INFLUENCE OF MANAGEMENT SYSTEMS ON SOIL PHYSICAL ATTRIBUTES

OLIVEIRA, Wendel Kaian Mendonça [1]
OLIVEIRA, Daiane de Deus [2]
MORAES REGO, Carlos Augusto Rocha de [3]
SILVA, Edilza Martins da [2]
OLIVEIRA, Adriane Silva de Mendonça[4]
SILVA, Raimundo Thiago Lima da [5]
MAGGI, Marcio Furlan[2]

Recebido em: 2022.10.14 **Aprovado em:** 2023.03.29 **ISSUE DOI:** 10.3738/1982.2278.4073

SUMMARY: The deterioration of soil quality has been widely studied and debated in Soil Science. Thus, this work aims to evaluate the effect of soil management systems, regarding the soil physical attributes. A New Holland tractor was used, model TL75, 4 x 2 TDA, in a randomized block design, with a split-plot plot scheme (5 x 3), that is, five soil tillage methods (leveling harrow, rotary hoe, manual weeding, subsoiler, and disc plow) and three periods (before tillage, after tillage and at the end of the implanted crop cycle) with three replicates, totaling 45 experimental units. For the water retention curve (SWRC), the SWRC Fit program was used. No significant difference was found among the soil tillage methods, however, when comparing the time before and after the preparation and the end of the implanted crop cycle, changes in the physical properties of the soil were observed in both treatments. The evaluation of the different methods allowed us to observe that the closer the results of parameters R^2 and the AIC, the most satisfactory the SWRC. Therefore, it is concluded that the different treatments do not cause changes in the physical properties of the soil, but when working with soil collections before and after sowing and harvesting, changes are found in the soil profile. The SWRC assessment methods were satisfactory; however, the Kosugi and Fredlund and Xing methods did not present significant values when compared with the others.

Keywords: Agricultural Mechanization; Mechanized Tillage; Tillage.

INFLUÊNCIA DOS SISTEMAS DE MANEJOS NOS ATRIBUTOS FÍSICOS DO SOLO

RESUMO: A deteorização da qualidade do solo tem sido amplamente estudada e debatida pelas ciências do solo. Dessa forma, esse trabalho tem por objetivo avaliar o efeito dos sistemas de manejo do solo, sobre os atributos físicos deste. Utilizou-se um trator New Holland, modelo TL75, 4 x 2 TDA, em um delineamento de blocos ao acaso, com esquema de parcela subdivididas (5 x 3), ou seja, 5 métodos de preparo de solo (grade niveladora, enxada rotativa, capina manual, subsolador e arado de disco) e três período (antes do preparo, depois do prepara e no final do ciclo da cultura implantada) com 3 repetições, totalizando 45 unidades experimentais. Para a curva de retenção de água (SWRC), utilizou-se o programa SWRC Fit. Não houve diferença significativa entre os métodos de preparo de solo, porém quando se compara o tempo antes e depois do preparo e final do ciclo da cultura implantada, em ambos os tratamentos ocorre modificações nas propriedades físicas do solo. A SWRC quando avalizado os diferentes métodos, observou-se os parâmetros R^2 e o AIC, no qual quanto mais próximo 1 os resultados, mais satisfatórios. Com isso, conclui-se que os diferentes tratamentos não causam alterações nas propriedades físicas no solo, mas quando se trabalha com coletas de solo antes e depois da semeadura e na colheita, verifica-se modificações no perfil do solo. Os métodos de avaliação da SWRC foram satisfatórios, porém os métodos Kosugi e Fredlund and Xing, não apresentaram valores significativos quando comparados com os demais.

Palavras-chave: Mecanização Agrícola; Preparo Mecanizado; Preparo do Solo.

INTRODUCTION

The degradation of soil quality has been widely studied and debated by Soil Science,

[1] Departamento de Ciência da Computação, Universidade Tecnológica Federal do Paraná (UTFPR), Campus Medianeira, Medianeira, Paraná, Brasil.
[2] Programa de Pós-graduação em Engenharia agrícola, Universidade Estadual do Oeste do Paraná (UNIOESTE), Campus Cascavel, Paraná, Brasil
[3] Centro de Ciências de Chapadinha, Universidade Federal do Maranhão (UFMA), Chapadinha, Maranhão, Brasil
[4] Tecnologia de Alimentos, Universidade Estadual do Pará (UEPA), Redenção, Pará, Brasil.
[5] Instituto de Ciências Agrárias, Universidade Federal Rural da Amazônia (UFRA), Capitão Poço, Pará, Brasil.

mainly because of the removal of cover and/or intensive use of agricultural mechanization in soil preparation and cultivation operations (ASSIS; LANÇAS, 2005).

Soil tillage systems promote changes in physical properties, such as density and porosity (HEBB *et al.*, 2017). This results in areas with a greater state of superficial compaction and the formation of compacted layers over its profile (ORTIGARA *et al.*, 2014). For Girardello *et al.* (2014), compaction is different from densification, i.e., it is a natural process caused by anthropic action in agricultural processes whose major cause is the frequent traffic of heavy machinery within the crop in conditions of high soil humidity.

Moreover, the negative effects that emerge with the increase of the compaction and the consequent reduction of the size of the pores to the point of blocking the passage of the main root, are compensated by the increase in the volume of lateral roots with smaller diameters, that form a very dense and shallow root system which, in the field hardly survive in water deficit conditions (KUNZ *et al.*, 2013).

Compaction impairs root growth by affecting plant development (MORAES *et al.*, 2020), water retention capacity (NADERI-BOLDAJI; KELLER, 2016), and the infiltration rate, influencing surface runoff in soil erosion (HEBB *et al*., 2017) and promoting a reduction in crop productivity (KUNZ *et al.*, 2013). These conditions of physical soil quality are strongly related to the capacity of the soil to perform its functions to sustain productivity, therefore, maintaining the quality of water and air (NADERI-BOLDAJI; KELLER, 2016).

The symptoms of compaction in the field can be observed both in the soil and in the plant; however, it is easily confused with similar symptoms caused by drought, nutritional deficiencies, aluminum and manganese toxicity, nematodes, among others (CAMARGO; ALLEONI, 2006). The main physical indicators of soil quality are texture, structure, resistance to penetration, depth of rooting, available water capacity, percolation or water transmission, and cultivation system (GOMES; FILIZOLA, 2006).

In the case of compaction, it can be observed slow emergence of seedlings, plants of different sizes, consequently with more plants of smaller sizes and with poor coloration, shallow root systems and malformed roots with the presence of absorbent hairs can be observed (CAMARGO; ALLEONI, 2006).

The root behavior of plants can be modified by the conditions of the environment where they are grown. Both the texture and the apparent density of the soil cause changes in the number of seminal adventitious roots (ROSOLEM *et al.*, 1999).

Root growth, crop development, and production are influenced by the level of soil compaction, which depends on the management system. Soil bulk density is a characteristic that changes according to the local water availability and soil management, so one of the trends in the no-tillage system is that over time, as a result of machine traffic, a compacted layer may form which may harm the development of crops (MORAES *et al.*, 2013).

