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EFFECTS OF COMPACTION DUE TO MACHINERY TRAFFIC ON SOIL PORE CONFIGURATION

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ABSTRACT

Soil compaction has been recognized as a severe problem in mechanized agriculture and has an influence on many soil properties and processes. Yet, there are few studies on the long-term effects of soil compaction, and the development of soil compaction has been shown through a limited number of soil parameters. The objectives of this study were to evaluate the persistence of soil compaction effects (three traffic treatments: T0, without traffic; T3, three tractor passes; and T5, five tractor passes) on pore system configuration, through static and dynamic determinations; and to determine changes in soil pore orientation due to soil compaction through measurement of hydraulic conductivity of saturated soil in samples taken vertically and horizontally. Traffic led to persistent changes in all the dynamic indicators studied (saturated hydraulic conductivity, K_0; effective macro- and mesoporosity, ε_{ma} and ε_{me}), with significantly lower values of K_0, ε_{ma}, and ε_{me} in the T5 treatment. The static indicators of bulk density (BD), derived total porosity (TP), and total macroporosity (θ_{ma}) did not vary significantly among the treatments. This means that machine traffic did not produce persistent changes on these variables after two years. However, the orientation of the soil pore system was modified by traffic. Even in T0, there were greater changes in K_0 measured in the samples taken vertically than horizontally, which was more related to the presence of vertical biopores, and to isotropy of K_0 in the treatments with machine traffic. Overall, the results showed that dynamic indicators are more sensitive to the effects of compaction and that, in the future, static indicators should not be used as compaction indicators without being complemented by dynamic indicators.

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Keywords: effective porosity, total porosity, soil pore anisotropy, hydraulic conductivity.

RESUMO: *EFEITO DA COMPACTAÇÃO DO SOLO PELO TRÁFEGO DE MÁQUINAS NA CONFIGURAÇÃO DOS POROS DO SOLO*

A compactação do solo tem sido reconhecida como um problema grave na agricultura mecanizada, influenciando em várias propriedades e processos do solo. Poucos são os relatos dos efeitos dessa compactação ao longo do tempo; a evolução da compactação do solo tem sido demonstrada por um número limitado de atributos do solo. Os objetivos deste trabalho foram avaliar a persistência dos efeitos da compactação do solo (três tratamentos com tráfego de máquina agrícola, sendo: T0, sem tráfego; T3, com três passadas de trator; e T5, cinco passadas de trator) na configuração do sistema poroso, utilizando determinações estáticas e dinâmicas; e determinar as mudanças na orientação do sistema poroso do solo após a compactação, utilizando os valores de condutividade hidráulica do solo saturado, em amostras coletadas na vertical e horizontal. O tráfego causou alterações em todos os indicadores dinâmicos estudados (condutividade hidráulica do solo saturado, K_0; e macro e mesoporosidade efetiva do solo, ε_{ma} e ε_{me}), com valores significativamente baixos de K_0, ε_{ma} e ε_{me} no tratamento T5. Já os valores dos indicadores estáticos como a densidade do solo, a porosidade total derivada do solo e a macroporosidade total (θ_{ma}) não apresentaram variação significativa entre os tratamentos. Esse é um indicativo que o tráfego de máquinas não influenciou na alteração dessas variáveis após dois anos. Já na orientação do sistema poroso do solo, mesmo em T0, ocorreram maiores alterações em K_0 medidas nas amostras coletadas na vertical do que os valores medidos na horizontal, sendo mais relacionados à presença de bioporos na vertical e à isotropia de K_0 nos tratamentos onde houve tráfego de máquinas. Assim, os resultados evidenciaram que os indicadores dinâmicos são mais sensíveis aos efeitos da compactação e que, futuramente, os indicadores estáticos não serão utilizados como indicadores da compactação do solo, sem a necessidade do complemento de indicadores dinâmicos.

Palavras-chave: porosidade efetiva, porosidade total, anisotropia da porosidade do solo, condutividade hidráulica.

INTRODUCTION

In recent decades, in agricultural production organized to meet the demands of an increasing population, the weight of agricultural machines has steadily increased, leading to soil compaction processes (Berisso et al., 2012).

Soil compaction has been recognized as a severe problem in mechanized agriculture and has an influence on many soil properties and processes, as well as on crop yield (Servadio et al., 2005). Even with a lack of experimental data on the persistence of compaction effects, there is a generalized idea that negative effects of soil compaction persist long after the occurrence of traffic (Etana et al., 2013).

