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Soil Physical Quality of Brazilian Crop Management Systems Evaluated with Aid of Penetrometer

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Abstract

Crop management affects soil attributes as well as its quality. We evaluated the following soil physical attributes: saturated hydraulic conductivity (K_0), soil resistance (RP) and soil bulk density (BD), in Araras-SP, Brazil. Areas with sugarcane (*Saccharum officinarum*), soybean (*Glycine max*), physic nut (*Jatropha curcas* L.) and native forest presented an increase of soil compaction in the 0.10 m surface layer for the three attributes in a following order: native forest <physic nut **<** soybean < sugarcane. Significant regressions were obtained for RP × K_0; BD × K_0 and BD × RP. Penetrometer measurements were essential to indicate differences among areassugarcane, native forest, physic nut and soybean; but for the measurements of K_0, only between sugarcane and native forest. RP measurements confirm anthropogenic changes in the soil profile up to the 0.3 m depth. In the "Canarache soil resistance classification" soils showed "low resistance" "without limitations to root development" for native forest and physic nut; "medium resistance" for soybean area with "some limitations to root development" and "high resistance" for sugarcane with "limitations to root development". The use of penetrometers is discussed in relation to the readiness of field measurements.

Keywords: saturated hydraulic conductivity, soil compaction, impact penetrometer

1. Introduction

Intensive crop use can lead to soil degradation also affecting soil physical attributes. One of the soil parameters used as an indicative of physical soil quality is the saturated hydraulic conductivity (K_0). Considering that water and air flow better in pores of larger diameter, the parameters K_0 and the macroporosity (MP) can be taken as indicators of soil compaction. External pressures applied to soils, coming from management practices reduce preferentially larger pores. In this way, low values of MP imply low values of K_0, low soil aeration and an increase of soil resistance to penetration (RP) of roots (Stolf, Thurler, Bacchi, & Reichardt, 2011; Mollinedo et al., 2015). Additionally to the importance of K_0 in the evaluation of soil compaction, RP has also been correlated with other soil physical parameters (Marques, Texeira, Reis, Junior, & Martins, 2008; Ramos et al., 2011; Mollinedo et al., 2016). K_0 is also essential in the description of water movement in soils, like the processes of infiltration, drainage, fertilizer losses, erosion, and leaching of chemicals (Warrick, 2002; Mesquita & Moraes, 2004). RP for the evaluation of the compaction status of a soil is one of the most employed practices because measurements are carried out directly in the field, without the need of a laboratory backup. Measurements are fast, approximately 1 min to sample a profile down to 0.50 m (Stolf, Murakami, Maniero, Silva, & Soares, 2012). Therefore, a large number of studies are found in the literature comparing native forest, orchards and other agro-forestry systems of low machinery impact, with agricultural systems (Martins et al., 2010; Portugal et al., 2010; Cardoso, Silva, Cury, Ferreira, & França, 2011; Iarema, Fonte, Fernandes, Shaefer, & Pereira, 2011; Ramos et al., 2011; Silva et al., 2011). Penetrometers have also been used in pastures (Ramos et al., 2010; Silva Filho, Cottas, & Marini, 2010; Cardoso et al., 2011; Castagnara et al., 2012; Moura, Marasca, Meneses, Pires, & Medeiros, 2012) and in crops with intense traffic of machinery as in areas of sugarcane and soybean (Machado et al., 2010; Debiasi & Franchini, 2012; Ecco, Carvalho, & Ferrari, 2012; Silva, Nunes, Caldeira, Arantes, & Souza, 2012).

In this study we look for relations between K_0 and RP in an area submitted to different forms of management, including a native forest which almost does not present environmental impacts. Four different scenarios were chosen: sugarcane production area (*Saccharum officinarum*); soybean production area (*Glycine max*), physic nut or jatrhopha production area (*Jatrhopha curcas* L.); and a native forest area.

