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TECHNICAL NOTE

Construction and performance of a simplified tension table for the determination of soil physicohydric attributes

Construção e desempenho de mesa de tensão simplificada para determinação de atributos físico-hídricos de solos

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ABSTRACT: For determining the soil attributes of water retention up to –10 kPa, including macroporosity and microporosity, the sand tension table has been proposed as a low-cost and high-performance alternative to Büchner funnels. This study demonstrates procedures for the installation, calibration and validation of a tension table built with inexpensive, easily purchased materials. We collected 14 oxisol samples with preserved structure to evaluate the efficiency of the constructed tension table as compared to Büchner funnels for determining the water content at potentials of –2, –4 and –6 kPa. No significant differences were observed for the porosity obtained using the tension table compared to that observed using the suction unit.

RESUMO: *Para determinação dos atributos de retenção de água no solo até o potencial matricial de –10 kPa, como a macroporosidade e a microporosidade, tem sido sugerido o uso da mesa de tensão de areia, que se apresenta como uma alternativa de baixo custo e, sobretudo, de alto rendimento de trabalho em relação aos Funis de Büchner. O objetivo deste trabalho foi demonstrar os procedimentos para montagem, calibração e validação de uma mesa de tensão construída com materiais de baixo custo e fácil aquisição. Foram coletadas 14 amostras indeformadas de um Latossolo Vermelho, para avaliar a eficiência da mesa de tensão construída em relação aos Funis de Büchner, na determinação dos conteúdos de água nos potenciais de –2, –4 e –6 kPa. Não foram encontradas diferenças significativas para porosidade, obtida na mesa de tensão, quando comparada à unidade de sucção.*

KEYWORDS
Field capacity
Laboratory measurement
Soil porosity
Soil water retention

PALAVRAS-CHAVE
Capacidade de campo
Determinação laboratorial
Porosidade do solo
Retenção de água

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1 Introduction

Physicohydric soil properties such as field capacity, macroporosity and microporosity provide practical technical information, such as the appropriate soil moisture content for irrigation and the friability/moment at which agricultural machinery should enter the field, by determining the association between the optimum moisture for tillage and matric water potential (DEXTER; BIRD, 2001). These properties also show whether the soil has and more or less susceptibility to compaction; high water retention at a tension of 6 kPa, equivalent to field capacity (also referred to as microporosity in latosols), signals increased micropores and reduced macropores (SEVERIANO et al., 2011). These physicohydric properties can be determined using a tension table (OLIVEIRA, 1968), a piece of equipment known and extensively used by researchers in Brazilian and international institutions (OLIVEIRA, 1968; TOWNEND; REEVE; CARTER, 2000; ROMANO; SANTINI, 2002; LIMA; SILVA, 2008), which allows for the quick determination of the water retention curve.

However, Büchner funnels are regarded as the standard equipment for determining water retention at high potentials (–2, –4, –6, –8, –10 kPa or low suction) (HAINES, 1930). The Büchner funnel operates using water drainage by applying different suctions to previously saturated soil samples. Because the funnel possesses a small porous plate, which limits the number of samples, it is a less dynamic apparatus for obtaining water retention curves. Multiple Büchner funnels are often used to determine the curve more quickly, which increases the cost of the process.

Oliveira (1968) first proposed building a tension table as an alternative to Büchner funnels, but Stakman, Valk and Van Der Harst (1969) proposed a simpler apparatus, consisting of layers of sand and kaolin, to determine a portion of the water retention curve, especially at high matric potentials. The operating principle of the tension table, similar to that of the Büchner funnel, is based on suction or vacuum, and the table establishes a hydraulic contact between the soil and a porous medium. This medium is composed of very small pores, which maintain a certain soil moisture level until a new suction (or tension) is established (TOWNEND; REEVE; CARTER, 2000). The first simple tension tables were constructed using mineral materials and exhibited a number of problems, such as an inability to prevent air from entering into the system. One solution to this problem arose from experiments using columns consisting of laminated layers of mineral materials such as gravel and sand in addition to blotting paper (which a exhibits bubbling pressure of approximately 70-80 kPa), in which the capillarity is capable of supporting a water column of varying height and exerting tension on the porous material (OLIVEIRA, 1968). At least one version of the tension table based on these principles is currently on the market (ROMANO; SANTINI, 2002).

