TRAFFIC CONTROL WITH AUTOPILOT AS AN ALTERNATIVE TO DECREASE SOIL COMPACTION IN SUGARCANE AREAS†

[CONTROL DE TRÁFICO CON AUTOPILOTO COMO UNA ALTERNATIVA PARA DISMINUIR LA COMPACTACIÓN DEL SUELO EN ZONAS DE CAÑA-DE-AZÚCAR]

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SUMMARY

Control the machinery traffic through autopilot and use the combined spacing of two rows are possible solutions to mitigate soil compaction problems. The objective of this study was to evaluate traffic control using autopilot in order to soften the problem of soil compaction in mechanically-harvested sugarcane areas. The study was conducted in two experimental areas belonging to Usina Santa Fe, in New Europe, São Paulo, Brazil. The design was a randomized block design, with 3 treatments: T1 = sugarcane planted in single spacing and without autopilot (1.50 m); T2 = sugarcane planted in single line spacing and managed on autopilot; T3 = sugarcane planted under combined spacing of two rows (1.50 × 0.90 m) and managed with autopilot, with 4 replications. Was collected samples in the wheel row (WR) and the seedbed (SB), which was located next to the plant row to, in layers from 0.00 to 0.15 and 0.15-0.30 m. It was observed that the seed bed area showed higher porosity in the treatments with autopilot in the second year of evaluation. There were no differences in pore sizes and shapes between the treatments in the two years studied. The large and complex pores were observed to be reduced in the second evaluation year.
Key words: Soil structure, micromorphometrics; traffic control; image analysis.

RESUMEN

El control del tráfico de maquinaria a través de piloto automático y el uso de la separación combinada de dos filas son posibles soluciones para mitigar los problemas de compactación del suelo. El objetivo de este estudio fue evaluar el control del tráfico mediante piloto automático, con el objetivo de reducir el problema de la compactación del suelo en las zonas de cultivo de caña de azúcar cosechadas mecánicamente. El estudio se realizó en dos áreas experimentales pertenecientes a Usina Santa Fe, en Nueva Europa, São Paulo, Brasil. El diseño fue de bloques al azar, con 3 tratamientos: T1 = caña de azúcar plantada en un solo espacio y sin piloto automático (1.50 m); T2 = caña de azúcar plantada en un solo espacio lineal y manejada en piloto automático; T3 = caña de azúcar plantada bajo espaciamiento combinado de dos filas (1.50 × 0.90 m) y manejada con piloto automático, con 4 repeticiones. Se recogieron muestras en la hilera de ruedas (WR) y en el lecho de siembra (SB), que estaba situado junto a la hilera de la planta, en capas de 0.00 a 0.15 y 0.15-0.30 m. Se observó que el área de lecho de siembra mostró mayor porosidad en los tratamientos con piloto automático en el segundo año de evaluación. No hubo diferencias en tamaños de poros y formas entre los tratamientos en los dos años estudiados. Se observó que los poros grandes y complejos se redujeron en el segundo año de evaluación.
Palabras clave: Estructura del suelo, micromorfometría; control de trafico; análisis de imagen.

† *Submitted December 06, 2016 – Accepted March 12, 2017.*

INTRODUCTION

Brazil ranks first among the world sugarcane producers and has São Paulo state as its largest producer, with a planted area of 4.648 million hectares (51.8%), followed by Goiás, with 908.000 hectares (10.1%), and Minas Gerais with 715.300 hectares (8.0%) in the 2015/2016 crop. The country is estimated to produce 348.4 million tons, with an average productivity of 74.945 kg ha^{-1} (Conab, 2015).

Such production is supported by the high mechanization level in cultivated areas, which is based on deep revolving of the soil during preparation and planting stages with large machines that coupled with the use of combines and sugarcane wagons – weighing 20 to 30 tons, circulate through the area during the six or seven cycles of the culture – have changed the physical properties of the soil (Torres *et al*., 2013).

This set of operations has raised the potential for soils to be compacted or have their densities increased, due to the repetition of traffic during culture cycles that are conducted under differ soil humidity conditions (Oliveira Filho *et al*., 2015), has also led to reductions in macroporosity and size of aggregates, allowing lower water infiltration rates in the soil (Vasconcelos *et al*., 2014). The increased resistance to penetration from the soil contributes to reducing the growth of roots, as it provides unfavorable water and nutrient absorption conditions, which leads to decreased productivity of cultures (Sousa *et al*., 2013).

With the increased traffic of heavy machines in sugarcane areas, the interactions between tire pressures, types of rolling surfaces, axle loads, intensities at which machines move, load application lengths, and the number of times a load is applied are the most relevant factors in soil compaction studies 2015 (Campos *et al*., 2015). This traffic of machines tends to increase in areas cultivated with sugarcane. Due to this, developing technologies to determine the impacts from these practices on the physical soil properties is required (Tavares *et al*., 2015). In this context, controlling the traffic of machines has become a promising alternative to minimize the compaction problem (Kamimura, *et al*., 2009).

