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Determination of the soil compaction in real time on field with plate penetrometer and data filtering system

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Soil compaction due to traffic is the process whereby soil bulk density is increased. The compaction level depends on the weight of the vehicle, and the soil susceptibility to compaction, which is characterized by its mechanical properties (that is, the stress-strain relationships). The plate penetrometer can be used to quantify the levels of soil compaction in-situ and supply a larger number of information on the control of this phenomenon, in real time. This paper evaluates the use of this tool with data filtering system assistance on semi confined compression assay, for predicting soil compaction in-situ, through parameters pre-compaction stress (σ_{pc}) and soil compression Index (Cc). The tests were carried out on Experimental Agricultural Engineering Nucleus (NEEA in Portuguese) at West Paraná State University - UNIOESTE - Brazil. The sample collection was carried at points along the tire track, 24 h after soil compaction induced by the rear tractor wheel with one, five and ten passages, on the same track. The information system is able to read all data derived from the compression test and carry out a filtering on the data by means of pre-selected parameters, plotting the compression curves and regression equations. The analysis, carried out "in situ", avoids laboratorial procedures and gives the farmer more agility in the decision process on the management of the agricultural machinery system.

Key words: Semi-confined compression test, information system, soil compaction *in-situ*.

INTRODUCTION

Causes of soil compaction are related to natural phenomena such as rain, as well as the use of heavy agricultural machinery and implements and its excessive traffic during activities of crop production. This unordered soil occupation can generate its fast and continuous degradation (Soane and Van Ouwerkerk, 1994; Dawidowski et al., 2001; Prado et al., 2002). Results of field trials and laboratory tests have indicated that the use of the appropriate size of agricultural machinery which also dictates the type and size of tires can result in less soil compaction (Dawidowski and Koolen, 1994). The most obvious visual indicator of topsoil compaction is rut depth affected by agricultural tractor and machinery's traffic on the soil. That rut depth will be principally related with initial soil condition, inflation pressure, tyre width and number of passes (Botta et al., 2009; Patel and Mani, 2011). The plate penetrometer, used "in-situ" for assay, is a tool that indicates the behavior of the soil compaction under different levels of traffic by agricultural machines (Dawidowski et al., 2001). It has been observed that it is necessary to enforce the use of information technology to support real-time production systems (Canillas and Salokhe, 2002), once great number of variables is present in the soil-machine interaction process, rendering the decision making process by the agriculturists more difficult (O'Sullivan et al., 1999). According to Dawidowski and Koolen (1994), the presence of a great number of records on an experiment renders the analysis arduous. They suggest a reduction in the number of records with a filtering system substantiated in limited differences.

The computing associated with the development of information systems allows the modeling of situations experienced in rural areas and the manipulation of data involved in obtaining information that may assist the user, who is often the decision maker on the farm. The aim of soil compression is to understand the soil behavior by exposure to different loads exerted by the machines during the activities on the field.

This way, the use of a computing tool like database software that enhances the capabilities of data storage in a computer, giving a range of ways to search for specific facts becomes indispensable.

The objective of this study was to evaluate the soil compaction parameters on the field in real time, with the use of plate penetrometer and data filtering system.

MATERIALS AND METHODS

Data filtering system

The coding of the information system proposed here was done using a computer equipped with *Microsoft Windows* and *Borland Delphi*, due to its operational ease and object oriented support asides allowing the development using the *3Tier* model. The difficulties observed in connection with the development environment to the database were overcome by the installation of the open source component *Zeos*, since the standard version of *Delphi 3* does not have a native connection component for the selected database. The relational model was chosen for data persistency, using *Firebird* version 1.5 exempting costs with the acquisition of a database management system (DBMS). For the creation of queries and direct access to the database, the freeware version of *IBExpert*, produced by *HK-Software* was used. The utilization of object oriented methodologies and *3Tier* allows the programmer more flexibility in coding economy as well as ease on the change of development programming language or database (Lamb, 2006).