A version of the tension table employing a porous medium, containing a sandy quartz and granite gravel material with different grain sizes, was proposed by Lima and Silva (2008). In that study, the authors tested the tension table for soils with different textures and organic carbon levels. Due to the easy handling of the sand column, its low cost and its flexibility in the construction, this tension table has been used in determining water retention for modeling applications, including determinations of the least limiting water range (BLAINSKI et al., 2012).

This paper presents a modified and simplified version of the tension table proposed by authors such as Lima and Silva (2008) and Reinert and Reichert (2006), which has been used in soil physics laboratories. The study describes the construction of a tension table built with inexpensive materials and the procedures for determining a number of soil properties. The study also considers the performance and calibration of the equipment, using the Büchner funnel as a standard, to validate its results and draw attention to the usefulness of this apparatus.

The objective of the present study was to demonstrate the procedures for the assembly, calibration and validation of a tension table built with low-cost and easily acquired materials.

2 Materials and Methods

The proposed tension table operates on the same principles as the equipment proposed by Lima and Silva (2008), differing only in the types of materials and assembly procedures (Figures 1a, 1b and 2).

The suction level to which the samples are subjected in the tension table is controlled by moving the U-shaped hose vertically (where the first point lies 20 cm above the bottom of the tray). Mineral materials are used in the tension table to fill the PVC pipe, in comparison to the porous plate of the Büchner funnel.

The tension table was built on a 1.40 m tall wooden base, which held a tray (42.5 cm long, 34.5 cm wide and 16 cm tall) connected to a PVC pipe (120 cm tall and 10 cm diameter) by an escutcheon. The PVC pipe was filled with mineral materials (predominantly quartz) of different particle sizes and granite gravel. Near the base of the pipe (10 cm height), a hose was connected to drain the water from the system. During assembly, it was necessary to compress and saturate the material to prevent air from entering the system, as this would have prevented the flow of water and altered the equipment's operation.

To fill the PVC pipe with mineral materials, it was necessary to work from the bottom up. Therefore, the material with the largest particle size was added first. Gravel type 2 (approximately 12.5 to 25 mm diameter) was placed first, followed by gravel type 1 (approximately 4.8 to 12.5 mm diameter) and gravel type 0 (approximately < 4.9 mm diameter), according to the standards NBR-7211/NBR-7225, in 15 cm layers. Next, a 25 cm layer of coarse sand (1-0.5 mm diameter) was placed, followed by a 30 cm layer of medium sand (0.5-0.25 mm diameter), an 18 cm layer of fine sand (0.25-0.10 mm diameter), and finally a 2 cm layer of very fine sand (0.10-0.05 mm diameter), in the same material used in the sample tray. Blotting paper (50 × 50 cm qualitative filter paper) was placed on top of the very fine sand layer; the paper should be replaced periodically to prevent the accumulation of sample residues. The connection between the mineral material column of the table and the sample holder was sealed