This control can be conducted using autopilot capabilities, which work under the principle of pre-established traffic routes, by preserving the areas where sugarcane roots grow, near the shoots (Souza *et al*., 2014). Associated with this technology, the adoption of double row spacing also has characteristics that may contribute to reduce soil compaction, as there is a reduction in the number of traffic-designated paths, due to the need to increase gauges (Souza *et al*., 2015). As a consequence, there will be a reduction in the soil penetration resistance in the zones where there is plant development, higher preservation of shoots, and longevity of sugarcane crops, which will lead to increased productivity of cultures (Lecler and Tweddle, 2010). Silva *et al*. (2011) highlighted that around 39% of Brazilian sugarcane mills already adopted the autopilot system.

Using physical properties as soil quality indicators is an important tool to evaluate the traffic of machines in sugarcane areas, as this is highly sensitive and can support decisions regarding the type of management to be chosen. When the undisturbed soil samples that were used to evaluate the density and porosity of the soil are analyzed through images of blocks impregnated with preserved structures, important information is obtained for the compaction diagnosis (Gonçalves and Moraes, 2012). Genaro *et al*. (2015) pointed out that studying soil quality through 2D imaging allows obtaining more detailed information on the physical changes that arise from the adopted management, such as size, type, and number of pores.

The objective of this study was to evaluate traffic control using autopilot in order to soften the problem of soil compaction in mechanically-harvested sugarcane areas.

MATERIALS AND METHODS

Location of the experiment

The study was conducted in the commercial area of Usina Santa Fé, located in Nova Europa, São Paulo, Brazil, under coordinates 48°34’41,76” W and 21°53’44,89’’ S, with an altitude of 490 m, with a terrain ranging from flat to slightly wavy, between June 2012 and July 2014.

The climate in the region is classified as tropical with dry seasons (Aw), according to Köppen’s climate classification, with mild summers and winters, with decreased rainfall rates. The average temperature ranges between 16° and 29° C, and the annual rainfall rate is around 1,340 mm.

The soil in the experimental area was classified as quartz-sand neosol, with a sandy texture (Embrapa, 2013). In its 0.00-0.20 m layer, it had: 80.90 g kg^{-1} clay, 811.74 g kg^{-1} sand, and 107.36 g kg^{-1} de silt.

Experimental Design

The experimental design chosen was the randomized block design (RBD), with three treatments: T1 = Sugarcane planted under single row spacing and managed without autopilot (1.50 m); T2 = Sugarcane planted under single row spacing and managed with autopilot; T3 = Sugarcane planted under combined double row spacing (1.50 x 0.90 m) and managed with autopilot, with four repetitions, totaling twelve experimental units.

Soil preparation, sugarcane cultivation and harvesting

The remainders of the previous culture were desiccated by applying 5.76 L ha^{-1} Tensor Plus and 5.76 kg ha^{-1} Roundup WG. Fifteen days after the desiccation, the total area was harrowed with a 28-disk, 32-inch harrow pulled by a Valtra BH 185 tractor. Following this, the area was subsoiled with a subsoiler with 7 legs that were 0.40 m away from each other and steel boot-like tips pulled by a Case Magnum 340 tractor.

In the plots cultivated under single row spacing (1.50 m), 20 lines that were 1.5 m apart were monitored, whereas in the double row spacing areas (1.50 × 0.90 m) 12 double row spacing lines were used. Each plot were 30 m × 50 m (1500 m^2).

The planting was conducted in a depth of 0.30 m, with density of 18 buds linear m^{-1}, with a DMB PCP 6000 chopped sugarcane planter pulled by a Valtra BH 185 tractor, with a rear gauge of 2.10 and a front gauge of 1.80 m.

The crop was fertilized with 0.45 ha^{-1} 05-25-23 formula + 1.5% zinc + 0.4% boron. 0.25 kg ha^{-1} 800 WG Reagent and 0.5 L ha^{-1} Comet were also applied to control pests and diseases. No filter cake or vinasse was applied in the experimental areas.

The sugarcane in the single row spacing area (1.50 m) was harvested with a Case 800 harvester, with an approximate mass of 15 tons.

Collection and preparation of the undisturbed soil samples

Undisturbed soil samples were collected at the spots corresponding to the wheel row (WR) and in the seedbed (SB), which was located beside the plant row, in the 0.00-0.15 m and 0.15-0.30 m layers. Moreover, samples were collected in a native forest area beside the experimental area, in a soil with the same classification as the one in the experimental area, in order to serve as a frame of a reference of an area with not sugarcane crops.