Field experiment

The assays of soil compaction were realized on the Experimental Agricultural Engineering Nucleus (Núcleo Experimental de Engenharia Agrícola - NEEA in Portuguese) on West Paraná State University (Universidade Estadual do Oeste do Paraná – UNIOESTE in Portuguese) geographically located on the coordinates 24°48' S and 53°26" W with an average altitude of 760 m. The soil is classified as L*atossolo vermelho distroférrico típico (Typic Hapludox), Brazilian classification* (EMBRAPA, 1999), corresponding to an Oxisol, FAO/ UNESCO (1975). The physical characteristics and organic level of the soil are given in Table1.

One tractor 4 x 2 TDA, Ford, Series 7630, was used during the test with the plate penetrometer attached to the back (Figure 1). A displacement sensor and a load cell for indication of the soil deformation and of the load at soil respectively were fixed on the plate penetrometer. Both sensors were connected to a data acquiring system, the Micrologger cr510 (CAMPBELL SCIENTIFIC, 2006), which was programmed to take four readings by second. The data acquired is transferred to a microcomputer by means of a serial interface, and software.

Cyclic loads of 50, 100, 200, 300, 400, 500, 600, 800, and 900 kPa were applied to the soil with the penetrometer on the rut left by the tractor tire to determine pre-compaction of the soil. In this study, the influence of excessive traffic machines in the soil compaction process was evidenced by conducting experiment with the passage of the tractor on the same track. The collection was made at points along the tire path. The tests were performed 24 h after rut of the rear tractor wheel formed on soil with one, five and ten passages from tractor, on the same rut. The application time of each load was 30 seconds, with an interval of 120 seconds for soil relaxation before the next load. The compressibility tests were conducted with a water content of 30%, less than the optimum water content of the soil (34%), on fragile range of the aggregates.

For data group of each load, the filtering algorithm used in the software finds the average pressure applied during the compaction time, with the maximum and minimum deformation and the difference between these deformations. The deformation was corrected because of the survey of the tractor caused by deflection of the rear tire during the application of the load. The deflection of the tire was determined by the linear equation:

$$y = 0.0302\sigma - 1.9555 \quad (1)$$

Where y is the deflection in mm, σ is the vertical pressure (kPa), obtained from the stress x strain diagram with data obtained from a test conducted on concrete runway. The corrected values are collected on each new load to plot the soil compaction curve. The prototype has two modules, one for reading and one for data filtering (Figures 2 and 3). The first reads the data file from the datalogger, and identifies the number of treatments present on the experiment and stores the information on the database. Each

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Table 1. Some physical and organic properties of the soil.

Soil layer depth (cm)	0 -10	10 - 20
Sand (g kg^{-1})	80	70
Silt (g kg^{-1})	320	300
Clay (g kg^{-1})	600	630
Particle density g cm^{-3}	2,80	2,75
Organic matter g dm^{-3}	46,81	45,20
Optimum water content (%)	34	34

Figure 1. Soil compaction test in-situ with plate penetrometer: 1 hydraulic cylinder, 2 plate, 3 pressure control valve, 4 manometer, 5 load cell, 6 displacement sensor, 7 datalogger, 8 sinkage, 9 device for adjusting the vertical position of the plate with the horizontal plane of the ground.

treatment corresponds to a repetition of data, with an equal number of strides by the tractor in order to simulate traffic. The second selects the treatment on the database, runs the filtering and calculates the variables relevant to the construction of the curve of compression, according to the filtering algorithm. Then, it issues the report with the filtered data for printing, exports to a Microsoft Excel spreadsheet with construction of soil compression curve and pre-compaction (Figures 3 and 4).

Determination of virgin compression line (VCL), secondary compression curve (SCC) and pre-compaction stress (□$_{pc}$)

Soil pre-compaction stress was determined from soil strain as a function of the logarithm of the applied stress, using method similar to that utilized by Dias Junior and Pierce (1995) and Arvidsson and Keller (2004) with intercept of the virgin compression line (VCL) and a regression with the first three or four points of the secondary compression curve (SCC). The system selects the points considering that contained in the range and uses simple linear regression based on least squares procedure to better represent the data obtained in the tests (Example Figure 4). The parameters S_{xy} and S_{xx}, corresponding to the standard deviation of the X and Y variables in the sample were determined by the equations:

$$S_{xy} = \sum_{i=1}^{n} x_i y_j - \frac{\sum_{i=1}^{n} x_i \sum_{j=1}^{n} y_j}{n} \quad (1)$$

$$S_{xx} = \sum_{i=1}^{n} x_i^2 - \frac{\left(\sum_{i=1}^{n} x_i\right)^2}{n} \quad (2)$$