According to Santana *et al.* (2018), the particle density can be defined as the ratio between the volume occupied by the solid particle and the mass of a sample, in which, this variable disregard the porosity, considering only the solid particles in the sample. Particle density is an intrinsic characteristic of soils, which does not change according to the management. Obtaining the actual values of particle density ensures the adequate characterization of structural changes in the soil as a result of management, in addition to the indirect determination of the total soil porosity (MORAES *et al.*, 2020).

The water retention curve (SWRC) is essential in studies of soil quality in relation to practices of use and sustainable management of agricultural production systems. Changes in their structure associated with the compaction and loss of stability of the aggregates alter the distribution of the pore size, as well as the retention, movement, and availability of water in it (MACHADO *et al*., 2008).

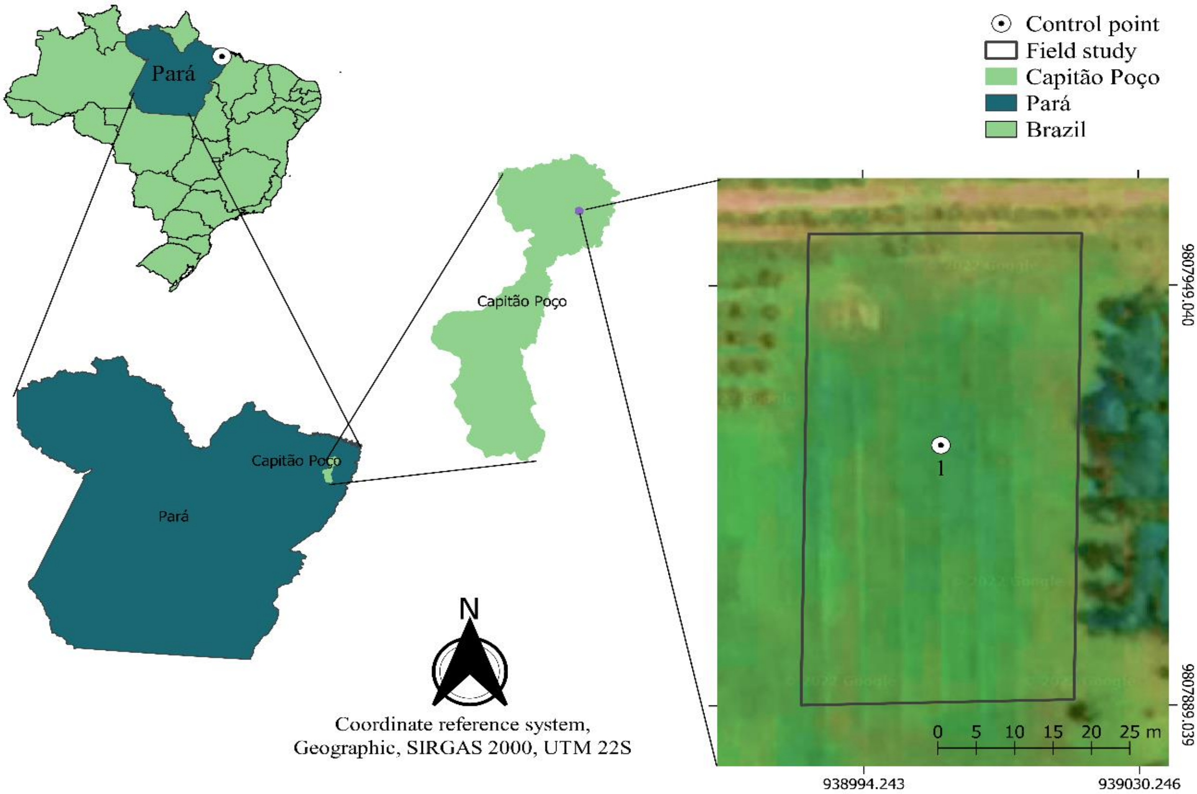
According to Nascimento *et al.* (2010), the soil water retention curve expresses the relationship between soil potential and soil moisture. In the case of irrigation, it is important to determine the water retention curve, which determines the energy of the water in the soil, which is also influenced by its physical and chemical characteristics. This allows determining the field capacity and the permanent wilt point (FILGUEIRAS *et al*., 2018).

Thus, this work aims to evaluate the effect of soil management systems, on their physical attributes.

MATERIAL AND METHODS

The experiment was conducted in the experimental field of the Federal Rural University of the Amazon (UFRA), Capitão Poço campus (Figure 1). The municipality of Capitão Poço has a thermal range of 25.7 to 26.9°C, with an annual average temperature of 26.2°C and only 1.2°C of variation (SILVA *et al.*., 2011). The soil in the area has characteristics of a Yellow Latosol EMBRAPA (2013), as shown in Figure 1, which presents the experimental area used for physical analysis of the soil, Capitão Poço - PA, 2016.

Figure 1: Experimental area used for soil physic analysis, Capitão Poço – PA, 2016.



Source: the authors

The experiment started on January 22, 2015, with the aid of a New Holland tractor, model TL75, 4 x 2 (4) TDA, with auxiliary front-wheel drive, and rated power of 78 hp and PTO 540 rpm, operating at an average speed of 5 km h^{-1}. The implements were coupled to the tractor and the different methods of initial soil preparation were executed in all the blocks.

The experimental design was applied in the blocks in a split-plot scheme (5 x 3), with three replicates, totaling 45 experimental units. The treatments were carried out according to the following Factors: 5 methods of initial soil preparation (main plot), which were: 1 - Subsoiling; 2 – harrowing; 3 –Rotary hoe; 4 – disc plow; 5 – manual weeding and the sub-plot had three collection periods (before preparation, after preparation and at the end of the cycle of the implanted crop).

The units in the experimental arrangement had a dimension of 6 m x 6 m, with an area of 36 m², where the total dimension of a block was 22 m long and 38 m wide, totaling 836 m². To characterize the planting area, collections were performed on disturbed soil samples with the aid of an auger inside each experimental unit in the 0.00-0.10 m layers, before tillage and 30 days after the preparation of the soil. at the crop harvesting.

Earth samples were dried in an oven at 105ºC and macerated with the aid of a crucible and pistil until they reached the smallest particle size. After, they were weighed to reach 20 grams and subsequently submitted to the volumetric flask, where they were measured using 70% alcohol in the capacity of 50 ml. The difference in particle density was determined using the following expression Eq. 1:

$$D_p = \frac{M_{ss}}{V_s} \quad \text{Eq. 1}$$

In which, Dp – Particle density; Mss –soil mass dried at 105 ± 5 ºC; Vs - volume of the alcohol used in the experiment, described by EMBRAPA (2011).

For soil bulk density, the methodology of (EMBRAPA, 2011) was used, with the following expression Eq. 2:

$$D_s = \frac{m_{ss}}{V_t} \quad \text{Eq. 2}$$

Where, Ds, soil bulk density (g cm^{-3}); Mss, soil mass dried at 105 ± 5 ºC; Vt, the volume of the used alcohol (cm^3).

The macroporosity (S - cm^3 cm^{-3}) from the $S = \alpha - \theta$ relation, where a (cm^{-3} cm^{-3}) is the total porosity calculated through Eq. 3:

$$\alpha = 1 - \left(\frac{D_s}{D_r}\right) \quad \text{Eq. 3}$$

Where, Ds, soil bulk density (g cm^{-3}); D_r (kg dm^{-3}) is the real density and Θ (cm^3 cm^{-3}) is the water content retained in the soil volume when subjected to a matrix potential of -60 cm of water column (EMBRAPA, 2011).