2. Material and methods

The experimental sites used for the evaluation of K_0, BD and RP are located in Araras, SP, Brazil, 22°18′52″S and 47°23′01″W, 560 m above sea level. The mean annual air temperature is 21.4 ºC and the annual rainfall is 1428 mm. According to the classification of Köppen adapted for Brazil, the local climate is of the type Cwa, mesothermic, with humid and warm summers and dry winters. Characteristics of the experimental areas are presented in Table 1.

Table 1. Characteristics of the experimental areas

Plot number	Cover	Plant	Soil classification[a]	Clay (%)	Sand (%)	Sampling method
1	Native forest	Atlantic forest	Oxisol	48	23	zig-zag path
2	Physic Nut	*Jatropha curcas* L.	Oxisol	58	29	in the plant row
3	Soybean	*Glycine max* L.	Oxisol	44	43	in the plant row
4	Sugarcane	*Saccharum officinarum* L.	Oxisol	59	21	in the plant row

Note. [a] US taxonomy classification.

The farm presents four typical areas managed in different ways:

- Native forest, with a seasonally semi-decidual cover, naturally growing on a clayey soil for very long time.
- Physic nut, an area cultivated for 16 years with *Jatrhopha curcas* L. at a spacing of 4 between rows and 2 m between plants in the row (Coelho & Gerald, 2013). Samplings were made in the plant row which was never exposed to machinery traffic.
- Soybean, an area cultivated for one year with *Glycine max* L. at a spacing between rows of 0.45 m. The soybean crop is not truly soybean because it was rotated with sugarcane and the previous sugarcane crop had five harvests performed with heavy mechanized harvesters. For the establishment of the last soybean crop, the sugarcane rhizome was destroyed with two heavy diskings (disc of 0.81 m diameter), and the soil prepared with an intermediate harrow (disc of 0.71 m diameter) and one levelling disking (disc of 0.51 m diameter).
- Sugarcane, area cultivated for 20 years with *Saccharum officinarum* L. at spacing between rows of 1.4m. The crop was grown in cycles of five years and had five harvests performed with heavy mechanized harvesters. For the establishment of each new crop the previous sugarcane ratoon was destroyed with two heavy disks (harrow disc 0.81 m diameter) and the soil prepared with an intermediate disk (0.71 m) and one leveling disking (harrow disc 0.51 diameter). Samplings were made in ratoon after second harvest

For K_0 and BD measurements, non-disturbed samples were extracted (February, 2013) from each plot with metallic cylinders of 0.070 m diameter and 0.072 m height, in the 0-0.1 m layer, with eight replicates. The constant head methodology was employed for obtaining K_0 (EMBRAPA, 1979; Reynolds et al., 2002). Soil samples were dried at 105 ºC during 24 h in the stove and weighted for obtaining soil BD. Penetrometer measurements were made close to K_0 and BD evaluations at eight sampling points, not only for 0-0.10 m, but for the 0-0.50 m soil layer, in 0.05 m increments. For measurements of RP the impact penetrometer described in Stolf, Fernandes and Furlani Neto (1983) was used as schematically shown in Figure 1. Field data were transformed into MPa according to (Stolf, 1991), using the software described in Stolf, Murakami, Brugnaro, Silva and Margarido (2014). Measurements consisted of eight replicates, and for the four treatments (32 profiles) result 320 RP data points. The speed of the penetrometer measurements, dispensing laboratory aid, combined with a computer program (Stolf et al., 2014), were some of the reasons for the adoption of this methodology. These instruments have been very useful in RP mapping, compaction and traffic control, soil spatial variability studies, and also as an indicator of soil quality (Stolf et al., 2012).