With the aid of a knife, the soil blocks were sculpted in the ditch walls with dimensions of 0.12 × 0.07 × 0.06 n, with the longer size facing the soil surface. Then, the blocks were accommodated in cardboard boxes with similar dimensions to the ones of the sample, and carefully taken away in order to prevent the structure from being deformed. After the collection, the samples were wrapped in PVC plastic and lined with aluminum foil, in order to avoid damages from possible mechanic shocks during transportation.

Preparation of the samples and slides

These samples were taken to the laboratory, where they were left to dry for 10 days. Then, they were put in a greenhouse at 40° C (Murphy, 1986). After dried, the samples were impregnated with a solution with 1 L polyester resin, 1 L styrene monomer, 5 g Tinotipal OB pigment, 15 drops of butanox, and 10 drops of cobalt octoate.

After impregnated, the samples were laid in a close environment and, whenever necessary, the impregnating solution was replaced, as solution is lost in the hardening process due to volatilization (Jongerius and Heintzberger, 1975; Murphy, 1986). After approximately 20 days after the impregnation, the samples were cured and ready to be cut in blocks of 0.12 × 0.07 × 0.02 m, through the use of a diamond blade in a humid medium.

After cut, the samples had their surfaces leveled on a stone, polished in a glass plate with a humid surface using abrasive power nos. 500 and 200, and sanded with a proper sandpaper for humid surfaces.

Pedological slides were only prepared in the samples taken from the native forest area, with the purpose of conducting a thorough description of the layers studied.

After the impregnation process, a glass plate of 0.10 × 0.04 × 0.001 m was attached to the surface of the blocks. Following this, these blocks were cut by a 0.03 µm thick diamond blade, put in Politriz LP 30 machine (Logitech brand) in a humid environment, until they reached the thickness of 1 mm, which was required for visualization through pedological microscopy. An OLIMPUS BX51 microscope was used in the description of the slides. In order to perform this step, we adopted the classification key proposed by Bullock *et al*. (1985).

Micromorphometric analyses

In order to analyze the specific surfaces of the pores, 10 random images of each block were captured by an Olympus SC20 camera connected to an Olympus BX51 microscope. These images were digitized with a spatial resolution of 1596 × 1196 pixels and a spectral resolution of 255 shades of gray, with 2x magnification in the ocular lens and 10 x magnification in the objective lens. These images were stored, named, and scanned, so the pores could be individually analyzed through imagJ software

(Rasband, 2008). The specific surface area of the poroids (SSA) was found through Equation 1.

$$SE = \frac{NPxP}{AT} \quad (1)$$

In which: NP = number of pores; P = perimeter; AT = total area.

The analyses of area, size, and shapes of pores were conducted using images that had been obtained with 10x magnification in the ocular lens and 10x magnification in the objective lens. In order to do so, 10 random images of the impregnated blocks were acquired using a petrographic microscope coupled with a CCD camera with a spatial resolution of 1024 x 768 pixels, and spectral resolution of 256 shades of gray. After captured, the images were scanned, named, and then analyzed through Visilog-Noesis5.4®. software.

The pores were classified in three groups regarding the sizes of their areas: small (0.000156 – 0.0156 mm^2), medium (0.0156 – 0.156 mm^2), and large (>0.156 mm^2). The indices described in Equations 2 and 3 were used to determine the pore sizes. (Cooper, 1999; Lima *et al*., 2006; Pires *et al*., 2008):

$$I_1 = \frac{P^2}{(4\pi A)} \quad (2)$$

$$I_2 = \frac{\frac{1}{m}\sum_i (N_I)_i}{\frac{1}{n}\sum_j (D_F)_j} \quad (3)$$

Where:
P = perimeter of a poroid;
A = area of a poroid;
N_I= number of intercepts of an object towards the i direction (i = 0°, 45º, 90°, and 135º);
D_F = Feret diameter of an object towards j direction (j = 0° and 90°);M and
N= numbers of i and j directions, respectively.

The values found using equations 2 and 3 were used to classify the shapes of pores according to Table 1.

The results from the analyses conducted were submitted to an analysis of variance and to a Tukey test at the 5% probability level for comparing the averages, through the use of Sisvar version 5.1 Build 72 computing system (Ferreira, 2011).

Table 1. Criteria for distinguishing between pore shape groups.

Pores	Shape index	
	I_1	I_2
Round	$I_1 \leq 5$	-
Elongated	$5 < I_1 \leq 25$	≤ 2.2
Complex	$5 < I_1 \leq 25$ or > 25	> 2.2

RESULTS AND DISCUSSION

Micromorphology

Upon analyzing the micromorphological characteristics of the native forest area in the 0.00-0.15 m and 0.15-0.30 m, we observed percentages of 45, 10, and 45% for the coarse material (g), the fine material (f), and porosity, respectively, with a g/f ration of 4/1, by adopting the limit of 20 µm (Figure 1). We identified particles of coarse sand (35%), medium-grain sand (25%), and fine sand (20%) and particles of silt and clay, filling some voids which, summed, resulted in around 20%.

