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DEVELOPMENT OF A LOW-COST ELECTROMECHANICAL PENETROMETER TO VERIFY RESISTANCE TO SOIL PENETRATION

Aldir Carpes Marques Filho[1], Lucas Rauen[2] & Kléber Pereira Lanças[1]

1 - São Paulo State University, Faculty of Agricultural Sciences, Botucatu, São Paulo, Brazil

2 - Faculty of Agronomy FAEF, Rosa Dourada Agricultural Science, Garça, São Paulo, Brazil

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ABSTRACT

Soil compaction is one of the great obstacles in modern agriculture. With the increase in size, weight and intensity of use of machines in crops in recent decades, the soil has suffered damage to its structure, compromising the productivity of vegetable crops. One of the ways to indirectly obtain the compaction state of the soil is through the resistance to penetration imposed by it on a standardized metal rod. Invariably, commercial equipment for this purpose is expensive. The objective of this study was to develop a low-cost system for evaluating the resistance to soil penetration, using a prototyping platform and specific sensors. The developed equipment, when compared with a calibrated standard equipment, presented a high correlation in the results of resistance to penetration in two soil conditions. The development cost of the proposed equipment was 800% lower than the average value of commercial equipment available on the market, so the measurements met the purpose of the project, showing the possibility of developing low-cost solutions through prototyping platforms, for the assessment of resistance to soil penetration.

Palavras-chave:
Índice de cone
Compactação do solo
Arduino

DESENVOLVIMENTO DE UM PENETRÔMETRO ELETROMECÂNICO DE BAIXO CUSTO PARA VERIFICAÇÃO DE RESISTÊNCIA À PENETRAÇÃO DO SOLO

RESUMO

Um dos grandes entraves na agricultura moderna é a compactação do solo. Com o aumento do tamanho, do peso e da intensidade de uso das máquinas nas lavouras nas últimas décadas, o solo vem sofrendo danos em sua estrutura, comprometendo a produtividade das culturas vegetais. Uma das maneiras de se obter indiretamente o estado de compactação do solo é através da resistência à penetração imposta por este à uma haste metálica padronizada. Invariavelmente, os equipamentos comerciais com essa finalidade apresentam alto custo. Objetivou-se com este trabalho, desenvolver um sistema de baixo custo para avaliação da resistência à penetração do solo, com o uso de plataforma de prototipagem e sensores específicos. O equipamento desenvolvido, quando comparado com um equipamento padrão calibrado, apresentou alta correlação nos resultados de resistência à penetração em duas condições de solo. O custo de desenvolvimento do equipamento proposto foi 800% inferior ao valor médio dos equipamentos comerciais disponíveis no mercado, de forma que as mensurações atenderam o propósito do projeto, evidenciando a possibilidade de desenvolverem-se soluções de baixo custo, através de plataformas de prototipagem, para a avaliação da resistência à penetração do solo.

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Email (corresponding author)*: aldir.marques@gmail.com

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Michael Silveira Thebaldi

INTRODUCTION

Over the years, agricultural machinery grew larger and heavier, causing the phenomenon known as soil compaction, a mechanical process originating from the repeated employment of loads on the soil (KELLER *et al*., 2019). Compaction occurs through the reorganization of solid particles, which occupy the voids in the soil (MOLINA JR., 2017). Compaction is a threat to global food security, as it prevents agricultural crops from expressing their greatest productive potential (COLOMBI; KELLER, 2019).

Compaction can be influenced by different factors and soil characteristics (MARTINS *et al*., 2018), by moisture and texture (ESTEBAN *et al.,* 2019). Compacted soils have less capacity to support crops and hinder plant growth, as they impede the absorption of water and nutrients (MORAES *et al*., 2020; OLUBANJO; YESSOUFOU, 2019; PEIXOTO *et al.,* 2019; UNGUREANU *et al.,* 2019). Soils are non-renewable systems and can suffer irreversible damage when handled incorrectly (HORN, 2015; SINGH *et al.,* 2019).

Alaoui and Diserens (2018) stated that assessing the soil is excessively complicated, because it varies in time and space. Laboratory evaluations are time-consuming and often expensive, but they are accurate. However, indirect field methods are more practical and less expensive, but have greater variability.

The equipment usually indicated to assess soil compaction is the cone penetrometer (LIMA, DE LEÓN; SILVA, 2013). In cone penetrometers a force is applied to a metal rod with a known tip area, and a pressure value is returned as a function of the penetration depth of the rod, this index is called the cone index.

