvesting was developed that does not require burning and deposits the cane trash to cover over the soil, protecting it from erosion loss and improving soil conservation (Souza et al., 2005; Luca et al., 2008). In addition, the system of mechanized or green cane harvesting has proved promising, both in technical and economic terms (Rodrigues & Saab, 2007).

The mechanized green harvesting of sugarcane can also increase the soil organic matter content and lead

to more homogenous micro and macropore distribution, improving aeration and water infiltration and retention, with an altogether positive effect on the soil physical and chemical quality (Canellas et al., 2003; Ng Cheong et al., 2009). Furthermore, the soil structure is improved and bulk density reduced, which means that more of the soil can be exploited by the roots (Passarin et al., 2007).

The reduced soil tillage on green cane plantations increases productivity (Canellas et al., 2003). Besides, in this system of mechanized harvesting without burning the leaves, sheaths, tips and variable quantities of stem sections are cut, shredded and cast over the soil surface, forming a cover of plant waste called “cane trash” (Souza et al., 2005). However, it is known that the traffic of machinery and equipment is one of the main factors involved in changing the soil physical properties (Sant’Anna et al., 2009). Therefore, burning the plantation causes great harm to soil and air quality (Allen et al., 2004). When cane is harvested green however, despite the increment in the layer of soil organic matter and improved physical and chemical soil quality (Canellas et al., 2003), the use of machinery under unsuitable humidity conditions can result in a series of changes in the soil physical properties (Severiano et al., 2008), including compaction (Ng Cheong et al., 2009).

The impact of different management systems on the soil physical quality has been quantified using different physical indicators related to the shape and structural stability of the soil, such as: bulk density (Llanillo et al. 2006), relative density (Carter, 1990;

Hakansson & Lipiec, 2000), porosity (Beutler et al., 2001; Oliveira et al., 2001), resistance to root penetration (Hammad & Dawelbeit, 2001; Tavares Filho & Ribon, 2008), aggregate stability (Amézqueta, 1999), preconsolidation pressure (Dias Junior & Pierce, 1996; Arvidsson & Keller, 2004; Imhoff et al., 2004), Least Limiting Water Range (Severiano et al., 2008), and the S parameter (Dexter, 2004; Streck et al., 2008).

The aim of this study was to assess the influence of the two harvesting systems (burnt cane - BCH, and green cane - MCH) on some of the physical properties of a dystrophic Rhodic Haplustox soil and to compare the data with results for the same soil under native forest.

MATERIAL AND METHODS

The study commenced in September 2008, in the municipality of Paraguaçu Paulista (22 ° 29 ' S, 50 ° 37 ' W) in the state of São Paulo, Brazil, on a medium texture dystrophic Rhodic Haplustox (USA classification) or Latossolo Vermelho distrófico (Brazilian classification, Embrapa, 2006). The climate is classified in the Köppen system as subtropical temperate (Cwa), with hot, rainy summers with average temperatures above 22 °C, and winters with average temperatures below 18 °C, with clearly-defined seasons and average annual rainfall of 1,359 mm. The primary vegetation in the region is Savanna (Cerrado). The landscape is undulating, with average declivity from 3 to 8 %.

Sugarcane had been grown at the study location for 15 years. After each cycle of 5 to 7 harvests, the plantation was amended with appropriate treatments, using equipment for hoeing or scarifying, fertilizer application and cultivation that simultaneously scarify, apply fertilizer, till and prepare the land. This practice, followed by chemical treatment, is usually sufficient to keep the stumps clean.

A fully randomized experimental design was used, with three treatments and 20 replications for all parameters evaluated. The treatments consisted of

the harvesting systems: (a) burning, manual cutting and mechanized loading of sugarcane (BCH), (b) mechanized harvesting of chopped unburned green cane (MCH), and (c) native forest (NF), consisting of remaining primary vegetation, representing tropical savanna (Cerrado). The adjacent native forest area was used as reference for the initial state of the soil prior to cultivation.