The values of the coefficients a and b of the equation y = a + bx are obtained through of equations

$$b = S_{xy} / S_{xx} \quad (3)$$

$$a = \bar{y} + b\bar{x} \quad (4)$$

RESULTS AND DISCUSSION

The utilization of the *Delphi* program allows a design of windows ergonomically correct, that has its components well distributed and, at the same time, can be easily accessed and utilized by the operator. The developed *software* presents a simple interface which encourages users regarding its operation so that at any moment, he can access the help file containing more information regarding the existing components functionality.

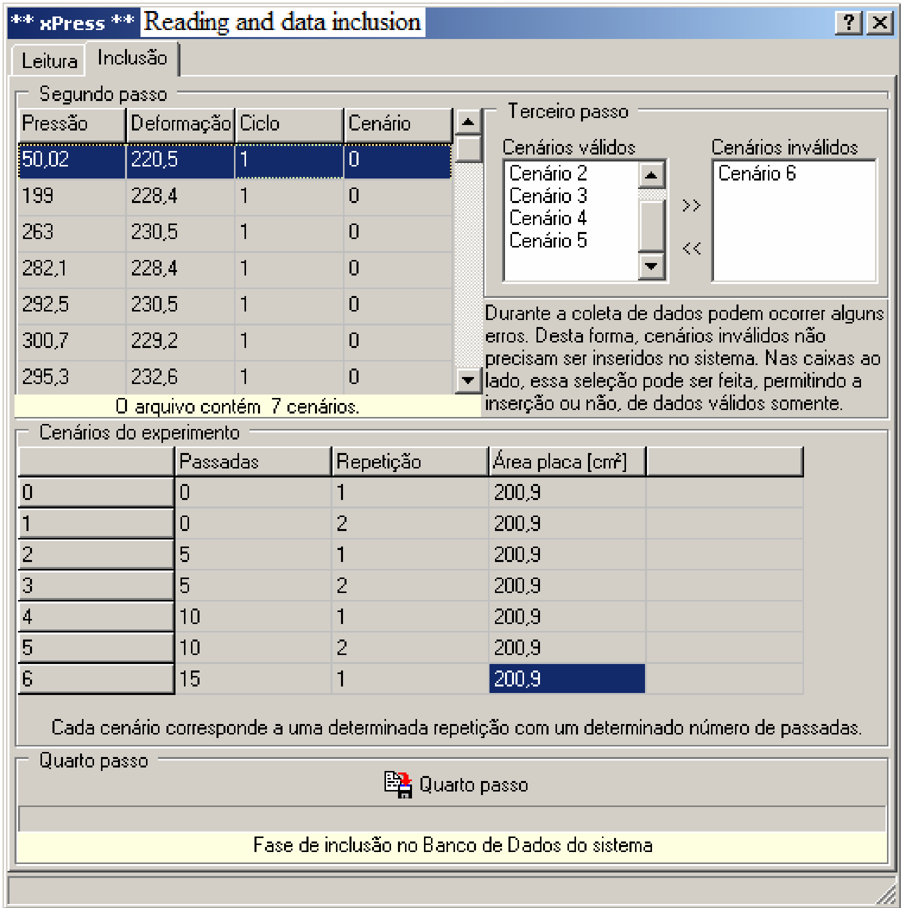

Figure 2. Screen shot with the reading and inclusion in the database of input parameters of Tractor pass number, cycle, repetition, plate area and parameters of output, pression and soil deformation (Lamb, 2006).