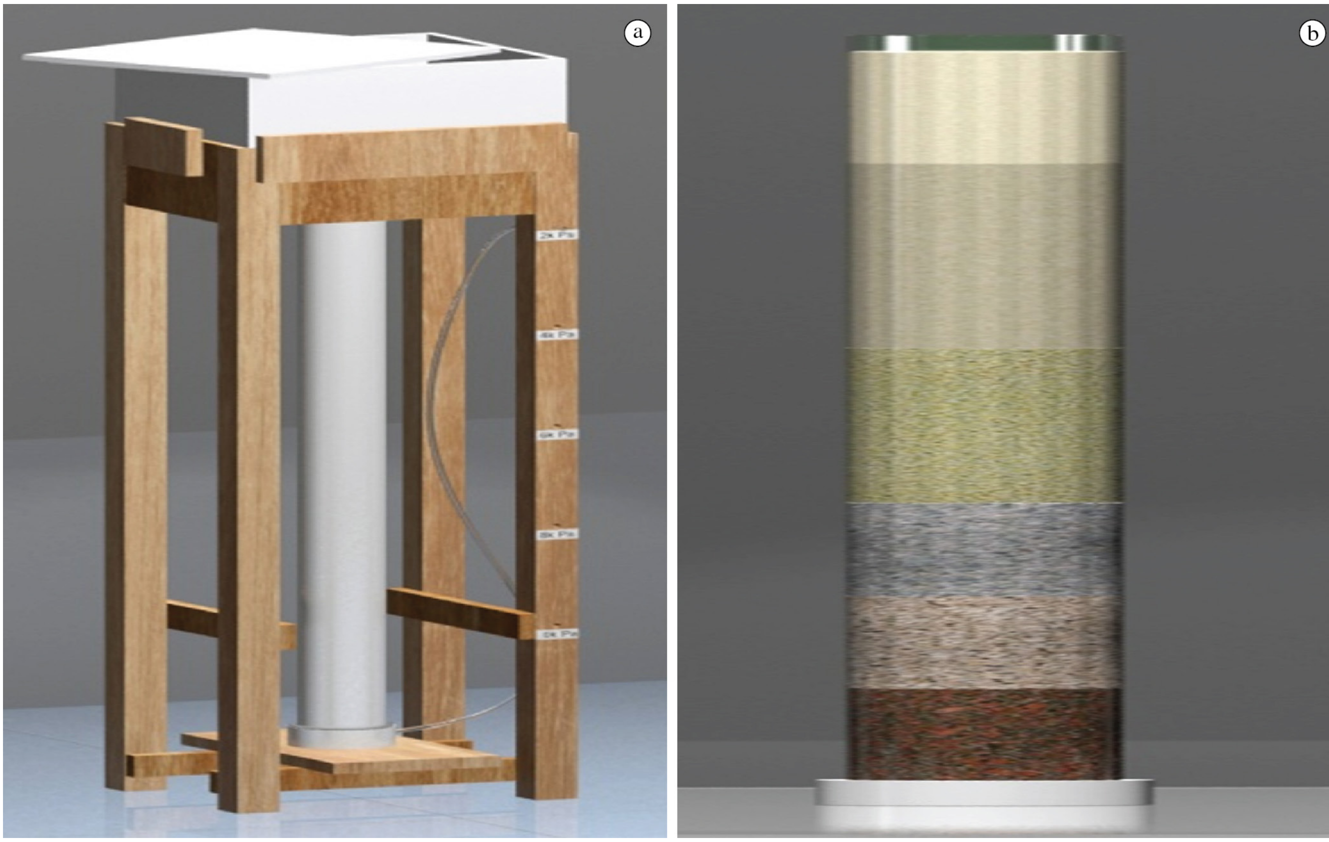

Figure 1. Schematic displaying the components of the tension table, showing the wooden base and PVC pipe in the center of the structure (a). Detail of the mineral material layers inside the PVC pipe (gravel type 2: approximately 12.5 to 25 mm Ø; gravel type 1: approximately 4.8 to 12.5 mm Ø; gravel type 0: approximately < 4.9 mm Ø; coarse sand: 1 to 0.5 mm Ø; medium sand: 0.5 to 0.25 mm Ø; fine sand: 0.25 to 0.10 mm Ø; and very fine sand: 0.10 to 0.05 mm Ø) (b).

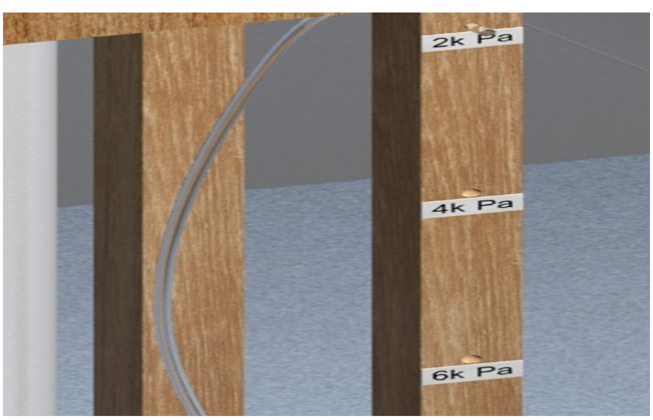

Figure 2. Detail of the allocation positions of the hose to determine the desired tension.

with high-temperature silicone and epoxy resin mixed with a catalyst agent.

The tension table supports the application of matric potentials ranging from 0 to –10 kPa. The table's U-shaped hose sucks out water at a certain rate when opened and allows the water to return to the tension table until an equilibrium is established, at which point it is closed. For the tension table to operate properly, it must be saturated with deaerated water to allow the mineral material particles to settle and to prevent air bubbles from forming (LIMA; SILVA, 2008). The column should be saturated from the bottom up and then drained for better sand settling. After this procedure, the column must be saturated (REINERT; REICHERT, 2006) until it starts to drip, but when very fast drainage is observed, more fine sand should be added to slow down the drainage rate and obtain the desired drip rate.