Soil compaction has traditionally been defined as a change in volume for a given dry mass of soil due to an applied load (Chamen et al., 2014). Bulk density (BD) is then used to evaluate the effects of traffic on soil quality (Petelkau, 1999; Arvidsson, 1999; Duttmann et al., 2014). This holds true only for a pure compaction process as variation of soil volume, but it does not include more complex processes like changes in pore orientation or tortuosity that result in no change in volume at all. Yet, these changes imply an intense deterioration of structure and homogenization of the pore system (Horn et al., 2003). These changes result in modification of soil hydraulic properties rather than modification of total porosity (TP). Results obtained by Tarawally et al. (2004) suggested that soil TP was not a good indicator of compaction effects, and that, therefore, it should not be used as a soil compaction index, as previously recommended by Al-Adawi and Reeder (1996), and later by Kuncoro et al. (2014a).

Characterization of the soil pore system is necessary to evaluate soil structure conditions because the size, shape, and continuity of pores affect many important soil processes; hence, their characterization allows quantification of soil structure quality. Evaluation and quantification of the soil pore system are widely applied tools for assessment of compaction in agricultural soils. Heavy machinery and intensive traffic can seriously compact soils, modifying soil structure and degrading its physical quality. In order to evaluate the impact of traffic on soil, it is necessary to quantify modifications to soil structure. Soil pore system configuration, i.e. pore size distribution, pore diameter, and continuity of macropores have a big impact on soil hydraulic properties (Hillel, 1998).

As the configuration of the soil pore system largely determines its hydraulic properties, any modification of this system will affect them. Therefore, changes in soil pore space are accompanied by modification of the hydraulic properties (Horton et al., 1994; Green et al., 2003). Soil compaction affects soil hydraulic properties and associated soil water flow. Flow in larger pores is more affected by compaction than flow in smaller pores. This observation suggests that compaction destroys mainly large pores, a phenomenon often measured in desorption curves (Abdollahi, 2014). Since infiltration rates measured under negative water potential are quite sensitive to compaction, the simplicity and quickness of these field techniques proves useful in quantifying compaction and other management effects on hydraulic properties (Horton et al., 1994). The tension disc infiltrometer is a valuable tool for understanding water movement through macropores and the soil matrix under near saturation conditions (Watson and Luxmoore, 1986; Logsdon and Jaynes, 1993; Moret and Arrúe, 2007). This device allows estimation of K from saturation to a few centimeters of suction head (Angulo-Jaramillo et al., 2000) and quantification of the role of macropores during infiltration (Bodhinayake et al., 2004; Soracco et al., 2012). This technique requires only minimal soil disturbance.

Another noted effect of soil compaction is a change in pore orientation (Dörner and Horn, 2006). This effect can be determined through the measurement of saturated K in samples taken vertically and horizontally (Soracco et al., 2010; Lozano et al., 2013).

In addition to minimal tillage, meadow rotations including alfalfa have been used and, when applied over several years (four or five), they may regenerate soil structure. Marsili et al. (1998) investigated the recovery of a clay soil cropped with alfalfa for five years, previously subjected to tracked tractors passes. They found no difference in BD between treatments with one and four passes of the tractor comparing to the control treatment. However, total macroporosity, expressed as the percentage of area occupied by pores larger than 50 μm on a thin section, decreased in the surface layer (0.00-0.10 m) after a single pass, and such a decrease was more pronounced after four passes. The reduction in macroporosity following compaction from one and four tractor passes was due to the decrease in the proportion of elongated pores. Such pores are very important because many of these pores directly affect plant growth by promoting root penetration and storage and transmission of water and gases (Marsili et al., 1998).

Alakukku (1996a) studied two different soils (Cambic Vermisol and Mollic Gellisol) and found that top- and subsoil compaction of clay soil persisted for at least three years, despite annual plowing of the topsoil to 0.2 m, cropping, deep freezing, and cracking due to drying.

Alakukku (1996b) emphasized that the long-term effects of soil compaction have seldom been documented, and that the persistence of subsoil compaction is often measured with a limited number of soil parameters, such as BD and penetrometer resistance. Berisso et al. (2012) found that even 14 years after a compaction event, the negative effects on soil porosity persisted. Moreover, these authors emphasize that there is a reason to believe that these compaction effects will persist for decades, or even longer (Berisso et al., 2012). They mentioned, however, that there are only limited experimental data on the persistence of the compaction effect on the functioning of soil pores.