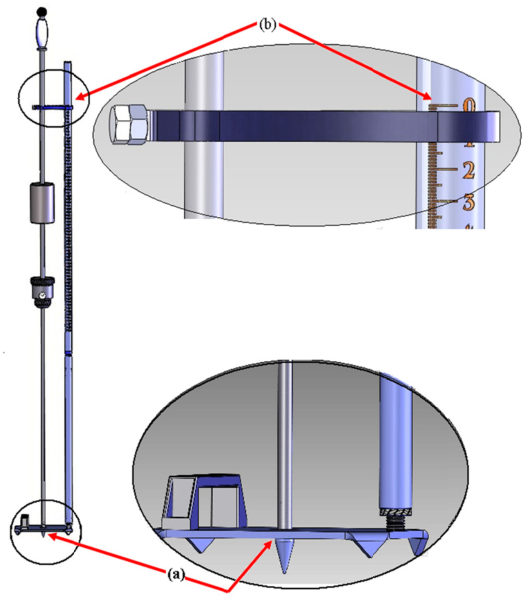

Figure 1. Schematic view of the impact penetrometer, showing the details of: (a) the cone platform, and (b) the millimetric scale for readings (Stolf et al., 2012)

Averages of treatments were compared by the Tukey test with 5% probability (Brugnaro, 2007). Linear correlations (Pearson) between variables were also performed and tested for statistical significance (t test).

3. Results and Discussions

The selection of the sites managed in different ways took into consideration the fact they all would be of clayey texture, therefore more subject to soil compaction. The second point taken into consideration was that the areas should present different stages of degradation due to different managements practiced on their vegetation covers.

The native forest was chosen because it is the least affected area by anthropic factors, even serving as a control treatment. Following the forest we chose the physic nut orchard, a perennial crop with very little machinery traffic. The two following crops, soybean and sugarcane, present an intense use of inputs and machinery, the last one submitted to very heavy traffic. Therefore, the expected sequence starting from the less impact system is: native forest < physic nut < soybean < sugarcane, all on clayey soils. Average values of K_0, RP and BD are here presented in Figures 2a, 2b and 2c, respectively. It is possible to verify that these variables indicate a "compaction gradient" starting from the system of lowest anthropic disturbance (forest) to that of highest (sugarcane), i.e., decrease in K_0 and increase in BD and RP. However, significant differences were found only for RP (3 contrasts) and K_0 (1 contrast), but none for BD (Tukey test, 5%, Figure 2). A significant linear correlation (t test) can, however, be observed between the variables showing a decrease for K_0 with the increase of RP and BD, within the sequence of the systems less to more compacted (Figures 3, 4 and 5).