The coarse material was found to be predominant, with equidimensionally shaped, slightly round, subangular minerals with wavy-like wall rugosity. The orientation of this material as compared to the surface was of the weak type, with no connections between the components of the same nature (Figure 2). The microstructure was classified as apedal and very dominant. However, it had small zones of peds with granule-like structures that were weakly developed and had rugose wavy walls.

The fine material was found to be heterogeneously distributed, which enabled to identify small distinct zones in regards to the g/f distribution. The two layers were observed to have predominant enaulic distributions, as well as chitonic and monic distributions.

The total porosity area of 45% was divided in canals, stackings, and cavities, with frequencies of 15%, 75%, and 10%, respectively, located between and within the aggregates, with base orientation of the weak type, classified as random and with no relationships with the reference. According to the formation, the pores were identified as biopores and physical-genetic pores.

The micromass was found to comprise clay, silt, organic matter, and red iron oxides and undifferentiated birefringent fabric, besides black, clean, long residues of roots with an approximate size of 1 mm, coal fragments, and spheroid and ellipsoid feces.

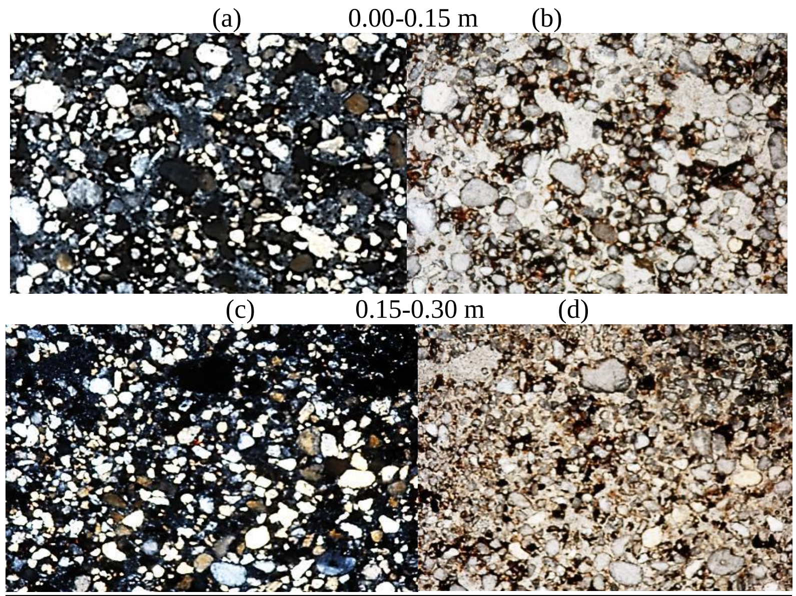

Figure 1. Micromorphological analysis of the native forest area, with (a and c) and without (b and d) polarized lighting, in the 8 µm scale.

Soil porosity and specific surface

Upon analyzing the average values of the total poroid area (TPA) of the studied treatments (T1, T2, and T3) in the first evaluation year, we observed that no significant differences existed between them ($p < 0.05$) for all collection points and layers evaluated. The same was not observed in the second evaluation year, as the values of the sampled points in the seedbeds (SB) were higher for T1, T2, and T3 as compared to the wheel row (WR). In the treatments that used the autopilot (T2 and T3), the total porosity (TP) values were higher as compared to T1 (Table 2). These lower values observed in T1 may be justified by the traffic of heavy machines that takes place in the WR, which reduce the connectivity of local pores.

Table 2. Total porosity (TP) obtained through digital images of a quartz-sand neosol cultivated with sugarcane managed with autopilot in distinct row spacing regimens.

Managements	Total porosity			
	Collection point		Layers (m)	
	WR	SB	0.00-0.15	0.15-0.30
	%			
	1st year			
T1	27.80 Aa*	36.80 Aa	31.70 Aa	32.90 Aa
T2	27.60 Aa	36.30 Aa	31.10 Aa	32.80 Aa
T3	36.20 Aa	43.20 Aa	38.50 Aa	40.90 Aa
CV (%)	30.58			
	2nd year			
T1	20.40 Bb	33.90 Ba	25.50 Ba	28.80 Aa
T2	26.00 Aab	34.40 Aa	28.30 Aba	32.10 Aa
T3	30.50 Aa	37.40 Aa	33.10 Aa	34.80 Aa
CV (%)	29.34			

* Averages followed by uncapitalized letters in the line and by a capital letter in the column do not differ as per Tukey test ($p > 0.05$). T1 = Sugarcane planted under single row spacing and managed without autopilot (1.50 m); T2 = Sugarcane planted under single row spacing (1.50 m) and managed with autopilot; T3 = Sugarcane planted under combined double row spacing (1.5 x 0.90 m) and managed with autopilot. SB = seedbed; WR = wheel row, CV - coefficient of variation.