The study of the effects of soil compaction and the changes it undergoes due to a forage crop, taking into account the connectivity and orientation of the porous system, would allow us to better understand the resulting changes in soil pore configuration, and the persistence of the compaction effect.

We hypothesized that static determinations such as TP and macroporosity derived from tension table measurements are not good indicators of soil compaction effects, and dynamic determinations such as K and effective macroporosity are well suited to establish these effects. We further hypothesized that the effects of soil compaction on soil pore configuration persist for a long time after traffic occurred.

The objectives of this study were to evaluate the persistence of soil compaction effects on pore system configuration, through static and dynamic determinations; and to determine changes in soil pore orientation due to soil compaction through the measurement of near-saturated hydraulic conductivity in samples taken vertically and horizontally.

MATERIAL AND METHODS

Sites and treatments

The experiment was carried out near the city of La Plata, Argentina, in the Research Field of the School of Agricultural and Forestry Sciences, Universidad Nacional de La Plata (34° 55' S, 57° 57' W). The climate in the region is temperate, with temperature rarely dropping below 0 °C (so freezing of the soil does not occur) and annual rainfall of approximately 1,000 mm. The soil was classified as a fine, silty, illitic, thermic Typic Argiudoll (USDA, 2006) with a silty loam A-horizon (clay content: 18 %, silt content: 61 %). The organic matter content did not differ between treatments at the time of sampling (organic matter content: 34.4 g kg^{-1}).

The traffic treatments were applied in June. Plots were managed under conventional tillage (CT) before the treatments (last tillage was performed two years before the treatments). The tractor used was a 78 kW (PTO), two-wheel drive (2WD), weighing 3.8 Mg (1.2 and 2.6 Mg on the front and rear axles, respectively) and new 7.50 × 16 and 18.4 × 34 (8 ply) single tires. Inflation pressure was 95 kPa in the front tires and 207 kPa in the rear tires. This tractor model is commonly used on commercial farms in the region of the experiment. The tractor speed was 5.5 km h^{-1}.

Three treatments were carried out on plots of 26 m length × 5 m width, where the experimental variable was traffic frequency of 0, three, and five tractor passes in the same tracks (T0, T3, and T5, respectively). Plots were in completely randomized blocks with three replications.

An alfalfa (*Medicago sativa* L.) pasture was sown in May of the following year, which covered all the treatments. Soil sampling and field measurements were carried out two years after the treatments, in the subsequent June.

Dynamic determinations were made both in the field (tension disc infiltrometer determinations) and in the lab (saturated hydraulic conductivity, K, on undisturbed samples). Static determinations were carried out in the lab (bulk density, BD; total porosity, TP; and total macroporosity on a tension table). Dynamic and static determinations are described below.

Dynamic determinations

In-situ infiltration test

A tension disc infiltrometer (Perroux and White, 1988) was used to determine the steady-state infiltration rate. The infiltration tests were carried out in June.

The infiltrometer disc had a base radius of 6.25 cm. Infiltration measurements were conducted at four randomly-selected sites for each replication (three replications per treatment, 12 measurements per treatment, total number of measurements: 36). To consider only the effects of the treatments on soil water infiltration, the crop residues were removed from the soil surface. To ensure good hydraulic contact between the device and the soil, the soil surface was flattened with a spatula and a thin dry sand layer was spread on it. Infiltration runs were performed at three values of water pressure head h (namely, -6, -3, and 0 cm, applied in this order and at the same place). This sequence of supply water pressure heads was used because a descending order might cause hysteresis, with progressive drainage occurring close to the disk while wetting continues at the infiltration front (Jarvis and Messing, 1995). Flow monitoring continued until steady-state flow from the disc was reached. The cumulative infiltration was recorded every min up to 10 min, every 5 min up to 30 min, and every 10 min until the end of the test. When the amount of water that infiltrated did not change with time for four consecutive measurements taken at 10 min intervals, steady-state flow was assumed, and the corresponding steady-state infiltration rate was calculated based on the last four measurements. The time necessary to reach the steady state was around 1.5 h for each tension.