Composite soil samples were collected after harvest from the 0–0.2 m layer, each consisting of four sub-samples. A part of the samples were analyzed chemically (Table 1) and for organic matter content (Table 2) (Embrapa, 1997). The remaining sample quantities were used to determine (a) soil texture by the pipette method with organic matter oxidation (Tavares Filho & Magalhães, 2008); (b) soil bulk density by the volumetric ring method (volume 50 cm³, diameter 15 cm), collected from the litter layer between 0 and 10 m; (c) total porosity, in terms of saturated soil mass and dry soil mass (oven at 10 °C for 24 h); (d) soil microporosity, determined by the tension table method; and (e) macroporosity, determined by the difference between total porosity and microporosity (Embrapa, 1997).

Soil penetration resistance was also determined by the method described by Stolf (1991), at 20 points down to a depth of 0.70 m, and the impact data in dm⁻¹ were converted into dynamic strength (MPa) using the formula: $RP \text{ (kgf cm}^{-2}\text{)} = 5.6 + 6.89 \text{ N (dm}^{-1}\text{ impact data)}$. To convert the penetration resistance (RP in kgf cm⁻²) into dynamic strength (MPa), the result obtained was multiplied by a constant (0.098). The saturation level was also determined in relation to the water volume (Va) and the total volume of voids in the soil (Vv), expressed in percentage (Embrapa, 1997).

Aggregate stability in the 0–0.20 m layer was evaluated using the method proposed by Yoder, modified by Castro Filho et al. (1998). The mean weighted diameter (MWD), mean geometric diameter (MGD) and aggregate stability index (ASI) were determined.

The results were subjected to analysis of variance and the treatment means compared by the Tukey test at 5 %.

Table 1. Texture and chemical properties of a dystrophic Rhodic Haplustox in the 0–0.20 m layer under burnt cane harvesting (BCH), mechanized cane harvesting (MCH) and native forest (NF)

Treatment	Clay	Silt	Sand	P	pH CaCl ₂	H + Al	Al ³⁺	Ca ²⁺	Mg ²⁺	K ⁺	CEC	V
		g kg ⁻¹		mg dm ⁻³				cmol _c dm ⁻³				%
CCQ	387	234	379	10.17	4.52	3.68	0.19	0.71	0.22	0.08	4.69	21.53
CSQ	372	243	385	17.16	5.13	3.18	0.10	1.26	0.38	0.14	4.96	35.89
MN	379	239	382	4.88	4.01	6.69	0.54	0.44	0.14	0.07	7.34	8.85

RESULTS AND DISCUSSION

The results for organic matter (OM), macroporosity (Ma), microporosity (Mi), total porosity (TP) and soil bulk density (Ds) are given in table 2.

There were significant differences in organic matter content for the management systems evaluated ($p < 0.05$). The organic matter content (5.83 g kg^{-1}) of the BCH system was lower than MCH (19.23 g kg^{-1}), whereas the MCH system did not differ statistically from NF (19.97 g kg^{-1}).

The lowest organic matter content values obtained for the BCH system were due to burning before the harvest, which eliminates the cane trash on the soil surface. Ceddia et al. (1999) showed that the pre-harvest burn of cane trash is prejudicial to the conservation of organic matter in the soil, since it reduces the contribution of raw organic matter and promotes the mineralization of existing organic matter. The drops in macroporosity (Ma) and total porosity (TP) are the result of increasing microporosity (Mi) in soils managed by burning before harvesting, and are compatible with an increase in soil bulk density (Ds) and lower organic matter content compared with the soil under native forest.

Macroporosity and total porosity were higher in the soil under NF, differing statistically from MCH and BCH. The microporosity values for BCH were significantly higher than those for the native forest area. MCH showed no difference in comparison to BCH and NF.

In the BCH system, the soil surface is exposed to raindrop impact, mainly in the post-harvest period, which coincides with the period of highest average monthly rainfall (October to January), causing an increase in soil bulk density (Ds) and microporosity (Mi) and a drop in macroporosity (Ma) and total porosity (TP). In this context, Souza et al. (2005) confirmed that Ma is the most affected property by continuous sugarcane cropping.

In the 0–0.20 m layer, the increase in microporosity for both harvesting systems compared to native forest is due to the intense use of machinery, which

compresses the pores in Haplustox soils. This was also reported by Silva & Ribeiro (1997) in Yellow clayey Oxisol (Latossolo Amarelo argiloso) and by Sant'Anna et al. (2009) in Red-Yellow Oxisol (Latossolo Vermelho-Amarelo).