The cone index can be related to the soil compaction in each layer. This information is important for localized decompression treatment (SINGH *et al*., 2019), widely used in precision agriculture and variable rate decompression. However, many farmers do not have the equipment to check soil compaction, since they are expensive.

The aim of this study was to develop an electromechanical penetrometer device for evaluating the resistance to soil penetration, of low cost and simple construction. Specifically evaluating the possibility of applying electronic prototyping platforms in the device design.

MATERIALS AND METHODS

The research was developed at NEMPA (Agroforestry Machines and Tires Testing Nucleus) belonging to the Faculty of Agronomic Sciences of the State University of São Paulo and to the Faculty of Agronomy FAEF / Garça - SP. To create the soil compaction assessment device, the product development followed methodology proposed by Rozenfeld *et al*. (2015). The system considered some existing technologies and was designed based on manual mechanical pressure penetrometers. The applied technology aims to reduce the price of equipment, so the project can be considered an improvement to the product.

The project developed considered some solutions already offered for the assessment of soil compaction, as well as expanding the applications and utilities of the equipment. The incremental model of technology and cost reduction was planned.

The following materials were used to assemble the system: “S” type load cell with a capacity of 100 kgf in the YZC-516C model; Arduino UNO Atmega 328P Platform; 20x4 LCD display with blue backlight; 24BIT Converter Module HX711; 9V battery; 70cm rod (drawn round iron ½ steel 1020); “Handlebar” bar ¾ bicycle type and plastic box (170x145x90 Steck), in addition to specific buttons and resistors (Figures 1 and 2).

A comparison of the device developed with a calibrated penetrometer was performed and by statistical analysis of Pearson’s correlation, equations were developed between the devices. Field tests were carried out at the Faculty of Agronomy of FAEF in Garça-SP (Figure 3). The developed prototype (PP) was compared with a calibrated penetrometer (PC) brand SOIL

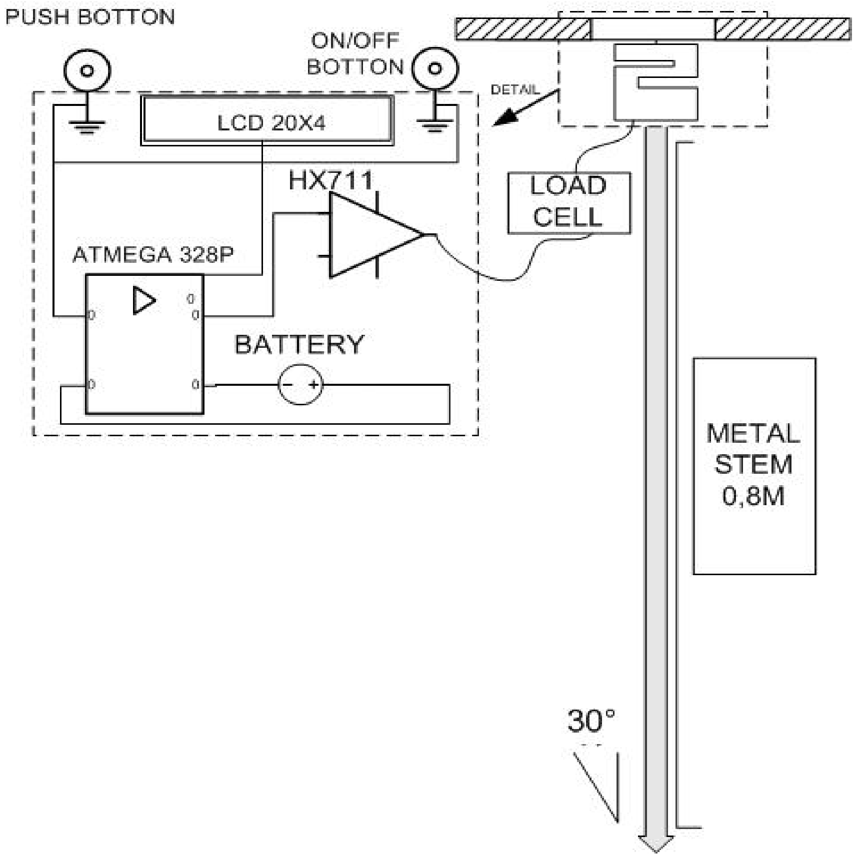

Figure 1. Assembly scheme of prototype for evaluating the soil resistance of penetration

Figure 2. Device Assembly details

CONTROL MOD. 625. The PC equipment was used to calibrate the PP system through an algorithm in the microcontroller. In PP, data were generated in kgf cm^{-2} and internally multiplied by 0.098 to obtain values in MPa. Through statistical analysis, we verified the relationships between the two devices.