The soil hydraulic conductivity, K, at the different soil water pressure heads, h (i.e., K_6, K_3, and K_0) were thus calculated from the cumulative water infiltration using the multiple-head method (Ankeny et al., 1991). Most of the decrease in water conductance is expected to occur at hydraulic pressure heads close to zero due to a reduction in different groups of macropores (Gebhardt et al., 2009). The procedure used to obtain K was based on the analysis of steady-state flux from the tension disc infiltrometer and its dependence on the water pressure head. This dependence was described by Gardner's exponential model (Gardner, 1958).

Water-conducting macro - and mesoporosity

Water-conducting (or effective) macro- and mesoporosity (ε_{ma} and ε_{me}, respectively) were calculated using the Watson and Luxmoore (1986) procedure.

The classical capillary rise equation allows calculation of the maximum water-filled pore equivalent radius, r [L], at a specific soil water pressure head, h [L]:

$$r = 2\,\sigma \cos(\alpha) / \rho\, g\, |h| \qquad \text{Eq. 1}$$

where σ is the surface tension of water [M T^{-1}], α is the contact angle between water and the pore wall (assumed to be zero), ρ is the density of water [M L^{-3}], and g is the acceleration due to gravity [L T^{-2}]. We were aware of the fact that α might be other than 0º. Woche et al. (2005) analyzed the dependence between the contact angle and the soil texture and observed small contact angles of 0º to 20º for silty loam soils. Moreover, α strongly depends on water content and probably approached 0º after a sufficient infiltration time (Buczko et al., 2006).

This procedure assumes that the equivalent pores with radii smaller than r calculated from equation 1 are filled with water and are responsible for the entire flux of water under a given water pressure head, and that the equivalent pores with radii larger than the value calculated from equation 1 are not contributing to the water flux. The hydraulically active (or water-conducting) porosity, conducting water in the pressure head interval corresponding to the two pore radii ra and rb (ra ≤ rb), ε (ra,rb), (assuming pore radius equal to the minimum equivalent pore radius), is then given by (Watson and Luxmoore, 1986):

$$\varepsilon(ra,rb) = 8\eta\Delta K(ra,rb) / \rho\, g(ra)^2 \qquad \text{Eq. 2}$$

where ΔK(ra,rb) is the difference in K values in the pressure head interval corresponding to ra and rb, η is the dynamic viscosity of water [M L^{-1} T^{-1}], ρ is the density of water [M L^{-3}], and g is the acceleration due to gravity [L T^{-2}]. Since ra is the minimum equivalent pore radius in the range, ε (ra,rb) is an estimation of the maximum water-conducting porosity. Implicitly assumed in equation 2 is a unit hydraulic gradient, i.e. steady-state conditions during infiltration (Wahl et al., 2004).

According to equation 1, infiltration at water pressure heads of -3 and -6 cm will exclude pores with equivalent diameters > 1 mm, and > 0.5 mm, respectively. In our study we defined water-conducting macropores (ε_{ma}) as those pores draining at h > -3 cm (equivalent r > 0.5 mm), and water-conducting mesopores (ε_{me}) as those draining at h between -3 and -6 cm (0.5 mm > equivalent r > 0.25 mm).

Pore orientation

Core sampling for laboratory determinations

Samples were taken in June. In order to determine if the hydraulic properties of the soil horizons had direction-dependent behavior, undisturbed soil samples were collected in PVC cylinders (15 cm height and 5.88 cm internal diameter), in vertical and horizontal directions (Petersen et al., 2008; Soracco, 2009). The inner surfaces of the cylinders were coated with a thin film of lithium grease to facilitate penetration into the soil and to prevent by-pass flux of water between the cylinder wall and the soil core during the saturated hydraulic conductivity (K_0) measurements.

In each treatment, cylindrical cores at the surface (0-15 cm) were carefully collected in different orientations. For each replication and treatment, five cylinders were extracted, for a total of 45 samples. The location of the sampling sites was chosen at random. The sampling cylinders were not completely filled with soil, but only to around 60 % of their volume, leaving the remaining part empty in order to be filled with several centimeters of water on top of the soil cores. The samples were covered with plastic caps to protect the soil from mechanical disturbances and evaporation.