Upon evaluating TP in sugarcane areas in the path of machines and devices to harvest and transport the production, Piron *et al*. (2012) and Souza *et al*. (2015) also observed that the points with higher TP are close to the plant row and the seedbed, besides the reduction in the connectivity of pores in the local with intense traffic of machines.

Considering that the row spacing in T3 was 1.50 × 1.90 m, for an area of 1.0 ha, the traffic of machines takes place in 41.66 lanes, whereas in T1 and T2m in which a row spacing of 1.50 m was adopted, 66.66 lanes are available for traffic. These row spacing differences enable and increase in the seedbed area for T3, as the traffic takes place at each 2.40 m and there was no traffic of machines between the double rows. Although the TP averages were the same in the first year, T3 has a larger area without traffic, and therefore a decreased risk of compaction and damage to the plants.

Upon analyzing the specific surfaces of the pores, we observed that no differences existed ($p < 0.05$) in the first evaluation year and that the same did not take place in regards to the second year, as T2 was found to have the lowest average in the WR, as compared to the SB (Table 3). Among the layers, only the 0.15-0.30 m layer was observed to have difference in its averages, in which T2, which did not benefit from the autopilot technique, was found to have the lowest values.

The compaction caused by the traffic, especially the one observed in WR, reduced TP and increases the contact between soil particles. Such effect promotes a reduction in the exposure surface of particles, and therefore diminishes the specific surfaces of pores. Although no differences were found between T1 and T3 between layers or collection points, it is important to mention that the traffic-designated zone in T1 is larger, and, therefore, is more subject to compaction damage, as the traffic takes place at each 1.50 m, which was also found by Roque *et al*. (2011). Mosaddeghi *et al*. (2007) highlight that compaction negatively influences all other physical properties, and due to that it has been pointed out as one of the main cases of soil degradation.

Only in the SB of the 0.00-0.15 m layer significant differences were found ($p < 0.05$) between the percentage of the complex pore area, where T3 was found to have the highest values (Figure 2). All treatments (T1, T2, and T3) were observed to have a predominance of complex pores, especially in the seedbed, followed by round pores, and, in a smaller quantity, the elongated pores.

Regarding pore sizes, we observed that, in the first year, in all treatments, there was a predominance of large pores, especially in the SB. These results are justified by the short time of application of the treatments, once conventional soil preparation practices were conducted in all of them (such as ploughing and harrowing, which may have contributed to increasing the percentage of complex pores, originated from the revolving. Genaro et al. (2015) state that not revolving the soil provides more round and less complex pores. Souza *et al*. (2006) complement this information by reporting that the increase in round pores leads to hydraulic conductivity of the soil, which increases the water infiltration time in the soil.

Table 3. Specific surface (SS) of the 2D pores of a quartz-sand neosol cultivated with sugarcane.

Management	Specific surface (mm)			
	Collection point		Layers (m)	
	WR	SB	0.00-0.15	0.15-0.30
	1st year			
T1	11.10 Aa	13.90 Aa	11.20 Aa	13.70 Aa
T2	7.70 Aa	9.50 Aa	8.14 Aa	9.11 Aa
T3	8.54 Aa	8.40 Aa	9.87 Aa	15.19 Aa
CV (%)	65.98			
	2nd year			
T1	7.60 Aa	8.10 Aa	7.89 Aa	7.92 Ba
T2	7.40 Ab	21.30 Aa	11.33 Aa	17.44 Aa
T3	11.20 Aa	13.00 Aa	12.24 Aa	12.04 ABa
CV (%)	58.83			

* Averages followed by uncapitalized letters in the line and by a capital letter in the column do not differ as per Tukey test ($p > 0.05$). T1 = Sugarcane planted under single row spacing (1.50 m) and managed without autopilot; T2 = Sugarcane planted under single row spacing (1.50 m) and managed with autopilot; T3 = Sugarcane planted under combined double row spacing (1.5 × 0.90 m) and managed with autopilot. SB = seedbed; WR = wheel row, CV = coefficient of variation.