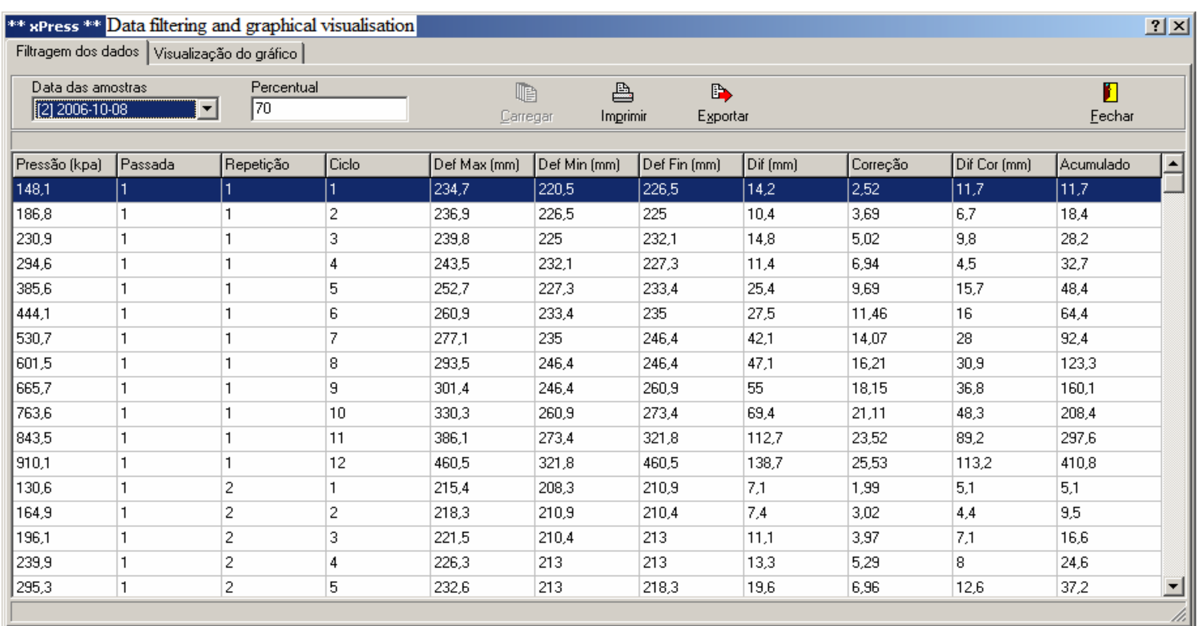

Figure 3. Screen shot with data filtering for the realization of the soil compression curves and calculations of the pre-compression (Lamb, 2006).