Laboratory Saturated Hydraulic Conductivity (K_{0l}) determination

Laboratory saturated hydraulic conductivity (K_{0l}) was measured in samples taken vertically (K_{0lv}) and horizontally (K_{0lh}) using the constant head method (Klute and Dirksen, 1986). The undisturbed soil sample was positioned vertically. A constant water height was maintained on top of the sample, and the bottom end was open to the atmosphere.

The following relation was used to estimate K_{0l} (Hillel, 1998):

$$\frac{Q}{A} = q = -K_{0l}\frac{\Delta H}{D} \qquad \text{Eq. 3}$$

where Q is the volume of water flowing per unit of time ($L^3\ T^{-1}$), A is the cross-sectional area of the soil column (L^2), q is the flux ($L\ T^{-1}$), K_{0l} is the saturated hydraulic conductivity ($L\ T^{-1}$), ΔH is the hydraulic head drop across the soil column (L), D is the length of the column (L), and $\Delta H/D$ is the hydraulic gradient (dimensionless).

The soil core with the sample was placed vertically inside a funnel with a barrier covered by a thin tissue to retain the soil in the core, at atmospheric pressure. On top of the cores, distilled water was siphoned from a common supply to the individual soil samples.

The K anisotropy factor (KA) was calculated for each treatment as K_{0lv}/K_{0lh}.

Static measurements

Total porosity and total macroporosity

Total porosity (TP) was estimated from BD. Bulk density (BD) was measured in each treatment using the core method (Blake and Hartge, 1986). Soil total macroporosity (θ_{ma} (%), r > 30 μm) was calculated from the soil water retention at -50 cm water pressure head. It was measured using a tension table with a hanging water column on undisturbed soil samples (sample size: 5 cm diameter; 5 cm height). Ten samples were taken in each replication, and three replications per treatment, for a total of 30 samples per treatment; the total number of samples was 90.

Statistical analysis

In order to determine the effects of the factor, K_0, TP, θ_{ma}, ε_{ma}, and ε_{me} were analyzed using ANOVA with traffic intensity and replication as factors (Sokal and Rohlf, 1995). K_{0l} values were analyzed for each treatment separately using ANOVA with orientation and replication as factors. The least significant difference (LSD) multiple comparison test was used to compare the means of the different treatments or orientations. The Kolmogorov-Smirnov test was applied to determine if replicates of measured quantities within a treatment were normally or log-normally distributed. All statistical tests on K_0 (and K_{0l}) were carried out using the log of the data since the statistical frequency distribution of the K_0 (and K_{0l}) data was log-normal, which is usual for this soil property (Bagarello et al., 2006). The BD and pore size fractions were normally distributed and, thus, no transformations were performed on these variables. For all analyses, significance was determined at p = 0.05.

RESULTS AND DISCUSSION

Traffic effects on dynamic indicators

The values of hydraulic conductivity determined from water infiltration at different tensions, K_0, K_3, and K_6; the derived water-conducting macro and mesoporosity (ε_{ma} and ε_{me}); the vertical and horizontal laboratory saturated hydraulic conductivity (K_{0lv} and K_{0lh}, respectively); and the respective anisotropy factor (KA) as a function of the traffic treatment are shown in table 1. The traffic significantly affected the dynamic indicators studied. K_0, K_3, ε_{ma}, and ε_{me} were significantly lower in the treatment with more traffic frequency (T5). This indicates that two years after the traffic, the negative effects remained in this treatment, affecting the flow through macro- and mesopores. This is in agreement with Alakukku (1996a), who found that traffic compaction produced reduced values of K_0 in the wheel tracks, in comparison with areas without traffic, due to lower macroporosity values. Horton et al. (1994) concluded that soil compaction mainly affects water flux through macropores. Etana et al. (2013) found that macroporosity and saturated and near-saturated hydraulic conductivity were smaller in the compacted plots 14 years after the traffic occurred, although these differences were not statistically significant.

In contrast, Richard et al. (2001) found higher unsaturated K in compacted soil than in uncompacted soil, while Zhang et al. (2006) found no significant differences between compacted and uncompacted soils. Our results show that, for the soil under study from the pampas region, soil compaction negatively affects water flux through meso- and macropores, and that this effect still persisted after two years.

Moreover, the values of K_0, ε_{ma}, and ε_{me} were similar to values previously reported in the region (Soracco et al., 2011, 2012; Lozano et al., 2014), and to values reported in other regions (Etana et al., 2013).