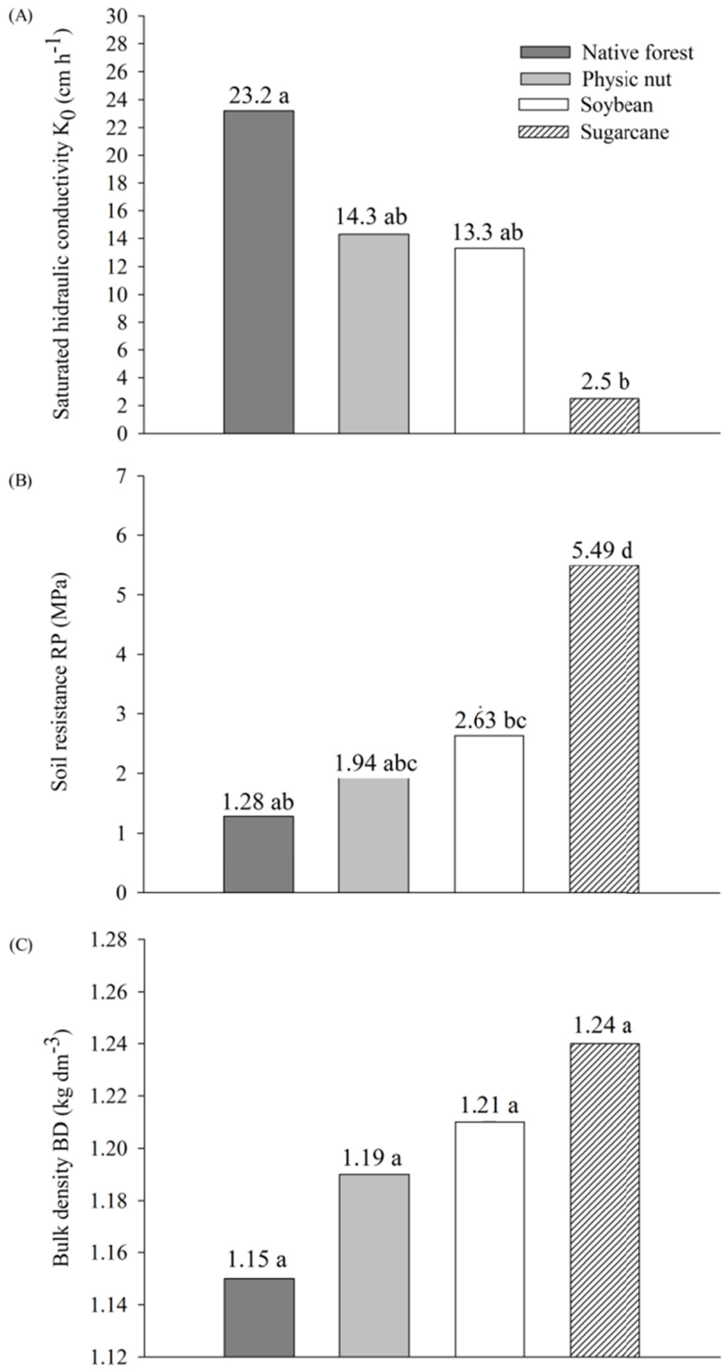

Figure 2. Histogram of the saturated hydraulic conductivity K_0 (A); of soil resistance to penetration RP (B) and soil bulk density BD (C) at the sites of different soil covers

Note. Lower case letters indicate differences at the 5% probability level.

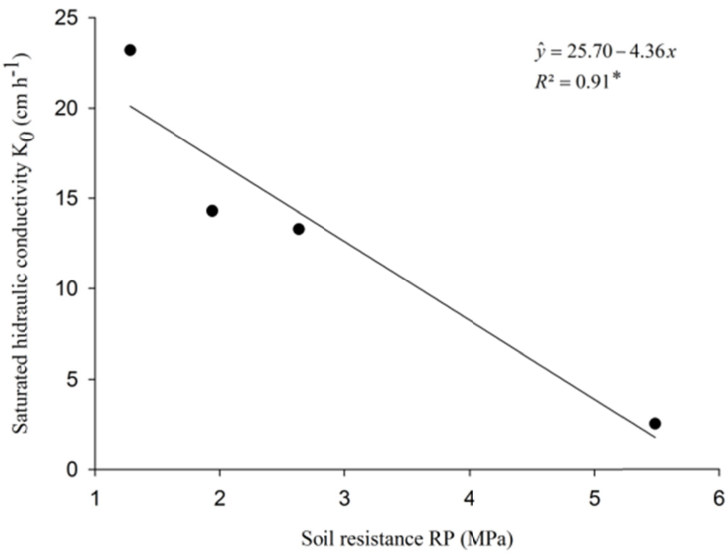

Figure 3. Linear correlation between saturated hydraulic conductivity (K_0) and resistance to penetration (RP)

Note. (*) significant at 5% probability according to the t test.