Microporosity was determined following the EMBRAPA methodology (2011), using the following expression Eq. 4:

$$\text{Microporosity} = \left(\frac{a-b}{c}\right) x\,100 \quad \text{Eq. 4}$$

Where, a = weight of the sample after being subjected to a tension of 60 cm of the water column, b = weight of the sample dried at 105ºC (g), c = volume of the cylinder.

Analysis of the methods was performed to estimate the volumetric moisture content of the soil during the different collection periods, and Microsoft Excel spreadsheets were used for curve adjustment. Immediately after, they were copied and pasted in the SWRC FIT program, to calculate the initial estimate of the parameters in which it was automatically determined using the program, for the BC methods (BROOKS AND COREY, 1964), VG (VAN GENUCHTEN, 1980), LN (KOSUGI, 1996), FX (FREDLUND; XING, 1994), DM (DURNER, 1994) and SK (SEKI, 2007), according to Seki's methodology (2007).

The experimental data were submitted to the Shapiro-Wilk (1965) and Bartlet (1937) tests ($p > 0.01$), to check normality and homoscedasticity. The data that did not fulfill the ANOVA assumptions were transformed using the Box-Cox method (BOX AND COX, 1964). As the basic assumptions were fulfilled, the set of values was subjected to ANOVA and Tukey test, with a probability of 5% error, performed in the Sisvar Software (FERREIRA, 2011).

RESULTS AND DISCUSSION

It could have been observed that there was no significant difference between the tillage methods (disc plow, leveling harrow, manual weeding, rotary hoe, and subsoiler) at 5% probability. However, a difference was observed between the collection time for the physical properties of the soil, as shown in Table 1 that also shows the means of the physical attributes of the soil, soil bulk density – DS, particle density – DP, macroporosity - Macro, microporosity – micro and total porosity – PT as a function of the initial soil preparation and sowing depth in the corn crop.

Table 1. Means of soil physical attributes, soil bulk density – SD; particle density – PD, macroporosity – Macro, microporosity – Micro, total porosity – TP as a function of the initial soil preparation and sowing depth in the corn crop

Physical parameters		SD	PD	Micro	Macro	TP
		-----------(g/cm³)-------		------------------------(%)-------------------		
Soil preparation						
Disc plow		1.55 a	2.79a	35.69 a	9.42 a	44.35 a
Leveling disc harrow		1.50 a	2.81a	35.04 a	12.49 a	46.49 a
Manual weeding		1.48 a	2.84a	36.62a	10.85 a	47.27 a
Rotary hoe		1.52 a	2.76a	36.71 a	9.74 a	44.68 a
Subsoiler		1.48 a	2.73a	34.84 a	10.91 a	45.54 a
LSD		0.14	0.26	4.78	5.54	9.82
Time						
Before sowing		1.62a	2.80ab	29.65a	12.45a	42.09a
After sowing		1.46b	2.83a	41.26b	8.62b	48.09b
Harvesting		1.44b	2.72b	36.44c	10.98ab	46.81b
LSD		0.05	0.09	2.37	2.88	2.82
Source of variation	d.f	Mean squares				
Block	2	0.07^{ns}	0.009^{ns}	50.30^{ns}	75.36^{ns}	21.95^{ns}
Soil preparation (SP)	4	0.019^{ns}	0.054^{ns}	20.36^{ns}	39.41^{ns}	40.25^{ns}
Error 1	8	0.024	0.077	25.90	34.76	109.03
Time (T)	2	0.380**	0.141**	1531.12**	168.09**	448.39**
(DS) x (T)	8	0.015^{ns}	0.017^{ns}	28.67^{ns}	23.07^{ns}	35.39^{ns}
Error 2	110	0.014	0.034	22.42	33.24	31.80

CV (%)	9.46	6.82	18.86	55.59	14.30

*Means followed by different letters are different from each Other in the column by the test of Tukey at 5% probability; coefficient of variation – CV (%). ** Significant at the 0.01 probability ($p < 0.01$) by the F-test. * Significant at the 0.05 probability ($p < 0.05$) by the F-test. NS, not significant ($p > 0.05$) by the F-test.

The soil collection performed before sowing showed a significant difference when compared to the collection of soil after sowing and harvesting for soil density. De Sá *et al.* (2016) observed that 38% of the reduction in root mass was attributed to the increase in the mechanical resistance of the soil to penetration, while 46% was attributed to the increase in the density of the soil and the degree of compaction.

It was found in this experiment that the particle density was higher in soil collection after sowing, differing statistically from other treatments with respect to the time. Santana et. al. (2018) considered that the particle density in the no-tillage system obtained higher values of this parameter in superficial layers in relation to the conventional system. Studies developed by Moraes *et al.* (2016) in Oxisol observed an increase in the values of particle density, resulting from the presence of high levels of iron oxides. Therefore, the higher the density, the more compact the soil, the lower the degree of structure, porosity, and, consequently, the greater the restrictions for plant growth (AMARO *et al.*, 2008).

The soil microporosity differed among the three soil collection periods, in which the collection after sowing stood out in relation to the others. However, the collection performed before corn sowing showed a lower value (Table 1). In experiments carried out by Moraes *et al.* (2016), the microporosity of the soil, which is responsible for storing water in its profile, has not been altered by the production models, indicating that the physical property is little sensitive to the alternation of root systems of different plants through rotation and or succession systems. Therefore, there is a reduction in the size of the pores, which becomes responsible for the storage of water and nutrients for the plants. Matias *et al.* (2012) found that microporosity is not much influenced by soil density, demonstrating that soil degradation or decreased soil aeration is directly linked to less macroporosity.

In the soil collection carried out after the corn harvest, for macroporosity obtained results statistically similar to the collections carried out before and after sowing. However, they differed from each other. The permanently uncovered soil showed physical degradation, which was expressed by the increase in the density of the soil and by the mechanical resistance to penetration, and a reduction in the rate of water infiltration and macroporosity in the soil (LANZANOVA *et al.*, 2010). Low macroporosity values can be indicative of degradation resulting in poor drainage, increased soil resistance to root penetration, and low aeration (STOLF *et al.*, 2011). These macroporosity values are considered adequate for plants, in terms of ensuring aeration of the root system (REYNOLDS *et al.*, 2002).

The soil collection before sowing differed statistically from the other treatments for total porosity. Ros *et al.* (1996) claims that the cultivation time in the no-tillage system up to nine years does not affect the total porosity, macroporosity, and microporosity of the soil. Studies developed by Machado *et al.* (1997) demonstrated that the average value of total soil porosity increased as the water content in the soil increased, thus showing a significant difference between water content in the soil as both microporosity and macroporosity increase with water content. Lima *et al.* (2013) state that the total porosity has a value inversely proportional to the soil density. In this work (Table 1) the same relationship was observed, where the lowest values of soil density were accompanied by the highest values of total porosity.