The equipment tests were performed in a completely randomized design (ICD), in paired collections spaced 0.1 m apart between samples. Data were collected in two conditions from the same soil. The soil was classified as a Typic Hapludox according to Soil Taxonomy (USDA, 2014) or “Latossolo Vermelho Amarelo distrófico típico” according to Brazilian Soil Classification System (SANTOS *et al*., 2018). Soil samples

Figure 3. Comparative tests of the prototype developed with equipment calibrated in two soil conditions

were collected to assess the water content (soil moisture), according to the methodology proposed by Brazão e Silva (2018). Area "A" had 16% water content and area "B" had 18%.

Pearson's correlation coefficient analysis was performed, comparing the two devices, grouping the values of the six repetitions, as well as applying Shapiro-Wilk normality tests, analysis of variance (ANOVA) and, when applicable, Tukey's test at 95% probability. Statistical parameters were analyzed using Mintab v.16 software.

RESULTS AND DISCUSSION

Comparative results between the devices are described in Table 1. The developed equipment presented mean values statistically equal when compared to the standard calibrated equipment. The absolute values of the resistance to penetration of the soil presented in the table were small, and according to the Tukey test at 95% probability, they did not present statistical difference for the depths from zero to 45 centimeters.

It was verified that in the soil "A" there was greater resistance to penetration, what can be explained by the fact that the soil has less moisture during the tests. The values found were statistically equal at all collection depths, except for the 50 cm depth, Peixoto *et al*. (2019) claim that the water content directly influences the resistance to soil penetration, they suggest this as a reference parameter for modeling and evaluating soil compaction, the potential of the soil matrix related to penetration resistance should be used.

The statistical difference found in 50cm may have occurred due to an abrupt variation in the sampled location, since in this type of comparison it is impossible to sample the same place twice, and the soil is a highly variable environment (ALAOUI; DISERENS, 2018).

In soil "B" no statistical difference was found at different depths, a fact that can be explained by the high humidity and homogeneity of the soil layers.

In Figures 4 and 5 it is possible to verify the behavior of the resistance to penetration of the soil at different depths with the two equipments, PP prototype and PC calibrated device.

Table 1. ANOVA and Tukey test between two devices at different depths

					Soil A					
Depth (cm)	5	10	15	20	25	30	35	40	45	50
PP (MPa)	0.68	1.10	1.59	2.16	2.60	2.82	2.82	1.86	1.32	1.05**a**
PC (MPa)	0.56	0.98	1.60	2.31	2.79	2.97	2.99	1.88	1.47	1.25**b**
F	0.71*	0.96*	0.01*	0.56*	0.5*	0.29*	0.42*	0.02*	3.86*	13.71
p-value	0.43	0.36	0.96	0.48	0.50	0.61	0.54	0.88	0.10	0.01
					Soil B					
PP (MPa)	0.13	0.44	0.58	0.98	1.71	1.88	1.76	1.66	1.42	1.27
PC (MPa)	0.14	0.36	0.68	1.07	1.66	2.07	1.96	1.89	1.47	1.34
F	0.01*	0.44*	0.33*	0.01*	0.22*	0.19*	0.06*	0.16*	0.01*	0.02*
p-value	0.92	0.53	0.58	0.92	0.65	0.67	0.81	0.7	0.93	0.88

Means followed by the same letter in the column do not differ from each other by the Tukey test (p <0.05). * NS - not significant