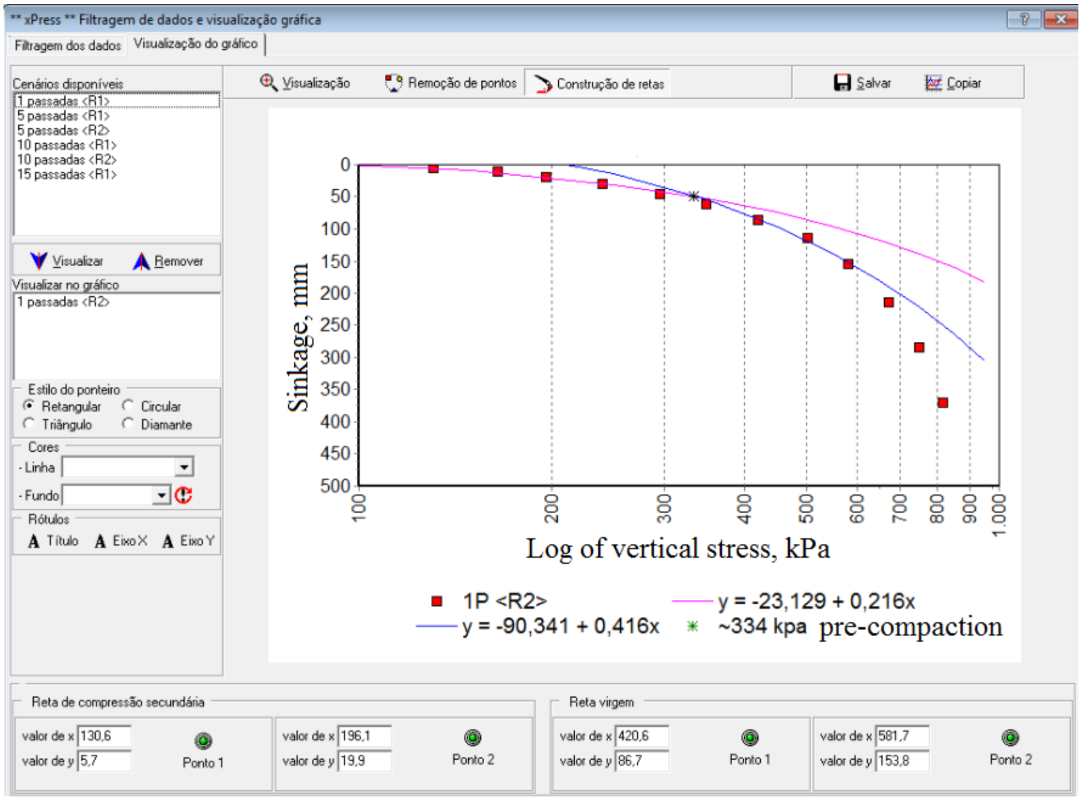

Figure 4. Screen shot with soil compression curves and calculations of the pre-compression stress (Lamb, 2006).

Figure 5 shows the behavior of the soil compression curve without any filtering mechanism in the experimental area with one, five and ten passage of the tractor. These results were considered only in the values of the load applied, without considering maximum deformities for each load, the height of the equipment to the soil and the error obtained by tire deflection. We can see a tendency in data behavior but the large amount of points, along with some discrepant points, reveal a deeper analysis. These discrepant points can be obtained from irregular manner when the hydraulic piston is put into action, or during the acquisition of the data, with the presence of some disturbance which might produce extremely high deformation expressed at the reading on the compression curves before filtering. So, filtering is needed, to cope with these small fluctuations ever-present in the experimental results. Soil compaction experiments are carried out with different pressure levels and different readings rates, obtaining a large amount of data collected by the acquisition mechanism (Dawidowski and Koolen, 1994). Thus, for a proper analysis, the data must be reduced by a filtering mechanism, eliminating much of the errors produced in the tests with the use of the penetrometer and resulting in better quality of information (Menegatti and Molin, 2004). Comparing data from our experiment, without use and with use data filtering system (Figure 6), it can be verified that the large amount of data obtained in the tests without filtering mechanisms (Figure 5), makes difficult a more detailed analysis of soil behavior.

Determination of virgin compression line (VCL), secondary compression curve (SCC) and pre-compaction stress (σ_{pc})

Behavior of the soil compression curves on semi-confined test condition, in field area used with agricultural tractor with one, five and ten passage under the same track, is illustrated in Figure 6.

The condition of semi-confined test allows the lateral expansion of the soil under loading, which represents the real field situation when soils are subjected to the use of agricultural machines. This technique of soil compression test semi-confined may become attractive for field use, since it allows farmers make more reliable plan towards agricultural production system. The regression equations of the virgin compression line (VCL) and the secondary compression curve (SCC) are shown in each corresponding graphic of the condition of soil compaction. Table 2 contains the values from pre-compaction stress of the soil. Our results show that the measured values of