It can be observed through statistical analysis of variance (ANOVA) that there was no significant interaction between the factors soil density and time (soil collections before and after corn sowing and harvest), as all values found in the experiment are higher than the p-value of 0.05% (Table 1).

The results found for the block and soil tillage factors were also not significant, as they obtained values above the p-value. However, the time factor was significant among all treatments, that is, it caused a significant influence concerning soil management.

The coefficient of variation is between 6.82 and 55.59% for the treatments, and Pimentel-Gomes (1990) states that the values of the coefficient of variation below 10% are considered great and homogeneous, nevertheless, values greater than 30% are very high and heterogeneous.

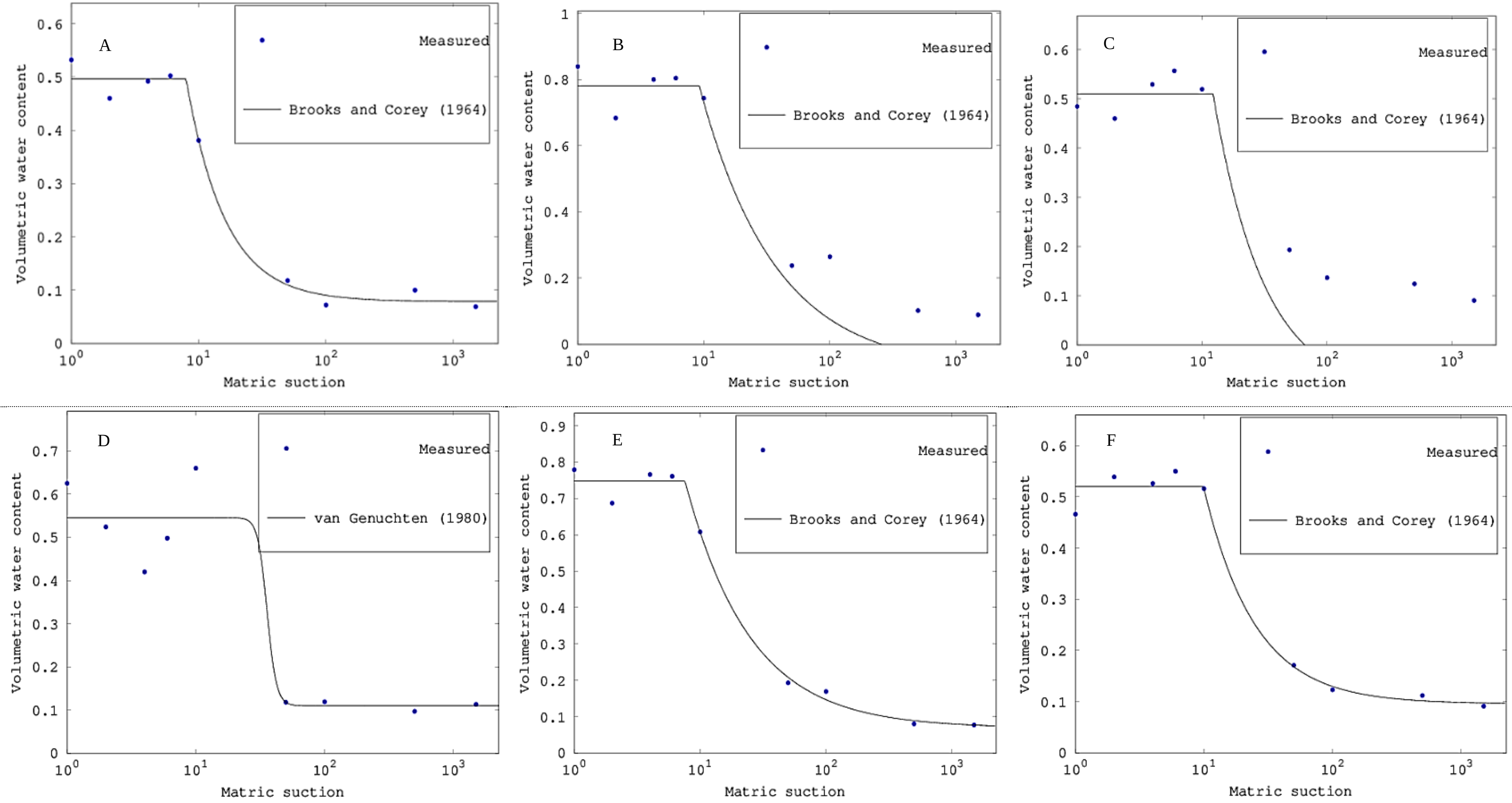
For Caviglione (2018), each adjusted curve was evaluated using the coefficient of determination (R^2) of the regression and Akaike Information Criteria (AIC) calculated by the SWRC. The AIC is a test used to differentiate the models, that is, the smaller the difference in the AIC value, the closer the models will be. Then, it can be observed that the parameter R^2 for the disc-plow treatment with soil collections 30 days before and after the corn sowing and end of the cycle, closer to 1 was found in the BC method, as well as the parameter AIC (Akaike Information Criterion) when compared with the others, as shown in Table 2 with the methods for estimating the volumetric soil moisture (cm^3 cm^3) for different periods of the collection (30 days before tillage (30DBT); 30 days after tillage (30DAT) and the end of the implanted crop (EC) cycle of the soil depending on the tillage system. It is observed that the BC method presented a point cloud closer to the line showing a high correlation with the data of volumetric soil moisture illustrated in Figure 2A, B, and C of volumetric soil moisture (cm^2 cm^2) as a function of the matrix potential for the different soil tillage methods (AD, Disc plow; CM, manual weeding; EX, Rotary hoe; GN, disc harrowing and SB, Subsoiling).