Soil bulk density values for the BCH and MCH were the same, and significantly higher than soil bulk density under native forest. The increase in soil bulk density at a depth of 0.20 m is due to heavy machinery traffic during sugarcane planting and harvesting, mainly for the MCH system. These findings are in line with those of Hammad & Dawelbeit (2001) and Silva et al. (2009), as the main cause of compaction in agricultural soils.

Soil penetration resistance (RP) was most uniform under native forest (NF) (Figure 1). A marked increase in penetration resistance was observed under BCH, at a depth of 0.35 m, and under MCH, at a depth of 0.55 m.

In the MCH system, the RP values were highest in the layer 0.40–0.55 m, with values above 4.0 MPa,

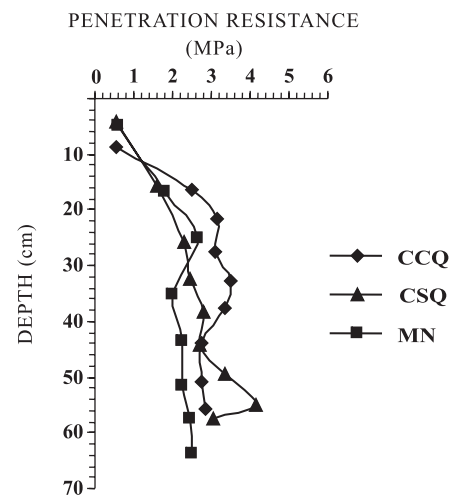


Figure 1. Resistance to vertical penetration in dystrophic Rhodic Haplustox to a depth of 0.70 m under burnt cane harvesting (BCH), mechanized cane harvesting (MCH), and native forest (NF).

Table 2. Results for organic matter (OM), macroporosity (Ma), microporosity (Mi), total porosity (TP) and soil bulk density (Ds) obtained in dystrophic Rhodic Haplustox, in the 0–0.20 m layer, under burnt cane harvesting (BCH), mechanized cane harvesting (MCH) and native forest (NF)

Treatment	OM	Soil porosity			Ds	Soil saturation
		Ma	Mi	TP		
	g kg^{-1}	$\text{m}^3 \text{ m}^{-3}$			kg m^{-3}	%
BCH	5.83 b	0.123 c	0.223 a	0.39 b	1.57 a	56.06 b
MCH	19.23 a	0.172 b	0.215 ab	0.35 c	1.55 a	64.60 a
NH	19.97 a	0.231 a	0.206 b	0.44 a	1.23 b	47.36 c

Values followed by the same letter were statistically not different in the Tukey test at 5 %.

classified as high and very high, exceeding the critical level (Tavares Filho et al., 2001; Llanillo et al., 2006). However, even though the values were highest in this layer, no significant resistance to sugarcane root growth was observed in these systems, which would cause a restrictive effect to yield increases. In a study by Tavares Filho & Ribon (2008), conservationist systems that involve less soil disturbance and an accumulation of organic matter showed the efficiency of root growth and microorganisms in structuring the soil, even at elevated penetration resistance values.

The highest penetration resistance value, found in the MCH system, is also related to heavy machinery traffic during cane harvesting. In areas of Oxisol (Latossolo), Tormena et al. (2004) attributed the naturally increased soil density to the management systems, highlighting the importance of using reference systems. Thus, a quantitative diagnosis (degree of soil compaction based on penetration resistance) (Ribon & Tavares Filho, 2004) is desirable to verify the management quality.

Table 3 gives the results for aggregate particle size (class) distribution. Only in the classes < 0.25 mm and from 0.50 to 1.00 mm the differences between BCH and MCH were significant. MCH showed no differences in comparison to native forest for only two classes (0.50–1.00 mm and 1.00–2.00 mm), and BCH for only one class (0.50–1.00 mm). For the majority of classes under MCH and native forest, the aggregate particles were larger and more stable.

An analysis of aggregate stability in water showed that the use of machinery on the soil caused a drop in aggregates > 2 mm in the BCH and MCH systems, in contrast to the NF area, which contained a higher quantity of this aggregate class since it had not been affected by human activity.

Finally, the results for weighted average density, average geometric density and average stability index are given in figure 2. The area of native forest (NF) exhibited statistically higher values for MWD (3.78 mm), MGD (1.05 mm) and ASI (77.74 %). MWD showed significant differences between the two management systems, with a higher value for MCH (1.55 mm) than for BCH (0.84 mm). However, in

terms of MGD, there was little difference between the values for BCH (0.79 mm) and MCH (0.87 mm) and the ASI under green cane harvesting (MCH) (65.45 %) was higher than under burned cane harvesting (BCH) (51.90 %).