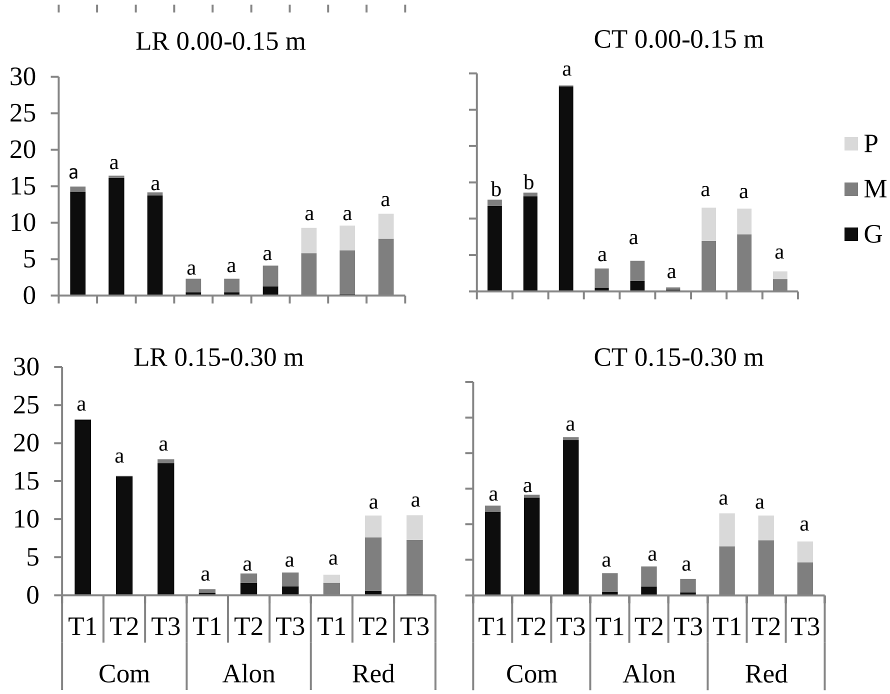

Figure 2. Sizes and shapes of the pores of a quartz-sand neosol cultivated with sugarcane after the first harvest. T1 = Sugarcane managed without autopilot and planted under 1.50 m row spacing; T2 = Sugarcane managed with autopilot and planted under 1.50 m row spacing; T3 = Sugarcane managed with autopilot and planted under combined double row spacing of 1.50 x 0.90 m. G = large; M = medium; P = small; Com = complex; Alon = elongated; Red = round.

In the second studied year, the traffic of machines was verified to contribute to reducing the percentage of large pores and their complexity in all treatments (Figure 3). Thus, the following cycles are expected to have a more marked effect, as the soil will not be revolved until the sugarcane crop is renovated. According to Piron *et al*. (2012), soil compaction reduces macroporosity and causes the structure to be solid and with less connectivity, which is related to the reduction in the complexity of pores.

The percentage of large pores decreased as compared to the first year in the collection points and layers evaluated. However, it remained over the percentage of small and medium pores, especially in the seedbed layers. These results reveal that the traffic, regardless of the management adopted, was responsible for reducing macroporosity, once this is more sensitive to changes as compared to meso and micropores. In their studies, Streck *et al*. (2004) and Naghdi and Solgi (2014) attributed the macroporosity and TP reductions to the traffic of machines.

CONCLUSION

The seedbed area was observed to have higher porosity in the treatments with autopilot in the second evaluation year; There were no differences in pore sizes and shapes between the treatments in the two years studied; The large and complex pores were observed to be reduced in the second evaluation year.

Acknowledgements

The authors thank the Foundation for Research Support of the State of São Paulo (FAPESP) for funding the research, through projects linked to the processes 2012 / 21094-0 and 2012 / 144-6.

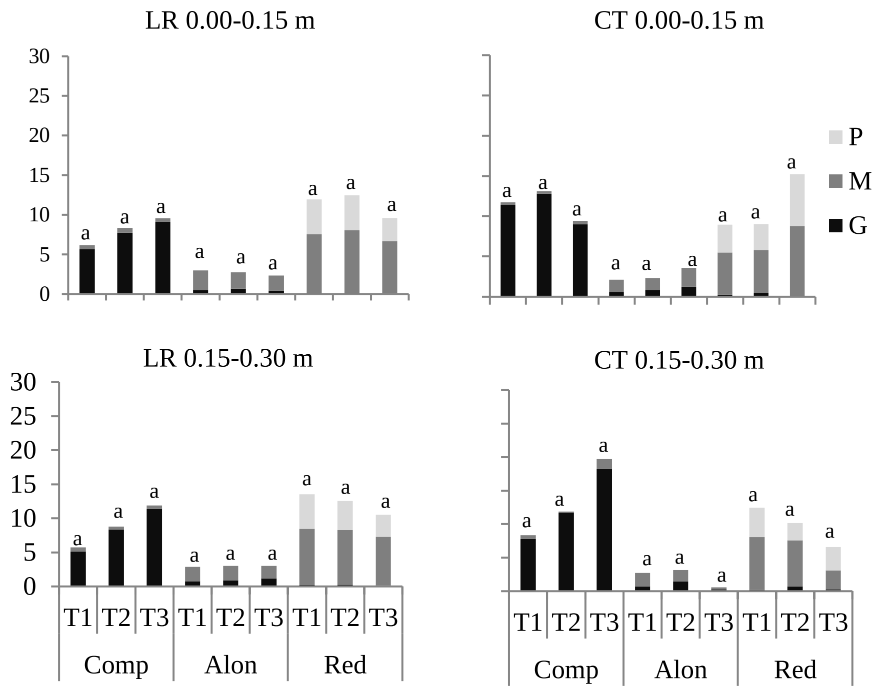

Figure 3. Sizes and shapes of the pores of a quartz-sand neosol cultivated with sugarcane after the second harvest. T1 = Sugarcane managed without autopilot and planted under a 1.50 m row spacing; T2 = Sugarcane managed with autopilot and planted under a 1.50 m row spacing; T3 = Sugarcane managed with autopilot and planted under a combined double row spacing of 1.50 × 0.90 m. G = large; M = medium; P =s mall; Com = complex; Alon = elongated; Red = round).