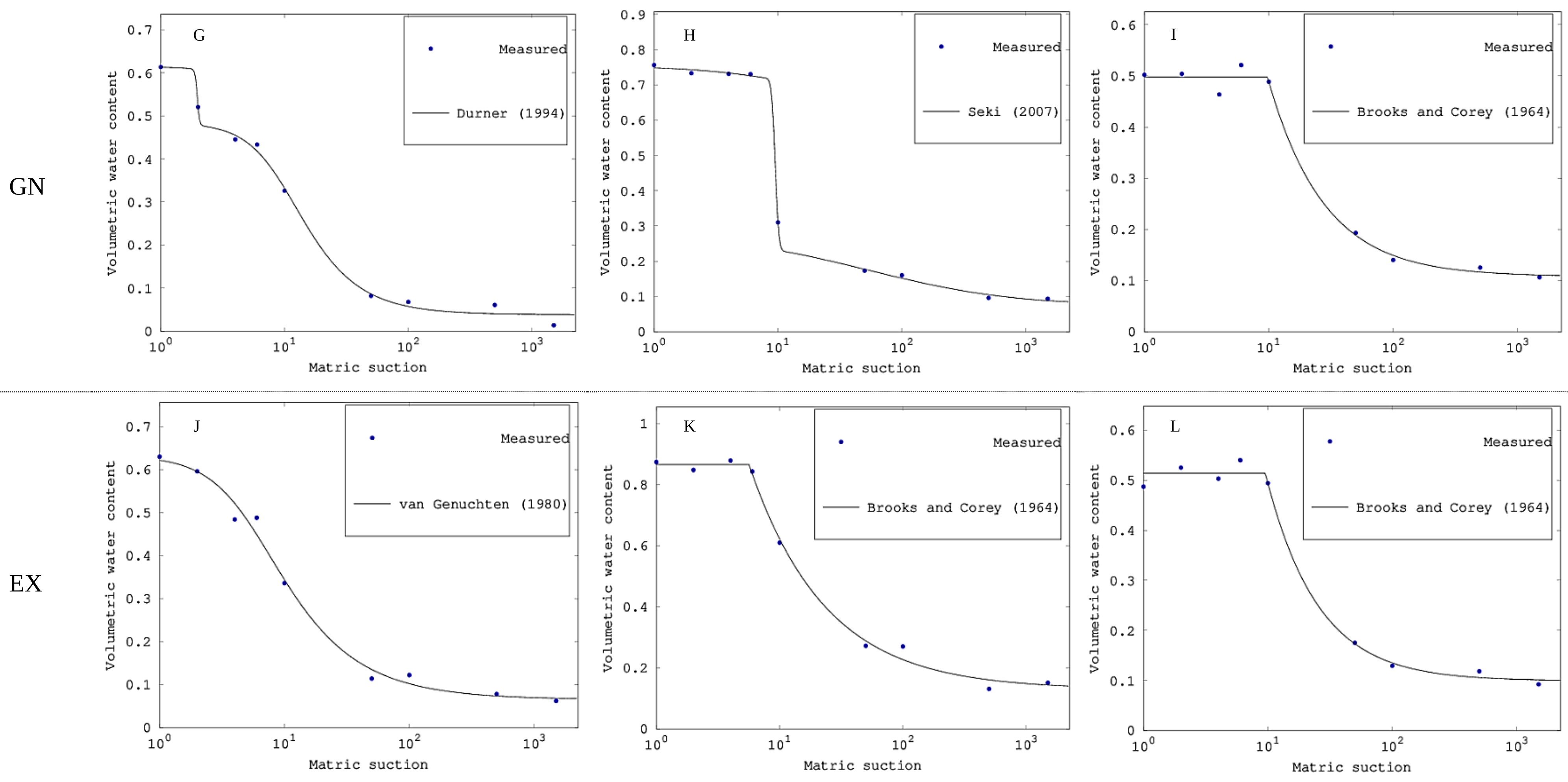
Table 2: Methods for estimating the volumetric soil moisture (cm^3 cm^3) for different collection periods (30 days before tillage (30DBT), 30 days after tillage (30DAT), and end of the implanted crop cycle (FC)) of the soil according to tillage

Methods	**Parameters**	**Disc plow**			**Manual weeding**			**Rotary hoe**			**Leveling disc harow**			**Subsoiler**		
		30DBT	**30DAT**	**FC**	**30DBT**	**30DAT**	**FC**	**30DBT**	**30DAT**	**FC**	**30DBT**	**30DAT**	**FC**	**30DBT**	**30DAT**	**FC**
Brooks and Corey	Os	0.50	0.78	0.51	0.61	0.75	0.52	0.61	0.87	0.51	0.60	0.74	0.50	0.70	0.73	0.51
	Or	0.08	0.08	0.10	2.07 e-05	0.07	0.10	0.03	0.13	0.10	0.00	0.13	0.11	0.00	0.10	0.11
	Hb	7.96	9.18	12.23	1. 5259	7. 5789	9. 9103	2.95	5.64	9.54	1.66	5.95	9.76	1.55	5.73	9.22
	lanbda	1.41	0.72	1.07	0.24	0.84	1. 0940	0.54	0.70	1.04	0.38	2.28	0.97	0.38	0.94	1.01
	R^2	0.99	0.98	0.98	0.74	0.99	0.99	0.98	1.00	0.99	0.96	0.99	0.99	0.97	0.99	0.99
	AIC	-62.54	-46.92	-57.36	-30932.00	-57843.00	-60577.00	-55.22	-61.88	-68.07	-48.08	-59.02	-67.83	-47.55	-60.38	-67.94
Van Genuchten	Os	0.50	0.79	0.51	0.55	0.76	0.52	0.63	0.90	0.51	0.60	0.74	0.50	0.77	0.73	0.51
	Or	0.08	0.11	0.11	0.11	0.09	0.11	0.07	0.15	0.11	0.02	0.13	0.12	0.02	0.14	0.11
	alfa1	0.08	0.05	0.03	0.03	0.07	0.04	0.19	0.10	0.04	0.21	0.11	0.04	0.40	0.10	0.05
	n1	3.27	2.41	4.10	12370.00	2. 3476	3. 9796	1.94	2.08	3.29	1.78	9.79	3.35	1.58	7.68	2.82
	R^2	0.99	0.97	0.98	0.92	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.97	0.99	0.99
	AIC	-60.38	-44.71	-56.76	-41169.00	-52974.00	-60246.00	-61.53	-50.50	-66.82	-58.88	-58.35	-67.46	-49.61	-53.91	-67.51
Kosugi	Os	0.50	0.79	0.51	0.55	0.76	0.52	0.65	0.89	0.51	0.63	0.74	0.50	0.83	0.73	0.51
	Or	0.90	0.12	0.12	0.11	0.09	0.11	0.08	0.16	0.11	0.03	0.13	0.12	0.05	0.14	0.12
	Hm1	10.42	29.17	33.62	33928.00	21927.00	30274.00	9.50	17.85	28.16	9.35	9.02	30.62	6.01	10.21	26.12
	sigma1	0.07	0.80	0.48	0.19	0.86	0.50	1.21	1.07	0.60	1.42	0.19	0.58	1.77	0.26	0.69
	R^2	0.99	0.97	0.98	0.92	0.99	0.99	0.99	0.98	0.99	0.99	0.99	0.99	0.98	0.99	0.99
	AIC	-60.84	-43.48	-56.59	-41169.00	-51603.00	-60078.00	-61.32	-48.04	-66.45	-61.70	-58.35	-66.63	-51.37	-52.93	-66.89
Fredlund and Xing	Os	0.50	0.79	0.51	0.55	0.75	0.52	0.65	0.87	0.51	0.69	0.74	0.50	0.87	0.73	0.51
	Or	0.05	0.00	0.00	0.11	9.27 e-05	0.08	0.06	0.00	0.00	0.04	0.00	0.10	0.04	0.00	0.10
	a	9.46	14.92	33.29	22508.00	10367.00	24413.00	7.98	7.45	12.06	80.06	6.62	23.42	10.92	7.52	17.43
	m	0.67	0.72	0.29	9. 0151	0.76	1. 0824	2.09	0.54	0.46	11.60	0.42	1.24	3.78	0.50	1.29
	n1	12.68	3.37	67.78	120.18	3. 3772	6. 2007	1.44	4.48	7.78	0.76	17.97	4.15	0.76	8.15	3.12
	R^2	0.99	0.98	0.98	0.92	0.99	0.99	0.99	0.99	0.99	0.99	1.00	0.99	0.98	0.99	0.99