The values for MWD and ASI were significantly lower in the BCH system (Figure 2), indicating lower soil quality than in MCH and NF, as stated by Souza et al. (2005). The lower MWD for BCH is related to cane trash burning and the consequent drop in organic matter content, as well as alterations in soil structure caused by the harvesting operations. In a Yellow Podzolic soil, Ceddia et al. (1999) verified a higher MWD in green cane as opposed to burnt cane, due to the higher organic matter content.

Of all areas studied, the MWD of the soil aggregates under NF was clearly the highest. According to Beutler

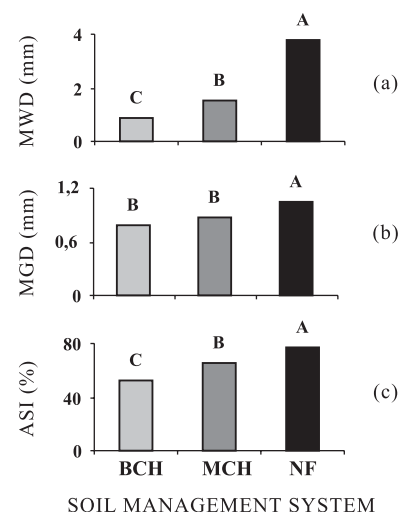


Figure 2. Mean Weighted Diameter - MWD (a), Mean Geometric Diameter - MGD (b) and Aggregate Stability Index - ASI (c) in the 0–0.20 m layer of a Rhodic Haplusdox, under burnt cane harvesting (BCH) and mechanized cane harvesting (MCH), and native forest (NF). Averages with different letters indicate significant differences in the Tukey test at 5 %.

Table 3. Aggregate particle size distribution in the 0–0.20 m layer of a Rhodic Haplusdox under burnt cane harvesting (BCH) mechanized cane harvesting (MCH), and native forest (NF)

Treatment	Aggregate particle size class (g)					
	< 0.25	0.25–0.50	0.50–1.00	1.00–2.00	2.00–8.00	8.00–19.00
	mm					
BCH	22.65 a	16.22 a	2.87 b	1.20 b	2.91 b	0.82 b
MCH	17.44 b	18.04 a	4.19 a	1.67 ab	3.43 b	1.15 b
NH	10.37 c	10.13 b	3.43 ab	2.14 a	12.63 a	7.89 a

Values followed by different letters indicate significant differences in the Tukey test at 5 %.

et al. (2001), the aggregates of Cerrado soils are larger and more stable, due to the physical effects of the roots and the constant layer of organic residues on the soil surface, associated with the action of macro and microorganisms, resulting in the formation of composts with cementing and stabilizing action.

An analysis of the aggregate stability for MGD (Figure 2) generally showed values of less than 1 mm for MCH and BCH. Significant differences were observed when the MGD values for the MCH and BCH systems were compared with those for native forest. Although no significant difference was observed for particles ≥ 1.00 mm, compared with the soil under BCH, the MCH system had a greater quantity of larger particles and a higher MWD. Thus, MCH proved more suitable for conservation of the soil structural quality, for being more similar to the soil under native forest.

Higher aggregate stability under MCH was due to the higher organic matter content which affected soil particle aggregation, in line with the observations of Camilotti et al. (2005) and Severiano et al. (2008). Furthermore, ASI under MCH was closer to that of the native forest soil, showing that appropriately managed systems enable the maintenance of the soil physical aggregates close to the ideal (Amézketa, 1999; Beutler et al. 2001; Abiven et al., 2009).

In general, the indicators for soil physical properties under BCH were less favorable and generally more distant from the conditions of native forest. Advantages in terms of organic matter content and aggregate stability were observed under MCH, despite limitations with regard to soil bulk density and penetration resistance.

CONCLUSIONS

1. Mechanized harvesting without crop burning is advantageous in terms of organic matter content and aggregate stability, but limited with regard to soil bulk density and penetration resistance.

2. The indicators of the soil physical properties under burnt cane harvesting were less favorable, and differed more from the soil conditions under native forest.

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