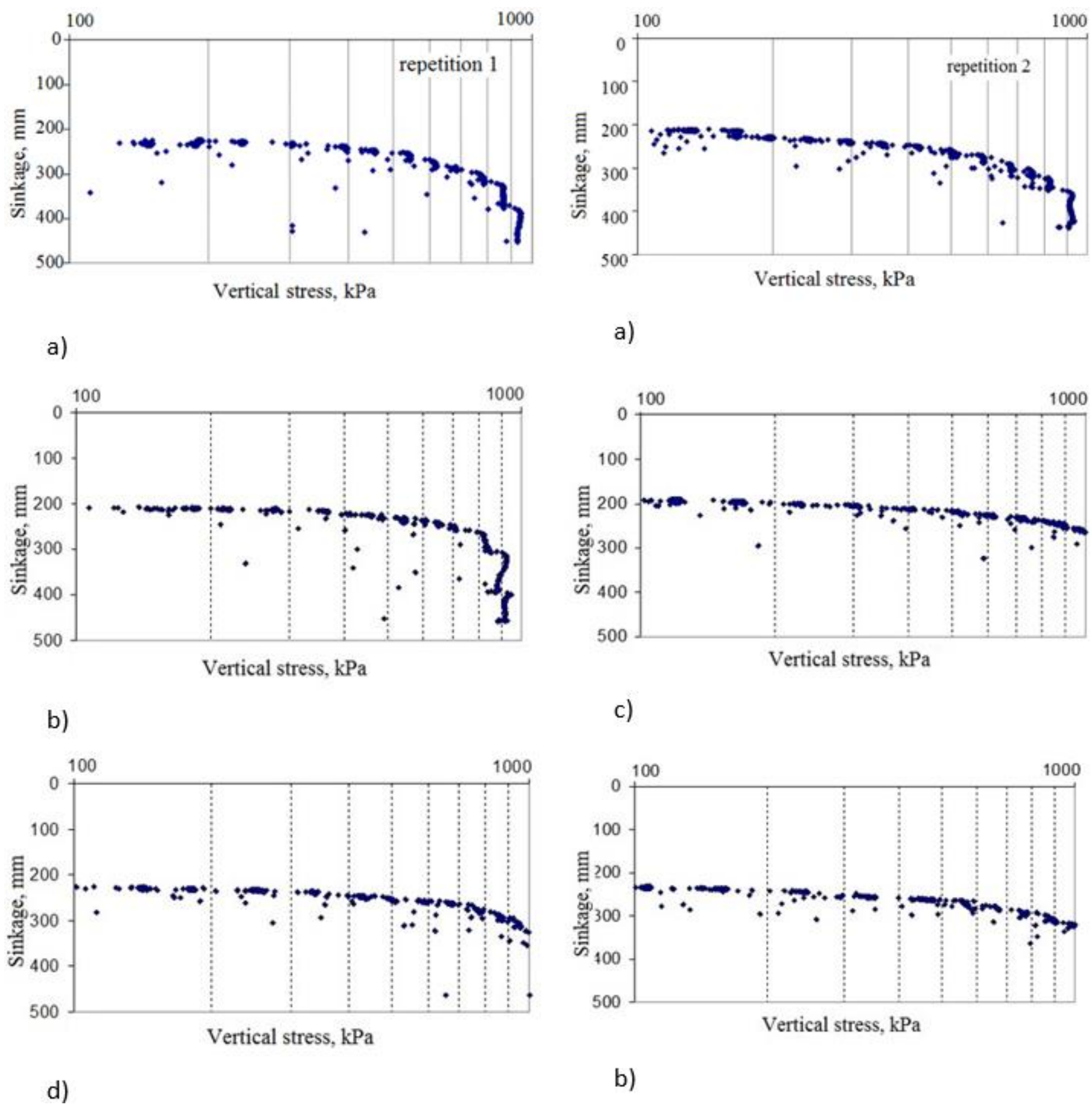

Figure 5. Behavior of the soil compression curve without any filtering mechanisms.

pre-compaction stress increased with the number of passes of the tractor on the soil. These results are expected since there was an increased load on the soil due to repeated number of passes tractor, causing stronger arrangement of soil particles (internal stress of soil aggregates tends to be weaker than the external vertical pressure, because of soil water content), thus producing an increase in soil density (1.18, 1.27 and 1.33 g cm^3, respectively, for the soil with one, five and ten passes of the tractor). Mosaddeghi et al. (2006) used reloading curves for determination of pre-compaction stress of the pre-compacted soil. They compared the actual and predicted values of σ_{pc}. They reasoned that pre-compaction stress should occur within the initial stage of compaction where the mode of soil deformation is more or less similar under confined and semi-confined conditions, which confirms our results. The results obtained in this work is similar to that of Dias Junior (2003), which points that soil disturbance could reduce the sharpness of the critical region (that is, pre-compaction stress region) on the stress–strain curve and consequently decrease the value of σ_{pc}. Since the soil under study was pre-compacted by passage of tractor wheel, which results in the arrangement of soil particles under external vertical stress, and does not result in soil disturbance, which causes an increase in pre-compacting pressure (σ_{pc}).The condition of the soil produced by one pass of the tractor showed larger deformation than the