REFERENCE

Bullock, P.; Fedoroff, N.; Jongerius, A.; Stoops, G.; Tursina, T.; Babel, U. 1985. Handbook for soil thin section description. Albrington: Waine Reserch, 152 p.

Campos, F.S.; Alves, M.C.; Souza, Z.M.; Torres, J.L.R. 2015. Cropping systems evaluation, fertilization, and effects on technological quality and sugarcane productivity. African Journal of Agricultural Research, 10: 3387-3393. doi: 10.5897/AJAR2015.9977

Conab - acompanhamento da safra brasileira de cana-de-açúcar, v. 2 – Safra 2015/16, n. 2 - Segundo Levantamento, Brasília, agosto/2015. Disponível em:<http://www.conab.gov.br/agosto -. 2015. pdf > Acesso em: 17.06. 2016.

Cooper, M. 1999. Influência das condições físico-hídricas nas transformações estruturais entre horizontes B latossólico e B textural sobre diabásio. 132 p. Tese (Tese de Doutorado) – Escola Superior de Agricultura "Luís de Queiroz", Universidade de São Paulo, 1999.

Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA). Sistema brasileiro de classificação de solos. 3ª ed. Brasília, EMBRAPA, 2013, 353p.

Ferreira, D. F. 2011. Sisvar: A computer statistical analysis system. Ciência e Agrotecnologia, Lavras, v.35, n.6, p. 1039-1042. doi: http://dx.doi.org/10.1590/S1413-70542011000600001

Genaro, L. A.; Souza, Z. M.; Silva, L. F.; Cooper, M. Campos, M. C. C. 2015. Estrutura do solo sob feijão irrigado e diferentes manejo do solo. Revista Brasileira de Ciência do Solo, Viçosa, v.39, n.2, p.608-614. doi: 10.1590/01000683rbcs20140441

Gonçalves, F. C.; Moraes, M. H. 2012. Porosidade e infiltração de água do solo sob diferentes sistemas de manejo. Irriga, 17: 337-345. doi: http://dx.doi.org/10.15809/irriga.2012v17n3p337

Jongerius, A.; Heintzberger, G. 1975. Methods in soil micromorphology: a technique for the preparation of large thin sections. Wageningen: SoilSurveyInstitute, (Soil

Survey Papers, 10), 48p. http://edepot.wur.nl/304516.

Kamimura, K.M.; Levien, R.; Trein, C.R.; Debiasi, H.; Conte, O. 2009. Parâmetros solo-máquina em função de doses de resíduos vegetais e profundidades de deposição de adubo em semeadura direta. Engenharia Agrícola, 29: 431-439. doi: http://www.scielo.br/pdf/eagri/v29n3/a10v29n3.pdf

Lecler, N. L.; Tweddle, P.B. 2010. Double profits with a controlled traffic zero-till irrigation farming system. South African Sugar Technologists Association, 83: 46-62. http://www.sasta.co.za/wp-content/uploads/Proceedings/2010s/2010-Lecler-and-Tweddle.pdf

Lima, H.V.; Silva, A.P.; Santos, M.C.; Cooper, M.; Romero, R.E. 2006. Micromorphology and image analysis of a hardsetting Ultisol (Argissolo) in the state of Ceará (Brazil). Geoderma, 132: 416- 426. doi: http://dx.doi.org/10.1016/j.geoderma.2005.06.006

Mosaddeghi, M.R.; Koolen, A.J.; Hemmat, A.; Hajabbasi, M.A.; Lerink, P. 2007. Comparisons or different procedures of pre-compactation stress determination on weakly structure soils. Journal of Terramechanics, 44: 53-63. doi:10.1016/j.jterra.2006.01.008

Murphy, C.P. 1986. Thin section preparation of soils and sediments. Berkhamsted, A.B. Academic Publishers,149 p. doi: 10.1111/j.1365-2818.1987.tb02834.x

Naghdi, R; Solgi, A. 2014. Effects of skidder passes and slope on soil disturbance in two soil water contents. Croatian Journal of Forest Engineering, 35: 73-80. doi: http://hrcak.srce.hr/120239