When not in use, the tension table should be constantly saturated with water in the sample tray, with the U-shaped hose closed, to prevent water from leaving the system. A cover for the sample tray is also necessary to minimize water loss from the system due to evaporation.

The soil samples placed on the tension table must be saturated with water and in direct contact with the porous medium to ensure that the height of the water output from the open U-shaped hose is equal to the desired matric potential. For example, if the hose is open at a height of 20 cm, the samples are subjected to a matric potential of –2 kPa.

For the best tension table performance, the sample tray should be wetted at every change in matric potential so that the system is not adversely affected by the entrance of air.

To test the tension table, the Büchner funnel method was used as a standard or reference. Fourteen undisturbed soil samples, collected in volumetric core samplers (65 × 25 mm) from the Bw horizon of an oxisol located at the Federal University of Lavras (Universidade Federal de Lavras - UFLA) campus, were used in the study. The 14 samples were placed in a tray with deaerated water for gradual saturation until they reached a water depth of two-thirds the height of the volumetric core sampler. Once saturated, seven samples were placed on the tension table, and seven samples were placed in Büchner funnels. For both apparatuses, matric potentials of –2, –4 and –6 kPa were applied. Equilibrium was established in approximately four days, as indicated by the absence of dripping water and the formation of menisci in the drainage pipes, as described by Klute (1986). Next, the samples were weighed to measure the mass of water after draining at each suction applied, then placed in an oven at 105 °C for 24 hours to determine the soil dry weight and water content of the samples. The soil density (Ds), macroporosity (Macro), microporosity (Micro) and total pore volume (TPV) of the soil were measured according to Embrapa (1997), where the water content under saturated conditions was considered as the total porosity. The determination of the soil properties Ds and TPV does not require the use of the tension table or Buchner funnel equipment; however, TPV is required for the calculation of the porosity and microporosity, and the latter may be affected by the equipment used. Thus, TPV and Ds were also analyzed to provide an estimate of the variability among the samples used in each apparatus.

The agreement between the devices was statistically evaluated in two ways. First, the accuracy of the tension table method compared to that of the Büchner funnel method was assessed using the RMSE indicator (root mean square error), the coefficient of determination (R^2), and visual analysis of the 1:1 slope between the methods (LIMA; SILVA, 2008). Second, the variables Ds, TPV, Micro and Macro were subjected to analysis of variance by applying the Scott-Knott test ($p < 0.05$) with the Sisvar software (FERREIRA, 2011) using a completely randomized design (CRD). A double factorial design was adopted, with two methods (Büchner funnel and tension table) and seven replicates. To evaluate the effectiveness of the equipment at each matric potential, a 2 x 3 x 7 factorial design was used, with two apparatuses, three matric potentials (–2, –4 and –6 kPa) and seven replicates.

3 Results and Discussion

The soil physical properties - macroporosity and microporosity - obtained using the tension table did not differ from those determined using the Büchner funnels (Table 1), suggesting that the tension table method is effective in determining these properties.

Authors such as Albuquerque et al. (1995) have found the tension table to be effective for determining the porosity of an oxisol under different soil management systems. Souza et al. (2006) found a positive correlation between the microporosity obtained using a tension table and the porosity results obtained by more sensitive methods, such as micromorphological analysis, and reported that the tension table can be used to study the water retention and porosity of compacted soils at sites cultivated with sugarcane.

The best accuracy for microporosity (water content), or the smallest difference between the Büchner funnel and tension table methods, was found at a potential of –6 kPa , followed by –4 kPa and –2 kPa (Table 2). The accuracy of the tension table, according to the RMSE, for determining the water content at the potentials of –2, –4 and –6 kPa was higher than the accuracy for Ds and TPV (Table 2). Ds and TPV were determined without using the tension table/Büchner funnel, but these properties were determined for the same samples, indicating that the variability between the methods is smaller than the natural variability of the samples for other measurements. The Ds property had the highest RMSE value; however, this value is not significant for the density evaluated for this soil, which has a density of close to 1.20 g cm^{-3} (Table 1).