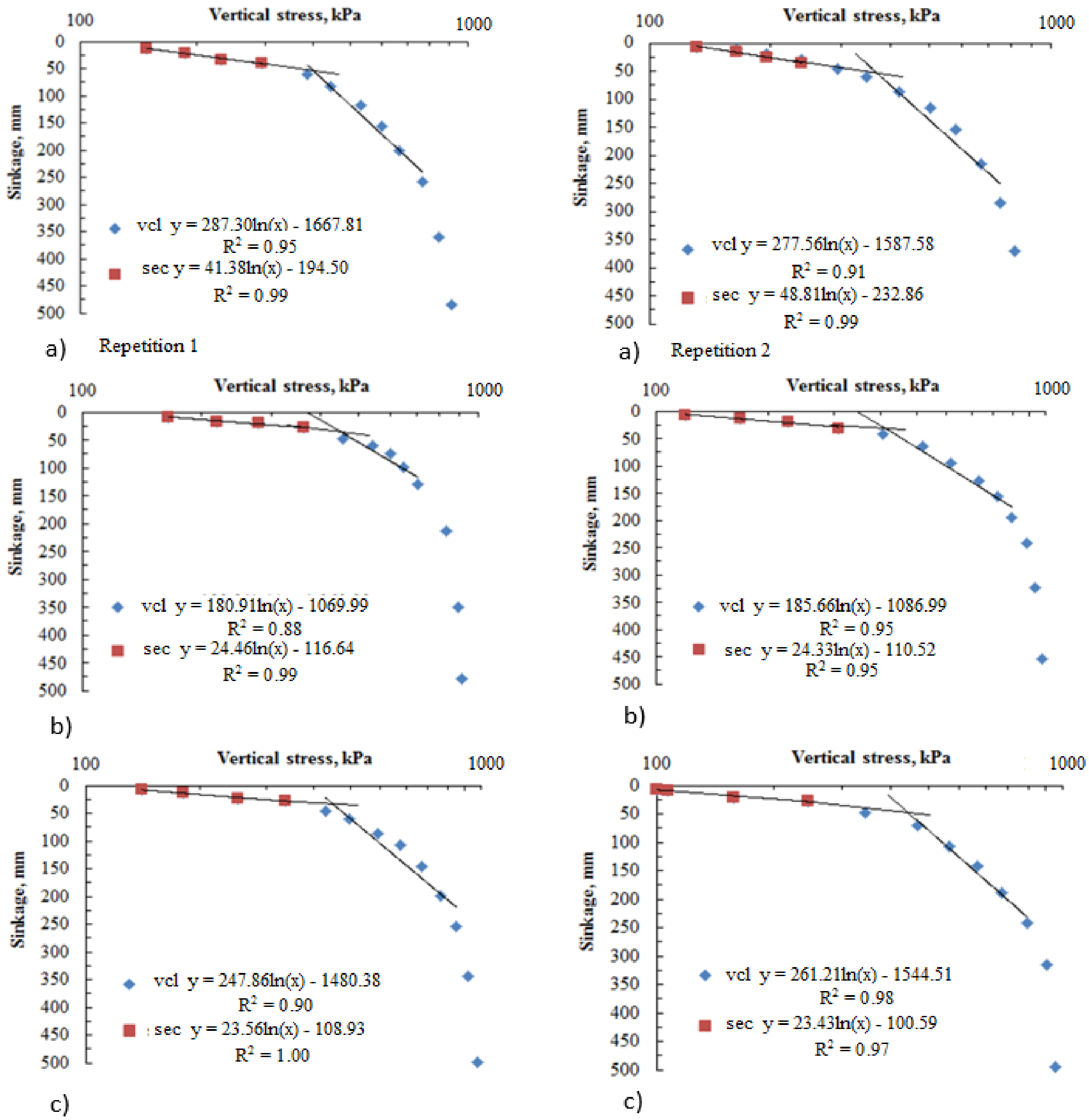

Figure 6. Virgin compression line (VCL) and secondary compression curve (SCC) and Pre-compaction stress of in-situ soil with: a) one; b) five and c) ten passage of the agricultural tractor wheel, measured by plate penetrometer test.

Table 2. Average of the soil pre-compaction stress as a function of the passage tractor number.