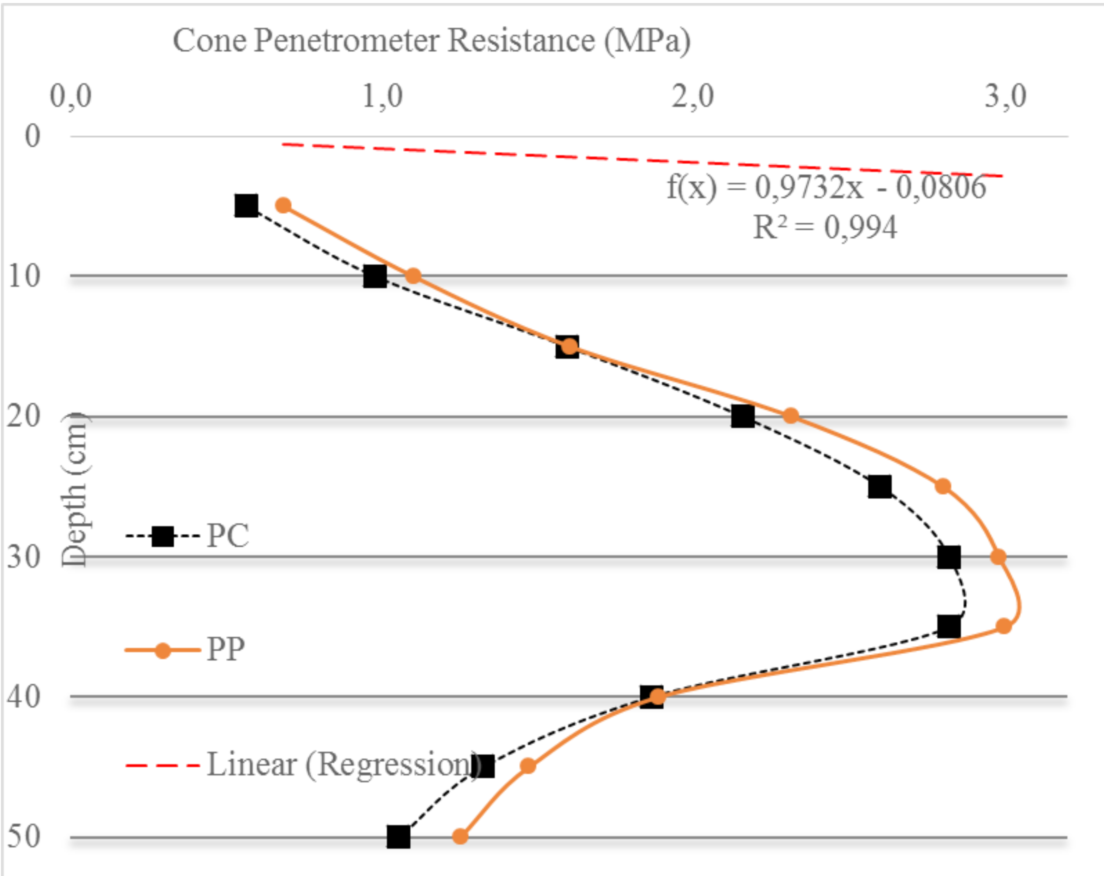

Figure 4. Cone index graph for resistance of penetration to soil in sample plot with 16% moisture, values are averages of 6 repetitions at each depth

The similarity data on resistance to soil penetration, found in paired samples, allows us to state that the two devices showed statistical equality and made it possible to evaluate compacted soil layers with a high degree of accuracy. Beutler *et al.* (2007) found a high correlation in three soil compaction assessment methods with different penetrometers. All models had acceptable measurements and r^2 above 0.96.