Methods	Parameters	Disc plow			Manual weeding			Rotary hoe			Leveling disc harow			Subsoiler		
		30DBT	**30DAT**	**FC**	**30DBT**	**30DAT**	**FC**	**30DBT**	**30DAT**	**FC**	**30DBT**	**30DAT**	**FC**	**30DBT**	**30DAT**	**FC**
	AIC	-60.18	-44.41	-55.55	-39157.00	-52866.00	-58686.00	-60.52	-56.49	-65.93	-61.20	-67.20	-66.10	-49.17	-59.11	-65.90
Durner	Os	0.53	0.85	0.55	0.64	0.78	0.55	0.63	0.99	0.53	0.61	0.76	0.54	0.71	0.75	0.52
	Or	0.09	0.11	0.11	0.11	0.09	0.10	0.09	0.15	0.11	0.04	0.13	0.12	0.07	0.00	0.00
	w1	0.10	0.08	0.10	0.18	0.02	0.07	0.27	0.11	0.04	0.23	0.04	0.09	0.41	0.34	0.36
	alfa1	0.71	1203.40	1.25 e+07	24741.00	1136.80	1.42 e+08	0.46	4100.00	1.60 e+11	0.51	0.59	69.59	0.49	0.64	0.81
	n1	47.05	47.65	21.35	24232.00	7. 1819	12746.00	12.29	38.55	42.59	49.98	14.89	33.42	49.79	1.12	1.08
	alfa2	0.10	0.05	0.03	0.02	0.07	0.04	0.10	0.10	0.04	0.10	0.11	0.04	0.06	0.10	0.05
	n2	16.02	2.41	4.09	49966.00	2. 3465	3. 9632	19.28	2.08	3.29	2.35	15.66	3.35	3.07	48.00	3.56
	R^2	0.99	0.97	0.98	0.92	0.99	0.99	0.99	0.99	0.99	1.00	0.99	0.99	1.00	0.99	0.99
	AIC	-59.07	-38.71	-50.76	-35167.00	-46974.00	-54246.00	-59.80	-44.50	-60.82	-64.13	-52.98	-61.46	-68.55	-53.29	-62.64
Seki	Os	0.58	0.81	0.51	0.73	0.79	0.57	0.63	1.05	0.53	0.61	0.75	0.54	0.71	0.73	0.56
	Or	0.09	0.12	0.12	0.11	0.09	0.11	0.09	0.16	0.11	0.04	0.08	0.12	0.07	0.09	0.00
	w1	0.20	0.03	0.01	0.30	0.04	0.12	0.27	0.18	0.05	0.21	0.71	0.09	0.41	0.85	0.58
	Hm1	1.00	0.00	0.00	0.04	8.8 e-04	7.05 e-09	2.17	24385.00	0.00	1.86	9.50	0.01	2.09	9.92	25.37
	sigma1	0.12	0.84	0.52	0.12	0.87	0.53	0.11	1.00	0.63	0.12	0.05	0.62	0.06	0.25	0.55
	Hm2	10.47	29.27	33.62	44185.00	21951.00	30263.00	10.43	17.85	28.16	14.21	53.75	30.49	23.23	167.90	575.41
	sigma2	0.07	0.81	0.48	0.06	0.86	0.50	0.14	1.07	0.60	0.95	2.07	0.65	0.62	0.54	7.90
	R^2	0.99	0.97	0.98	0.92	0.99	0.99	0.99	0.98	0.99	1.00	1.00	0.99	1.00	1.00	0.99
	AIC	-59.30	-37.48	-50.59	-35169.00	-45603.00	-54078.00	-59.80	-42.04	-60.45	-61.81	-76.91	-60.57	-66.62	-59.47	-63.01

	30DBT	30DAT	END OF THE CYCLE
AD			
CM			




GN
EX
G
H
I
J
K
L
Measured
Durner (1994)
Seki (2007)
Brooks and Corey (1964)
van Genuchten (1980)
Volumetric water content
Matric suction

SB

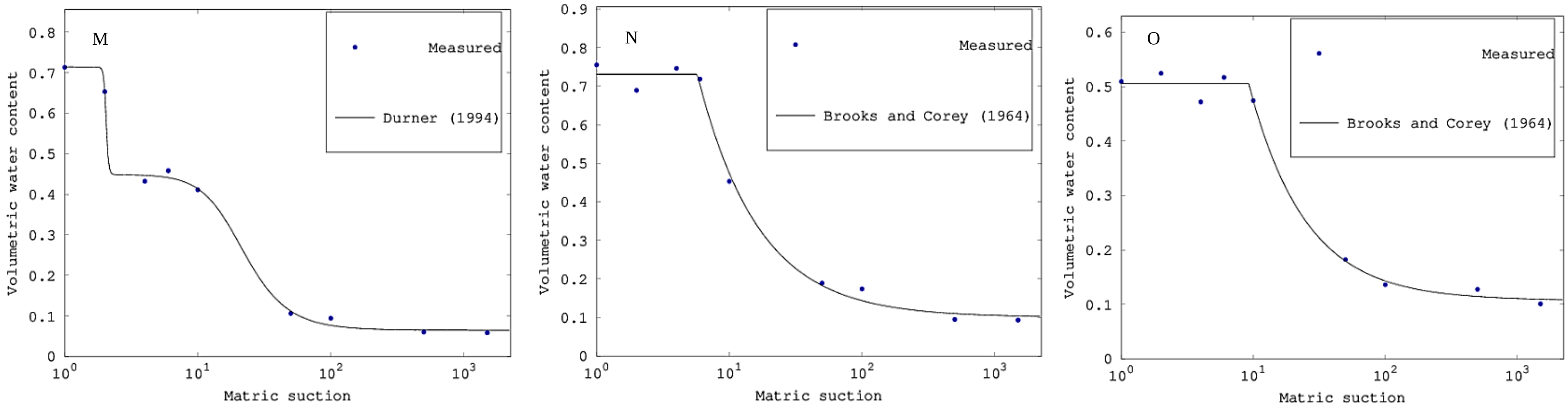


Figure 2: Soil volumetric moisture (cm^2 cm^2) as a function of the matric potential for the different tillage methods (AD, Disc plow; CM, manual weeding; EX, Rotary hoe; GN, Leveling disc harrow and SB, Subsoiling).

Manual weeding at 30 days before sowing showed the best adjustment using the VG methods, as it has a higher AIC than the others, as well as the R^2 closest to 1 (Figure 2D). However, the soil collection 30 days after sowing and the final crop cycle, presented satisfactory results in the BC method (Figure 2E and F).

It can be seen (Figure 2G) that the point cloud that most approached the line can be described using the DM method since the R^2 parameter is closer to 1 and the AIC is larger than the others for estimating the water content of the soil with leveling harrow 30 days after sowing. For the same treatment, but 30 days after sowing, it can be seen through Table 2 and Figure H, that the best-adapted method is SK. Finally, at the end of the corn crop cycle, the BC method best describes the analyzed parameters.

In the Rotary Hoe treatment, the method that VG best adapted to the parameters analyzed in relation to the collection performed 30 days before sowing. However, the BC method was best explained using the soil moisture curve, in which the R^2 and the AIC showed better values when compared to the other methods for the collections made 30 days after sowing and at the end of the cycle.

The DM method best describes the collection performed 30 days before sowing for treatment with subsoiler. However, the BC method is best adapted to the soil collection performed 30 days after sowing and at the end of the cycle. The LN and FX methods presented lower R^2 and AIC results than the other methods.