Nº passage of the tractor	Repetition	Pre-compaction stress (kPa)	Average (kPa)
1	1	400	387
1	2	373	
5	1	443	433
5	2	424	
10	1	452	443
10	2	434	

conditions produced for five and ten passages, considering the first four pairs of values (stress-strain) of the secondary compression curve (Figure 6a, b and c). Our results showed that although there is a clear trend in increasing the pre-compaction pressure with the increase in the number of tractor passages in the soil (Table 2), we found that with regard to the compression index and linear coefficient of the equations for Virgin compression line, there was no tendency to decrease or increase when the state of soil compaction increased, due to the passage of the tractor, 287.3, 180.91 and 247.86, respectively for one five and ten passage of the agricultural tractor wheel. The other coefficients were -1667.81, -1069.99 and -1480.38 for one, five and ten passage of the agricultural tractor wheel. We use two conditions to explain this behavior: a) it is a semi-confined test; b) the number of ten passage of the agricultural tractor wheel in the soil causes a stronger arrangement of the soil particles than in the one with five passage (Lamb, 2006). Our assumption is that these joint conditions led to a stronger and faster deformation in the soil with five passes of the tractor than in the one with ten passes, for the same stronger pressures. Figure 6a, b and c on the right-hand side is the repetition of each structural state of the soil. Compression indexes between repetitions of each structural state of the soil showing basically the same, indicating parallelism between the virgin compression lines (VCL). This result agrees with the results of researches with confined and semi-confined compression tests (Pereira et al., 2007; Chaplain et al., 2011; Mosaddeghi et al., 2006). In this study it was found that the virgin compression line (VCL) was steeper for all structural soil conditions, allowing a clearer detection of the more plastic soil region. For Mosaddeghi et al. (2006), this fact may occur because the compression under semi-confined conditions consists of lateral and vertical deformations of the soil under the plate, producing great stress and large increase on the soil strain.

Data filtering system

The system still allows the selection of different settings according to user's need, allowing the visualization of several simultaneous graphics. To each line of compaction one can trace, the point of pre-compaction on visual mode. The access component *Zeos* provided agility on the coding of classes in the access on the database of the *Delphi*. The database proved efficient and secured on data storage. The chosen DBMS, asides the financial value because of license exemption shows advantages to many others in the market, especially because of the capability of storing millions of records without any problems, thus assuring data integrity and total independence to other programs. Once the software is installed, with the respective DBMS, it does not require the use of some other application for data manipulation. The construction of compression curves allows user to conduct compaction tests which have its data imported by the program, enabling immediate findings of the soil compaction. These assays can be done in any type of soil, under any compaction condition, having its results processed immediately by the information system has the technical capacity of its users as the only limiting factors. The agility on the analysis of the soil compaction helps with the decision taking on soil management system, decreasing the number of laboratorial tests (thus saving time and money) and avoiding compromise in the process of soil preparation. The determination of the pre-compaction stress on the graphic, on the way it quickly and easily allows the visualization of the soil support capacity with the respective VCL and secondary compression curve and its equations, assisting in the selection of the agricultural machinery in order not to impair soil structure.

Conclusions

1) In this study, the field plate penetrometer test, with the aid of data filtering system showed efficiency in determining soil compaction.
2) The soil compression test semi-confined with plate penetrometer shows steeper virgin compression line as well as, strong pre-compaction values because the compression under semi-confined conditions consists of lateral and vertical deformations of the soil under the plate, resulting in great stresses and large increase on the soil strain.
3) The values of measurement of pre-compression stress increases with the number of tractor passes, in the soil, as consequence of increased soil compaction state due to the strong arrangement of soil particles caused by the increase of the applied load.
4) The information system is able to read all data derived of the compression test and carry out a filtering on the data by means of pre-selected parameters, plotting the compression curves and regression equations
5) The developed software proved efficient and precise on filtering the received data, being able to determine soil compaction curves and the point of pre-compaction through assays of uniaxial compression with the plate penetrometer under the soil conditions studied.
6) The analysis, carried out “in-situ”, avoids laboratorial procedures and gives the farmer more agility in the decision process on the management of the agricultural machinery system.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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