The developed device PP presented values

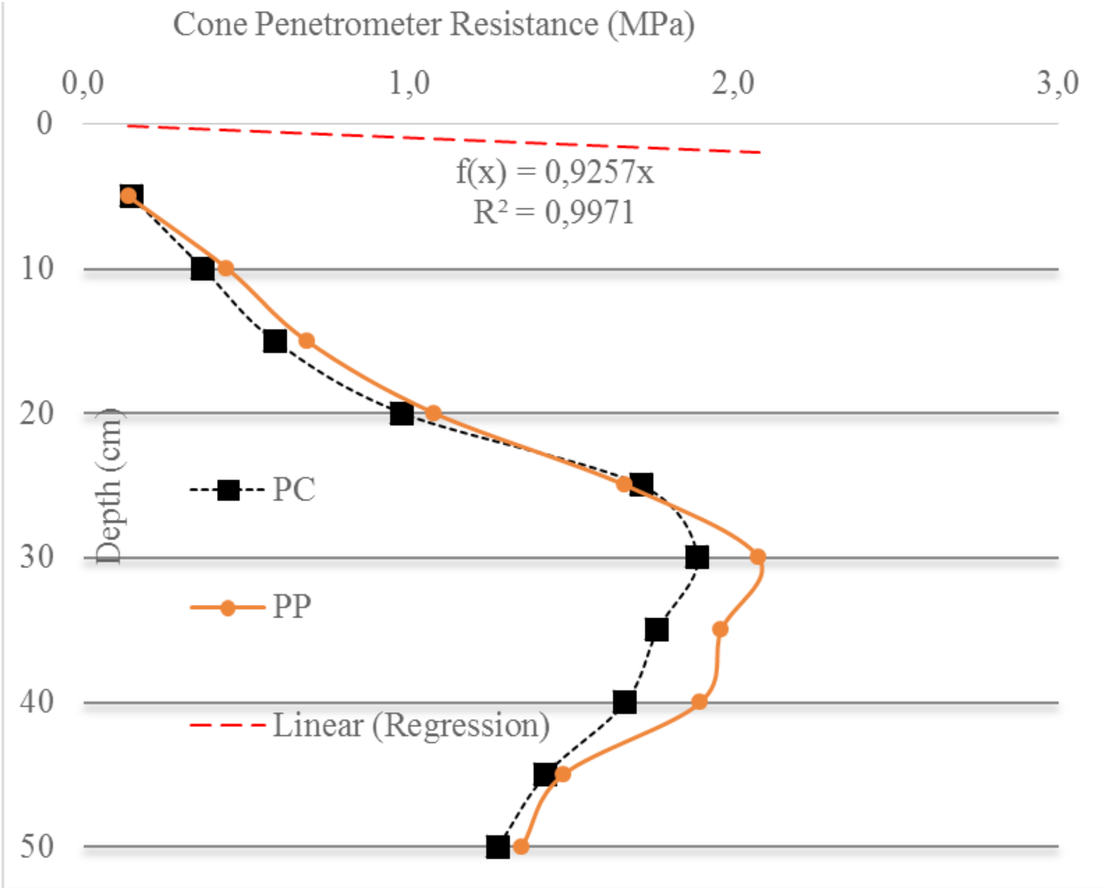

Figure 5. Cone index graph for resistance of penetration to soil in sample plot with 18% moisture. Values are averages of 6 repetitions at each depth

slightly higher than the calibrated equipment, however, due to the high variability that agricultural soils present, the correlation values 0.994 and 0.997 can be considered high. The results of resistance to penetration obtained can also be associated with other process variables, such as nutrient content or productivity, increasing the reliability of the technology in practical application. Martins *et al.* (2018) state that the use of mathematical models to cross-reference soil compaction information allows for a better understanding of the process over time. In this way, devices such as the PP can contribute to increasing the efficiency of agriculture.

The identification of areas with critical compaction for crops is important because it allows corrective measures to be taken, such as subsoiling. Singh *et al.* (2019) in research relating cotton and wheat productivity to soil compaction, obtained the best results in areas where the subsoiling operation took place. The authors verified the persistence of the results of the operation in the productivity of the cultures until 3 years after the subsoiling.

Olubanjo and Yessoufou (2019) obtained a reduction of 18.8% in the productivity of corn in compacted soil, and the compaction had a negative influence on the absorption of nutrients. The authors stated that corn should not be grown in soils with resistance to penetration greater than 2MPa. The developed device "PP" allows the correct assessment of resistance to soil penetration, collaborating with the theory proposed by Hargreaves *et al.* (2019), where the soil compaction should be identified, as it decreases crop yield.

The acquisition system developed had an approximate total cost of materials and components of US$ 90 (ninety dollars) and adequately served the initial purpose of evaluating soil compaction according to the results obtained in the test collections in the field situation. It may be necessary to create calibration templates for other soil classifications, however, the strategy seems promising in terms of cost reduction and reliability of the data obtained.

Under review during the survey, market values for commercial equipment ranging from $720 to $2,000 were assessed. When comparing the gross value applied in the development of this equipment with the prices of equivalent commercial ones, the developed technology represents a cost reduction of more than 800%.

AUTHORSHIP CONTRIBUTION STATEMENT

MARQUES FILHO, A. C.: Conceptualization, Methodology, Software, Writing – original draft, Writing – review & editing; **RAUEN, L.:** Funding acquisition, Investigation, Methodology, Resources, Validation; **LANÇAS, K. P.:** Methodology, Resources, Supervision.

DECLARATION OF INTERESTS

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CONCLUSIONS

- The developed electromechanical penetrometer met the expectation of evaluating the resistance to soil penetration at depths from 0 to 50 cm and provided savings of 800% in operational instrumentation.
- Prototyping platforms can be used to create low-cost solutions for agricultural, and soil research applications.

REFERENCES

ALAOUI, A. DISERENS, E. Mapping soil compaction. A review. **Environmental science e health**, v.5, p.60-66, 2018.