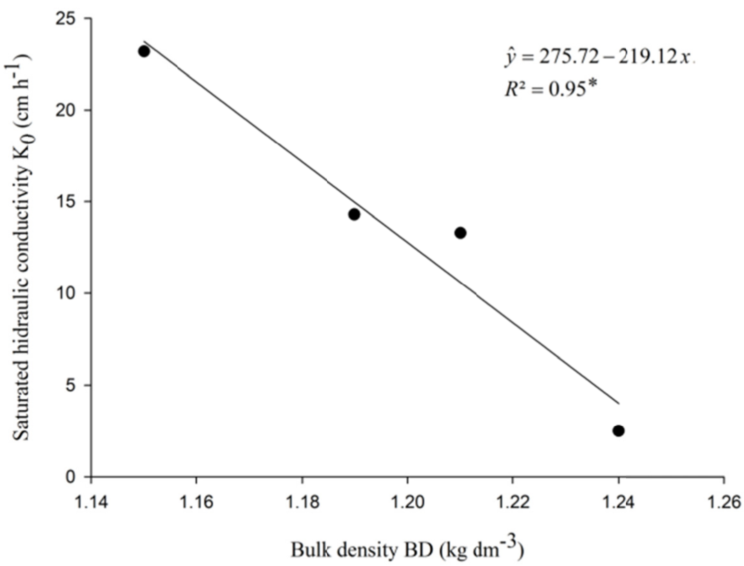

Figure 4. Linear correlation between saturated hydraulic conductivity (K_0) and soil bulk density (BD)

Note. (*) significant at 5% probability according to the t test.

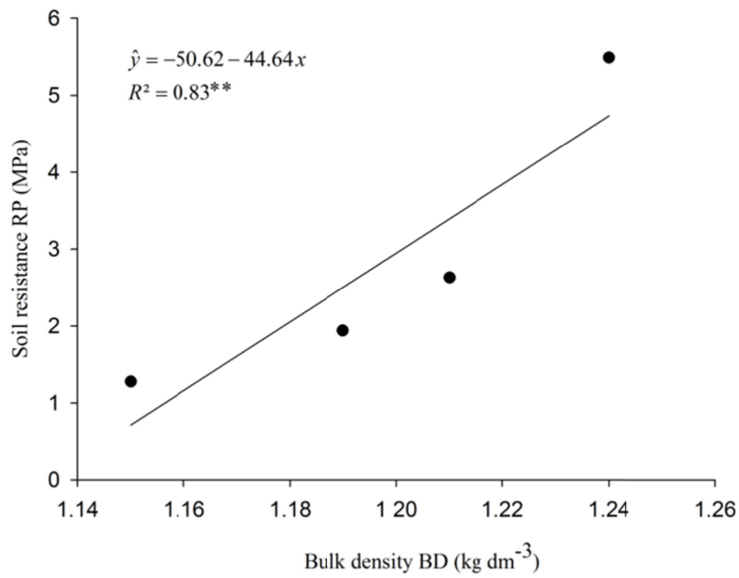

Figure 5. Linear correlation between resistance to penetration (RP) and soil bulk density (BD)

Note. (**) significant at 10% probability according to the t test.

Therefore, these results are indicative of a harmonic behavior of the variables, i.e., the increase of RP and BD leads to a decrease of K_0, and more, this behavior is manifested according to the sequence of areas less compacted to areas with more anthropic impact. The high and significant correlation coefficients (R^2) shown in Figures 3, 4 and 5 confirm the negative correlation existing between K_0 and each of RP and BD.

Canarache (1990) developed a soil classification in relation to soil resistance and root growth (Table 2) in agreement with many experimental data found in the literature (Taylor et al., 1966; Barley et al., 1968; Gooderham & Fisher, 1975; Ehlers et al., 1983). Applying the Canarache (Canarache, 1990) classification to our resistance data in layer 0-0.10 (Table 2, last colunm) shows that the native forest is next to the lower limit of the "low" class, physic nut near the upper limit of the same class. Moreover, Soybean is in the "medium" class and sugarcane, in the "high" class. For the latter two land uses the classification indicates soil compaction resulting in "some limitations to root development" for soybean and "limitation" for sugarcane.

Table 2. Recommended limits for classes of soil resistance to penetration according to Canarache (1990) and classification of the treatments

Resistance to penetration class	Limits (MPa)	Limitations for root growth	Experiment (MPa)
Very low	≤ 1.0	No limitation	-
Low	1.1-2.5	No limitation	Forest(1,28); Phisical nut (1,94)
Medium	2.6-5.0	Some limitations	Soybean (2,63)
High	5.1-10.0	Limitations	Sugarcane (5,4)
Very high	10.1-15.0	No root growth possible	-
Extremely high	> 15.0	No root growth possible	-