CONCLUSION

Soil tillage methods (disc plow, rotary hoe, subsoiler, manual weeding, and leveling harrow) did not cause changes in the soil profile. However, when the time between sowing and harvest is evaluated, changes in the physical factors of the soil are observed. Therefore, the higher the value of the soil density, the lower the values of macroporosity and total porosity of the soil, resulting in a greater degree of compaction, in addition to a reduction in the rate of water infiltration.

The soil water retention curve can be better observed employing the methods of Brooks and Corey, Van Genuchten, Durner, and Seki. Fredlund and Xing and Kosugi methods did not show satisfactory results when compared to the others.

ACKNOWLEDGEMENTS, FINANCIAL SUPPORT, AND FULL DISCLOSURE

The authors thank the Brazilian National Council for Scientific and Technological

Development (CNPq) and the Brazilian Federal Agency for Support and Evaluation of Graduate Education (CAPES) for the financial support.

The authors report that there is no conflict of interest.

REFERENCES

AMARO, J.F., ASSIS, R.N.J., MOTA, J.C.A. Física do solo: conceitos e aplicações. **Fortaleza: Imprensa Universitária**, v. 1, 2008.

ASSIS, R.L., LANÇAS, K.P. Evaluation of physical attributes of a dystrophic red nitosol under no-tillage, conventional tillage and native forest systems. **Revista Brasileira de Ciência do Solo**, v. 29, p. 515-522, 2005. DOI: https://doi.org/10.1590/S0100-06832005000400004.

BARTLET, M.S. Properties of sufficiency and statistical tests. In: the Royal Society of London. Series A-Mathematical and Physical Sciences, **Proceedings …** v. 160, n. 901, p. 268-282, 1937. DOI: https://doi.org/10.1098/rspa.1937.0109.

BOX, G.E.P., COX, D.R. An analysis of transformations. **Journal of the Royal Statistical Society. Series B (Methodological**. v.26, n.2, p. 211-252. 1964. DOI: https://doi.org/10.1111/j.2517-6161.1964.tb00553.x.

BROOKS, R.H., COREY, A.T. Hydraulic properties of porous media. **Hydrology Paper 3.** Colorado State Univ., Fort Collins, CO, USA, 1964. Disponível em: <chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/viewer.html?pdfurl=https%3A%2F%2Fmountainscholar.org%2Fbitstream%2Fhandle%2F10217%2F61288%2FHydrologyPapers_n3.pdf&clen=10654441>, Acesso em: 06 apr. 2022.

CAMARGO, DE O.A., ALLEONI, L.R.F. **Reconhecimento e medida da compactação do solo.** 2006. Disponível em: <http://www.infobibos.com/Artigos/2006_2/C6/Index.htm>. Acesso em: 06 april. 2022.

DURNER, W. Hydraulic conductivity estimation for soils with heterogeneous pore structure. **Water resources research**, v. 30, n. 2, p. 211-223, 1994.DOI: https://doi.org/10.1029/93WR02676.

EMBRAPA. Empresa Brasileira de Pesquisa Agropecuária. **Manual de métodos de análise de solo.** 2 ed. Rio de Janeiro, Embrapa solos, 2011, 230p. Disponível em: < chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/viewer.html?pdfurl=https%3A%2F%2Fwww.agencia.cnptia.embrapa.br%2FRepositorio%2FManual%2Bde%2BMetodos_000fzvhotqk02wx5ok0q43a0ram31wtr.pdf&clen=629989&chunk=true>. Acesso em: 06 apr. 2022.

EMBRAPA. Empresa Brasileira de Pesquisa Agropecuária. **Sistema brasileiro de classificação de solos**. 3 ed. Brasília, 2013. 353p. Disponível em: <chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/viewer.html?pdfurl=https%3A%2F%2Flivimagens.sct.embrapa.br%2Famostras%2F00053080.pdf&clen=413553&chunk=true>. Acesso em: 06 apr. 2022.

FERREIRA, D.F. Sisvar: a computer statistical analysis system. **Ciência e agrotecnologia**, v. 35, p. 1039-1042, 2011. DOI: https://doi.org/10.1590/S1413-70542011000600001 .

FILGUEIRAS, R., OLIVEIRA V. M. R. DE, CUNHA, F. F. DA, MANTOVANI, E. C., SOUZA, E. J. D. 2018. Modelos de curva de retenção de água no solo. **Irriga**, v. 1, n. 1, p. 115-115, 2016. DOI: https://doi.org/10.15809/irriga.2016v1n1p115-120.

FREDLUND, D.G., XING, A. Equations for the soil-water characteristic curve. **Canadian geotechnical journal**, v. 31, n. 4, p. 521-532, 1994.DOI: https://doi.org/10.1139/t94-061.

GIRARDELLO, V., AMADO, T., ERTEL, C. Benefícios do trafego controlado de máquinas. **Revista a Granja**, Edição: 785, Porto Alegre, 2014. Disponível em: < https://edcentaurus.com.br/agranja/edicao/785/materia/5996#:~:text=Entre%20os%20principais%20benef%C3%ADcios%20destacam,e%20maior%20produtividade%20das%20culturas.>. Acesso em: 06 apr. 2022.

GOMES, M.A.F., FILIZOLA, H.F. **Indicadores físicos e químicos de qualidade do solo de interesse agrícola.** Jaguariúna: Embrapa, Meio Ambiente, 2006. Disponível em: < chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/viewer.html?pdfurl=https%3A%2F%2Fwww.agencia.cnptia.embrapa.br%2Frecursos%2FGomes_Filizola_indicadoresID-u1keja1HAN.pdf&clen=282934&chunk=true>. Acesso em: 06 apr. 2022.

HEBB, C., SCHODERBEK, D., HERNANDEZ, R.G., HEWINS, D., CARLYLE, C.N., BORK, E. Soil physical quality varies among contrasting land uses in Northern Prairie regions. **Agriculture, Ecosystems & Environment**, v. 240, p. 14-23, 2017. DOI: https://doi.org/10.1016/j.agee.2017.02.008.

KOSUGI, K. Lognormal distribution model for unsaturated soil hydraulic properties. **Water Resources Research**, v. 32, n. 9, p. 2697-2703, 1996. DOI: https://doi.org/10.1029/96WR01776.

KUNZ, M., GONÇALVEZ, A.D.M.A., REICHERT, J.M., GUIMARÃES, R.M.L., REINERT, D.J., RODRIGUES, M.F. Soil compaction in a soy-dairy cattle system on a clayey Oxisol under no-tillage and chisel plowing. **Revista Brasileira de Ciência do Solo**, v. 37, p. 1699-1708, 2013. DOI: https://doi.org/10.1590/S0100-06832013000600026.

LANZANOVA, M.E., ELTZ, F.L.F., NICOLOSO, R.S., AMADO, T.J.C., REINERT, D.J., ROCHA, M.R. Physical properties of a typic paleudalf under long-term no-tillage and cropping systems. **Revista Brasileira de Ciência do Solo**, v. 34, p. 1333-1342, 2010. DOI: https://doi.org/10.1590/S0100-06832010000400030.