The orientation of the porosity, determined by K_0 measurements, was significantly affected by both traffic frequencies. T3 and T5 presented isotropy of K_{0l}, whereas the treatment without traffic (T0) showed higher vertical K_{0l}. Moreover, the traffic treatments affected soil pore configuration, producing a change in pore orientation. The preferential vertical connectivity was modified and disappeared due to traffic. The traffic likely destroyed or blocked vertical biopores, which were abundant in the T0 treatment but scarce in the T3 and T5 treatments, as was observed at the time of field sampling and measurements.

This is in agreement with Dörner and Horn (2006), who concluded that changes in the geometry and continuity of the pore system exceed those of pore volume and lead to changes in the anisotropy of saturated hydraulic conductivity and air permeability. They emphasized that changes in soil structure due to soil compaction are of major importance.

Traffic effects on static indicators

The measured values of BD, derived TP, and total macroporosity (θ_{ma}) did not vary significantly among treatments (Table 1). This means that the traffic did not produce persistent changes on these variables after two years.

The effects of traffic on BD and TP have been frequently documented in the bibliography. A significant increase in BD and a reduction in TP were found by Botta et al. (2009) after tractor passes on a fine clayey soil. The same trend was reported by Hassan et al. (2007). It is well-known that traffic processes leads to an increase in BD and its corresponding reduction in TP (Kuncoro et al., 2014b). The persistence of these traffic effects has been less reported, and there is a lack of information on this topic. Berisso et al. (2012), in the subsoil of a sandy clay loam soil, found persistent effects of traffic on soil pore configuration even 14 years after the compaction event. Our results are in disagreement with these reports. We found that effects of traffic on static indicators were not detectable two years after traffic, even for the most intense traffic event. This could be attributed to the fact that three and five tractor passes did not deliver a very extreme energy of compaction, and therefore its persistence is reduced as well. We choose this energy of compaction because it represents the common regional practice.

Overall, the results showed that dynamic indicators are more sensitive to compaction effects,

Table 1. Values of field hydraulic conductivity at 0, 3, and 6 cm water tension (K_0, K_3, and K_6, respectively); water-conducting macro- and mesoporosity (ε_{ma} and ε_{me}); vertical and horizontal laboratory saturated hydraulic conductivity (K_{0lv}, and K_{0lh}, respectively); saturated hydraulic conductivity anisotropy factor (KA); bulk density (BD); derived total porosity (TP), and total macroporosity (θ_{ma}) as a function of traffic treatments (traffic frequency of zero, three, and five tractor passes in the same tracks - T0, T3, and T5, respectively)

Treatment	K_0 (1)	K_3	K_6	ε_{ma}	ε_{me}	K_{0lv}	K_{0lh}	KA	BD	TP	θ_{ma}
	cm h^{-1}			$m^3\ m^{-3} \times 100$		cm h^{-1}		dimensionless	kg dm^{-3}	$m^3\ m^{-3} \times 100$	
T0	1.79 a	0.75 a	0.33 a	0.0009 a	0.0016 a	11.5	3.2	**3.6** (2)	1.17 a	55.8 a	19.7 a
T3	1.59 a	0.73 a	0.39 a	0.0008 a	0.0012 a	4.5	5.7	0.8	1.20 a	54.7 a	18.5 a
T5	1.07 b	0.45 b	0.26 a	0.0005 b	0.0007 b	3.8	3.8	1.0	1.15 a	56.7 a	18.8 a

Values followed by the same letter in each column are not significantly different (LSD test; p = 0.05). (1) Statistical analysis on K_0, K_3, and K_6 was performed on log-transformed values. (2) Values in bold mean significant differences between K_{0lv} and K_{0lh} for the respective treatment.

and furthermore, that static indicators should not be used as compaction indicators without complementary dynamic indicators. Differences in the values of water-conducting porosity are significant; therefore, this kind of determination may detect property changes that would remain undetected if using BD, TP, or macroporosity. This is an important finding of this study.

CONCLUSIONS

Static determinations such as TP and macroporosity derived from tension table measurements are not good indicators of soil compaction effects; dynamic determinations such as K and effective macroporosity are better suited for detecting these effects.

Effects of soil compaction on soil pore configuration persist two years after the traffic occurred. The effects of this persistence are significantly shown through dynamic properties.

Soil compaction leads to a change in pore orientation that persists two years after the traffic event.

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