BRAZÃO E SILVA, S. Análise de solo para ciências agrárias. 2 ed., Universidade Federal Rural da Amazônia. Belém: EDUFRA, 2018.

BEUTLER, A. N.; CENTURION. J. F.; SILVA. A. P. Comparação de penetrômetros na avaliação da compactação de latossolos. **Engenharia Agrícola**. v. 27. n. 1. p. 146-151. 2007.

COLOMBI, T.; KELLER, T. Developing strategies to recover crop productivity after soil compaction - A plant eco-physiological perspective. **Soil and Tillage Research**, v.191, p.156-161, 2019.

ESTEBAN, D. A. A.; SOUZA Z. M.; TORMENA, C. A.; LOVERA, L. A.; LIMA, E. S.; OLIVEIRA, I. N.; RIBEIRO, N. P. Soil compaction, root system and productivity of sugarcane under different row spacing and controlled traffic at harvest. **Soil and Tillage Research**, v.187, p.60-71, 2019.

HARGREAVES, P. R.; BAKER K.L.; GRACESON A.; BONNETT, S.; BALL B.C.; CLOY, J.M. Soil compaction effects on grassland silage yields and soil structure under different levels of compaction over three years. **European Journal of Agronomy**, v.109, 2019.

HORN, R. Soil compaction and consequences of soil deformation on changes in soil functions. In Task force: soil matters – solutions under foot. **GeoEcology Essays**, v.1, p.28-32, 2015.

KELLER, T.; SANDIN, M.; COLOMBI, T.; HORN, R. OR, D. Historical increase in agricultural machinery weights enhanced soil stress levels and adversely affected soil functioning. **Soil and Tillage Research**, v.194, p.1-12, 2019.

LIMA, R. P.; DE LEÓN, M. J.; SILVA, A. R. Comparação entre dois penetrômetros na avaliação da resistência mecânica do solo à penetração, **Rev. Ceres**, v. 60, n.4, p. 577-581, 2013.

MARTINS, P. C. C.; DIAS JUNIOR. M. S.; AJAYI. A. E.; TAKAHASHI. E. N.; TASSINARI. D. Soil compaction during harvest operations in five tropical soils with different textures under eucalyptus forests. **Ciência e Agrotecnologia**. v.42. p.58-68. 2018.

MOLINA JR, W. F. Comportamento mecânico do solo em operações agrícolas. Escola superior de agricultura Luiz de Queiroz. Piracicaba: ESALQ/USP, 2017.

MORAES, M. T.; DEBIASI, H.; FRANCHINI, J. C.; MASTROBERTI, A. 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.1-14, 2020.

OLUBANJO, O. O.; YESSOUFOU, M. A. Effect of Soil Compaction on the Growth and Nutrient Uptake of Zea Mays L. **Sustainable Agriculture Research**, v.8, n.2, 2019.

PEIXOTO, D. S.; SILVA, B. M.; OLIVEIRA, G. C.; MOREIRA, S. G.; SILVA F.; CURI, N. A soil compaction diagnosis method for occasional tillage recommendation under continuous no tillage system in Brazil. **Soil and Tillage Research**, v.94, p.1-12, 2019.

ROZENFELD, H.; FORCELLINI, F. A.; AMARAL, D. C.; TOLEDO, J. C.; SILVA, S. L.; ALLIPRANDINI, D. H.; SCALICE, R. K. G. Gestão de desenvolvimento de Produtos. Uma referência para melhoria do processo. São Paulo: Saraiva. 2015.

SINGH, K.; CHOUDHARY, O. P.; SINGH, H. P.; SINGH, A.; MISHRA, S. K. Sub-soiling improves productivity and economic returns of cotton-wheat cropping system. **Soil and Tillage Research**, v.189, p.131-139, 2019.

SANTOS, H.G.; JACOMINE. P. K. T.; ANJOS. L. H. C.; OLIVEIRA. V. A.; LUMBRERAS. J. F.; COELHO. M. R.; ALMEIDA. J. A.; ARAUJO FILHO. J. C.; OLIVEIRA. J. B.; CUNHA. T. J. F. Sistema Brasileiro de Classificação de Solos. 5 ed. Brasília: EMBRAPA 2018.

USDA. Soil Survey Staff, Keys to Soil Taxonomy. 12th edition. Washington: United States Department of Agriculture, 2014.

UNGUREANU, N.; VLADUT, V.; CUJBESCU, D. Soil compaction under the wheel of a sprayer. **E3S web of conferences**. v.112, n.03027, 2019.