Oliveira Filho, F.X.; Miranda, N.O.; Medeiros, J.F.; Silva, P.C.M.; Mesquita, F.O.; Costa, T.K.G. 2015. Zona de manejo para o preparo do solo na cultura da cana-de-açúcar. Revista Brasileira de Engenharia Agrícola e Ambiental, 19:186-193. doi: http://dx.doi.org/10.1590/1807-1929/agriambi.v19n2p186-193

Pires, L.F.; Cooper, M.; Cássaro, F.A.M.; Reichardt, K.; Bacchi, O.O.S.; Dias, N.M.P. 2008. Micromorphological analysis to characterize structure modifications of soil samples submitted to wetting and drying cycles. Catena, 72: 297-304. doi: http://dx.doi.org/10.1016/j.catena.2007.06.003

Piron, D.; Pérès, G.; Hallaire, V.; Cluzeau, D. 2012. Morphological description of soil structure patterns produced by earthworm bioturbation at the profile scale. European Journal of Soil Biology, 50: 83-90. doi: http://dx.doi.org/10.1016/j.ejsobi.2011.12.006

Rasband, W. ImageJ 1.40. National Institute of Health, USA, 2008. Disponível em: www.google.com.br/?gws_rd=ssl#q=National+Institute+of+Health&. Acesso em: Janeiro. 2014.

Roque, A. A. O.; Souza, Z. M.; Araújo, F. S.; Silva. G. R. V. 2011. Atributos físicos do solo e intervalo hídrico do solo de um Latossolo Vermelho distrófico sob controle de tráfego agrícola. Ciência Rural, 41: 1536-1542. doi: http://dx.doi.org/10.1590/S0103-84782011005000117.

Silva, G.L.; Lima, H.V.; Campanha, M.M.; Gilkes, R.J.; Oliveira, T.S. 2011. Soil physical quality of Luvisol sunder agroforestry, natural vegetation and conventional crop management systems in the Brazilian semi-arid region. Geoderma, 167-168: 61-70. doi:10.1016/j.geoderma.2011.09.009

Sousa, A. C. M.; Matsura, E. E.; Elaiuy, M. L. C.; Santos, L. N. S.; Montes, C. R.; Pires, R. C. M. 2013. Root system distribution of sugarcane irrigated with domestic sewage effluent application by subsurface drip system. Engenharia Agrícola, 33: 647-657. doi: http://dx.doi.org/10.1590/S0100-69162013000400006

Souza, G.S.; Souza, Z.M.; Silva, R.B.; Araújo, F.S.; Barbosa, R.S.; Araújo, F.S. 2014. Effects of traffic control on the soil physical quality and the cultivation of sugarcane. Revista Brasileira de Ciência do Solo, 38:135-146. doi: http://dx.doi.org/10.1590/S0100-06832014000100013.

Souza, G. S.; Souza, Z. M.; Cooper, M.; Tormena, C. A. 2015. Controlled traffic and soil physical quality of an Oxisol under sugarcane cultivation. ScientiaAgricola, 72: 270-277. doi: http://dx.doi.org/10.1590/0103-9016-2014-0078.

Souza, Z. M.; Marques Júnior, J.; Cooper, M.; Pereira, G.T. 2006. Micromorfologia do solo e sua relação com atributos físicos e hídricos. Pesquisa Agropecuária Brasileira, 41: 487-

492. doi: http://dx.doi.org/10.1590/S0100-204X2006000300016

Streck, C.A.; Reinert, D.J.; Reichert, J.M.; Kaiser, D.R. 2004. Modificações em propriedades físicas com a compactação do solo causada pelo tráfego induzido de um trator em plantio direto. Ciência Rural, 34: 755-760. doi: http://dx.doi.org/10.1590/S0103-84782004000300016

Tavares, R.L.M.; Farhate, C.V.V.; Souza, Z.M.; Scala Junior, M.; Torres, J.L.R.; Campos, M.C.C. 2015. Emission of CO_2 and soil microbial activity in sugarcane management systems. African Journal of Agricultural Research, 10: 975-982. doi: http://dx.doi.org/10.1590/S0103-84782004000300016

Torres, J.L.R.; Pereira, M.G.; Cunha, M.A. Martins, M.E.; Vieira, D.M.S. 2013. Physicochemical properties of soil and biomass in sugarcane harvesting systems. Revista Ciências Agrárias, 56: 311-318. doi: http://dx.doi.org/10.4322/rca.2013.047

Vasconcelos, R. F. B.; Souza, E. R.; Cantalice, J. R. B.; Silva, L. S. 2014. Qualidade física de Latossolo Amarelo de tabuleiros costeiros em diferentes sistemas de manejo de cana-de-açúcar. Revista Brasileira de Engenharia Agrícola e Ambiental, 18: 381-386. doi: http://dx.doi.org/10.1590/S1415-43662014000400004