The RMSE for the macroporosity property is below the error considered significant (±0.05) (Table 2), suggesting accuracy. However, in studies aimed at proper soil management, the RMSE of 0.0306 m^3 m^{-3} determined in this study must be considered, as regardless of the equipment used (Buchner funnel or tension table), macroporosity values were approximately 0.10 m^3 m^{-3} (Table 1) with an error of 0.0306 or less, which may be interpreted as an aeration deficit for the roots (ANDRADE, STONE, 2009).

As seen from the values above the 1:1 slope (Figure 3), the water levels determined by the tension table at potentials of –2, –4 and –6 kPa were overestimated compared to those determined by the Büchner funnel. The samples had greater drainage when they were placed into the Büchner funnel, which is considered the standard method, and thus the tension table had a lower relative efficiency for extracting water. The equation that corrects the data obtained from the tension table, i.e., the calibration equation, is shown in Figure 3 and exhibited high predictive power ($R^2 > 0.80$).

The interaction between the factors equipment and matric potential was not significant (p-value > 0.8195). There was also no significant difference between matric potentials (p-value = 0.0682). A significant difference did exist

Table 1. Soil physical properties evaluated using a tension table and Büchner funnels.

Apparatus	Ds(1)	TPV(2)	Micro(3)	Macro(4)
	g cm^{-3}	m^3 m^{-3}		
Büchner funnel	1.237 a	0.490 a	0.370 a	0.118 a
Tension table	1.147 a	0.534 a	0.414 a	0.122 a
$F_{calculated}$	2.216	0.880	1.703	0.039
Significance (p-value)	0.162	0.366	0.216	0.847
Coef. Variation (%)	9.49	17.24	16.19	33.84

Means followed by the same letter in a column do not significantly differ from each other according to the Scott-Knott test at 5% probability. 1 - soil density; 2 - total pore volume; 3 - microporosity; 4 - macroporosity.

Table 2. Evaluation of the accuracy of the tension table method compared to that of the standard Büchner funnel method in determining soil physicohydric properties.

Property	Ds(1)	TPV(2)	Micro(3)	Macro(4)	–2	–4
	g cm^{-3}	m^3 m^{-3}			kPa	
RMSE*	0.0777	0.0353	0.0116	0.0306	0.0451	0.0221

*RMSE: Root mean square error, values closer to 0 indicate higher accuracy. 1 - soil density; 2 - total pore volume; 3 - microporosity; 4 - macroporosity.

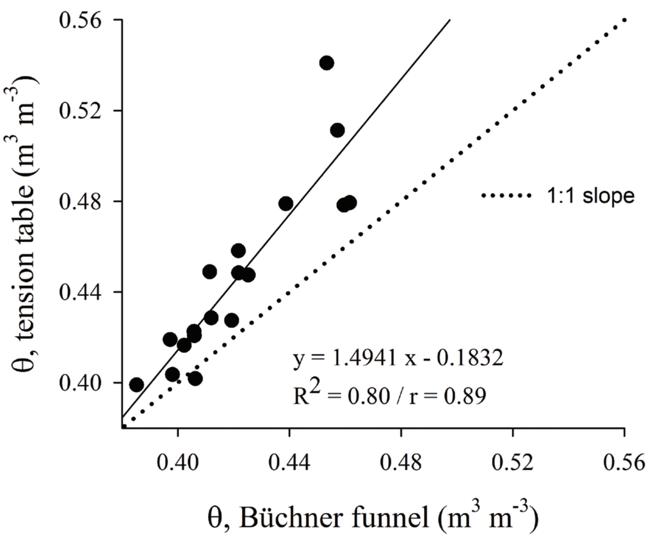

Figure 3. Water content (θ) from soil samples at matric potentials of –2, –4 and –6 kPa using the tension table and Büchner funnel. Sample N = 42.

Table 3. Mean water content determined at potentials of –2, –4 and –6 kPa in the tension table and Büchner funnel.

Apparatus	Soil water content ($m^3\ m^{-3}$)
Büchner funnel	0.388 b
Tension table	0.447 a

Means followed by the same letter in a column do not differ according to the Scott-Knott test at 5% probability.

between the apparatuses (p-value = 0.0058). The tension table overestimated the water levels at the different matric potentials evaluated (Table 3). Considering that more samples were evaluated simultaneously in the tension table, while the Büchner funnel handled fewer samples (and in the case of the volumetric core sampler, only one sample) these results may be associated with the different durations required for the samples to reach equilibrium. Thus, some samples may not have reached equilibrium and lost water via evaporation, while those that reached equilibrium may have absorbed water, resulting in heavier samples.