The discussion made above refers to data obtained for the 0-0.1 m soil layer. One question that arises when analyzing a shallow single top soil layer is: And what about the deeper layers? Is there any other root growth restriction? With penetrometers it is possible to measure different soil layers in depth at a given point at the same time in an easy and fast way. In our study we have obtained resistance values of 0.05 by 0.05 to 0.5 m deep, taking about one minute per point. By the results (Figure 6) it can clearly be seen that the four management systems are also differentiated in the sequence of less to higher impact: native forest < physic nut < Soybean < sugarcane. However, the RP values approximating to each other below 0.3 m, indicate that below this depth we find values of the natural soil resistance to penetration due to predominating texture, and without anthropogenic changes. Regarding Latosols, one would expect little change of the resistance in depth. The curve of the sugarcane plot, with a pronounced strength peak indicates the location of maximum disturbance in depth (Figure 6).

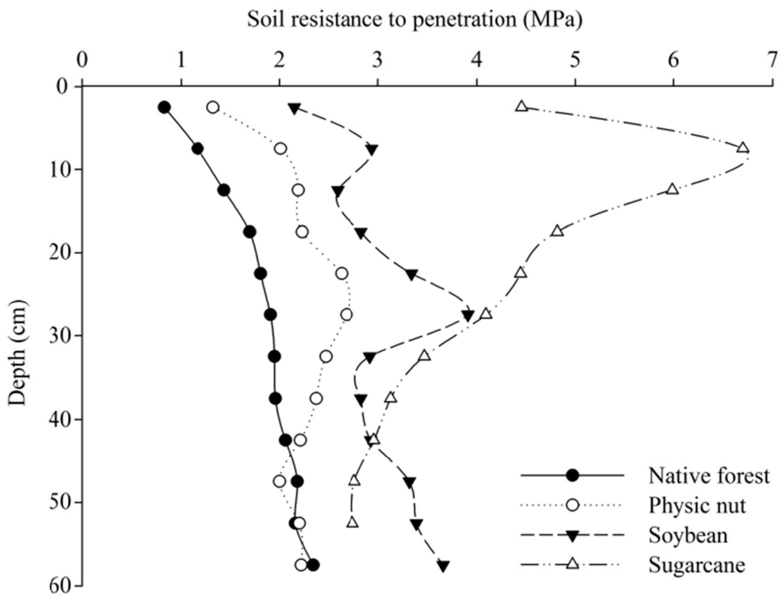

Figure 6. Soil resistance to penetration RP (average values) for the four sites with different soil conditions

Compared to BD, K_0 or any other soil attribute used to evaluate degrees of soil compaction, we cannot say that RP is the best measure. However, penetrometers allow quick and easy measurements of RP to be taken down to relatively deep layers.

4. Conclusions

It is demonstrated that the different managent practices employed on this soil, added to the different soil covers affect its physical quality. The most affected system is the sugarcane cultivation due to the traditional way of growing this crop, with the need of heavy machienery. Saturated hydraulic conductivity K_0, soil bulk density BD and resistance of soil penetration RP, allowed the characterization of the tendency of increase of the degree of compaction of a clayey soil in the sequence of management systems: native forest < physic nut < soybean < sugarcane. The behavior of these three variables in the characterization of the state of compaction of the soils was corroborated by the high coefficients of determination (R^2) between them. Significant differences (Tukey 5%) between averages for the management systems sugarcane and native forest were found for K_0 (2.5 cm h^{-1} × 23.2 cm h^{-1}). Also for RP significant differences were found between sugarcane and the other three areas, native forest, physic nut and soybean (5.49 MPa × 1.28, 1.94, 2.63 MPa, respectively). RP values in depth indicate anthropogenic alteration in the sugar cane area down to 0.3 m. On the other hand, below this depth values of RP approach the natural soil resistance to penetration. Canarache classification (Canarache, 1990) applied to our penetrometer data shows that the native forest and physic nut areas fall into the “low resistance class” with “no limitations for root growth”. The soybean area into the “medium resistance class, with “some limitations for root growth” and the sugarcane area into the “high resistance class” with “limitations for root growth”.

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