LIMA, I.M.A., ARAÚJO, M.C., BARBOSA, R.S. Avaliação das propriedades físicas do solo em sistemas silvipastoris, região centro-norte, estado do Piauí. **Agropecuária Científica no Semiárido**, v. 9, n. 1, p. 117-124, 2013. DOI: http://dx.doi.org/10.30969/acsa.v9i1.252.

MACHADO, J.L., TORMENA, C.A., FIDALSKI, J., SCAPIM, C.A. Inter-relationships between physical properties and the coefficients of soil water retention curve in an oxisol under different soil use. **Revista Brasileira de Ciência do Solo**, v. 32, p. 495-502, 2008. DOI: https://doi.org/10.1590/S0100-06832008000200004.

MACHADO, R.L.T., TURATTI, A.L., ALONÇO, A.S., MACHADO, A.L.T., REIS, A.V. Effects of chiselling on physical parameters of a planosol. **Revista Brasileira de Ciência do Solo**, v. 21, p. 519-523, 1997. DOI: https://doi.org/10.1590/S0100-06831997000300023.

MATIAS, S.S.R., CORREIA, M.A.R., CAMARGO, L.A., FARIAS, M.T., CENTURIO, J.F., NÓBREGA, J.C.A. Influência de diferentes sistemas de cultivo nos atributos físicos e no carbono orgânico do solo. **Revista Brasileira de Ciências Agrárias**, v. 7, n. 3, p. 414-420, 2012. DOI: https://doi.org/10.5039/agraria.v7i3a1462.

MORAES, M. T., DEBIASI, H., CARLESSO, R., FRANCHINI, J.C., SILVA, V. R., LUZ, F. B. Soil physical quality on tillage and cropping systems after two decades in the subtropical region of Brazil. **Soil and Tillage Research**, v. 155, p. 351-362, 2016. DOI: https://doi.org/10.1016/j.still.2015.07.015.

MORAES, M. T., DEBIASI, H., FRANCHINI, J.C., MASTROBERTI, A., LEVIEN, R., LEITNER, D., SCHNEPF, A. Soil compaction impacts soybean root growth in an Oxisol from subtropical Brazil. **Soil and Tillage Research**, v. 200, p. 104611, 2020. DOI: https://doi.org/10.1016/j.still.2020.104611.

MORAES, M.T., DEBIASI, H., FRANCHINI, J.C., SILVA, V.R. Soil penetration resistance as a function of tillage system and soil water content. **Engenharia Agrícola**, v.33, n.4, p.748-757. 2013. DOI: https://doi.org/10.1590/S1415-43662002000100030.

NADERI-BOLDAJI, M., KELLER, T. Degree of soil compactness is highly correlated with the soil physical quality index S. **Soil and Tillage Research**, v. 159, p. 41-46, 2016.DOI: https://doi.org/10.1016/j.still.2016.01.010.

NASCIMENTO, P. DOS S., BASSOI, L. H., PAZ, V. P. DA S., VAZ, C. M. P., NAIME, J. DE M., MANIERI, J. M. Estudo comparativo de métodos para a determinação da curva de retenção de água no solo. **Irriga**, v. 15, n. 2, p. 193-207, 2010. DOI: https://doi.org/10.15809/irriga.2010v15n2p193.

ORTIGARA, K., KOPPE, E., LUZ, F.B., BERTOLLO, A.M., KAISER, R., SILVA, V.R. Soil use and physical-mechanical properties of a Red Oxisol. **Revista Brasileira de Ciência do Solo**, v. 38, p. 619-626, 2014. DOI: https://doi.org/10.1590/S0100-06832014000200026.

PIMENTEL-GOMES, F. **Curso de Estatística Experimental**. Escola Superior de Agricultura “Luiz de Queiroz”, Universidade de São Paulo, Piracicaba. 1990.

REYNOLDS, W.D., BOWMAN, B.T., DRURY, C.F., TANA, C.S., LU, X. Indicators of good soil physical quality: density and storage parameters. **Geoderma**, v. 110, n. 1-2, p. 131-146, 2002. DOI: https://doi.org/10.1016/S0016-7061(02)00228-8.

ROS, C.O., LOPES, C.E.L., SECCO, D., PASA, L. Influence of time of cultivation under no-tillage system on physical characteristics of an oxisol. **Ciência Rural**, v. 26, p. 397-400, 1996. DOI: https://doi.org/10.1590/S0103-84781996000300009.

ROSOLEM, C.A., FERNANDEZ, E.M., ANDREOTTI, M., CRUSCIOL, C.A.C. DA ROS, Clovis Orlando *et al.*. Influence of time of cultivation under no-tillage system on physical characteristics of an oxisol. **Ciência Rural**, v. 26, p. 397-400, 1996. DOI: https://doi.org/10.1590/S0100-204X1999000500013.

SÁ, M.A.C., SANTOS, J.D.G.J., FRANZ, C.A.B., REIN, T.A. Soil physical quality and sugarcane yield with the use of inter-row chiseling. **Pesquisa Agropecuária Brasileira**, v. 51, p. 1610-1622, 2016. DOI: https://doi.org/10.1590/S0100-204X2016000900061.

SANTANA, J.S., LIMA, E.F., KOMATSU, R.S., SILVA, W.A., RIBEIRO, M.I.D. Caracterização física e química de solo em sistemas de manejo de plantio direto e convencional. **Revista Enciclopédia Biosfera**, v.15, n.27, p.1-22, 2018. Disponivel em: < chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/viewer.html?pdfurl=https%3A%2F%2Fwww.conhecer.org.br%2Fenciclop%2F2018a%2Fagrar%2Fcaracterizacao%2520fisica.pdf&clen=374449&chunk=true >, Acesso em: 06 april. 2022.

SEKI, K. SWRC fit–a nonlinear fitting program with a water retention curve for soils having unimodal and bimodal pore structure. **Hydrology and Earth System Sciences Discussions**, v. 4, n. 1, p. 407-437, 2007. DOI: https://doi.org/10.5194/hessd-4-407-2007.

SHAPIRO, S.S., WILK, M.B. An analysis of variance test for normality (complete samples). **Biometrika**, v. 52, n. 3/4, p. 591-611, 1965. DOI: https://doi.org/10.2307/2333709.

SILVA, A. G. D.A, BOIÇA JUNIOR, A. L., FARIAS, P. R. S., BARBOSA, J. C. Infestation of citrus blackfly in citrus (Aleurocanthus woglumi Ashby) orchards conventional and agroforestry. **Revista Brasileira de Fruticultura**, v. 33, p. 053-060, 2011. DOI: https://doi.org/10.1590/S0100-29452011005000038

STOLF, R., THURLER, A.M., BACCHI, O.O.S., REICHARDT, K. Method to estimate soil macroporosity and microporosity based on sand content and bulk density. **Revista Brasileira de Ciência do Solo**, v. 35, p. 447-459, 2011. DOI:https://doi.org/10.1590/S0100-06832011000200014.

VAN GENUCHTEN, M. A closed- form equation for predicting the hydraulic conductivity of unsaturated soils. **Soil science society of America journal**, v. 44, n. 5, p. 892-898, 1980. DOI: https://doi.org/10.2136/sssaj1980.03615995004400050002x