Moreover, in Richards chambers, where water from the samples and porous plate evaporates and then condenses on the chamber walls due to temperature fluctuations, it may be difficult to identify equilibrium through the visualization of the volume drained (MORAES; LIBARDI; DOURADO NETO, 1993), i.e., by the absence of water drips and menisci formed on the output pipes. The same phenomenon may also occur in the tension table due to water evaporating from the samples and blotting paper, which can condense on the tray walls. To reduce this problem, Moraes, Libardi and Dourado Neto (1993) suggest using moist paper towels, which saturate the environment through evaporation to ensure that there is no water loss due to evaporation from the samples.

The mean water contents at the potentials evaluated (Table 3) and the 1:1 slope between the water levels at the potentials evaluated (Figure 3) indicate that the tension table overestimates the water content. This result could have implications in measuring field capacity, an important property for irrigation management; if this value is overestimated, it may be used to recommend a higher water depth than is desirable. However, Table 2 shows that smaller errors are observed at lower potentials. As field capacity is generally estimated for water content at potentials of –6 or –10 kPa in Brazilian soils, the proposed tension table can provide reasonably accurate estimates of this value at low cost. To improve the accuracy of the results obtained from the tension table, the samples should be arranged in groups based on similarity (e.g., appearance, color) when possible to reduce effects of the factors that affect water retention.

4 Conclusions

This study demonstrates the procedures for building a simplified and low-cost tension table for determining soil water retention at low suction. After comparing the measurements of this table with those taken using a Buchner funnel, the viability the apparatus for determining the soil water content at equilibrium within a range of tensions from 2 to 6 kPa, as well as up to 10 kPa, was confirmed. This apparatus enables the easy determination of porosity and water retention in the range usually associated with field capacity (6 to 10 kPa).

References

ANDRADE, R. S.; STONE, L. F. O índice S como indicador da qualidade física de solos do Cerrado brasileiro. *Revista Brasileira Engenharia Agrícola e Ambiental*, v. 13, p. 382-388, 2009. http://dx.doi.org/10.1590/S1415-43662009000400003

ALBUQUERQUE, J. A.; REINERT, D. J.; FIORIN, J. E.; RUEDELL, J.; PETRRE, C.; FONTINELLI, F. Rotação de culturas e sistemas de manejo: efeito do solo ao final de sete anos. *Revista Brasileira da Ciência do Solo*, v. 19, p. 115-119, 1995.

BLAINSKI, É.; TORMENA, C. A.; GUIMARÃES, R. M. L.; NANNI, M. R. Qualidade física de um latossolo sob plantio direto influenciada pela cobertura do solo. *Revista Brasileira de Ciência do Solo*, v. 36, p. 79-87, 2012. http://dx.doi.org/10.1590/S0100-06832012000100009

DEXTER, A. R.; BIRD, N. R. A. Methods for predicting the optimum and the range of soil water contents for tillage based on the water retention curve. *Soil and Tillage Research*, v. 57, n. 4, p. 203-212, 2001. http://dx.doi.org/10.1016/S0167-1987(00)00154-9

EMBRAPA. *Manual de métodos de análises do solo*. 2. ed. Rio de Janeiro: Ministério da Agricultura e do Abastecimento, 1997. 212 p.

FERREIRA, D. F. SISVAR 5.0. Sisvar: a computer statistical analysis system. *Ciência e Agrotecnologia*, v. 35, n. 6, p. 1039-1042, 2011.

HAINES, W. B. Studies in the physical properties of soil. *Journal of Agricultural Science,* v. 20, p. 97-116, 1930. http://dx.doi.org/10.1017/S002185960008864X

KLUTE, A. Water retention: laboratory methods. In: BLACK, C. A. (Ed.). *Methods of soil analysis. I. Physical and mineralogical methods. Madison: American Society of Agronomy*, Soil Science Society of America, 1986. p. 635-662.

LIMA, H. V.; SILVA, A. P. Mesa de tensão com areia: procedimentos para montagem e validação. *Revista Brasileira de Ciência do Solo*, v. 32, n. 5, p. 2209-2214, 2008. http://dx.doi.org/10.1590/S0100-06832008000500041

MORAES, S. Q.; LIBARDI, P. L.; DOURADO NETO, D. Problemas metodológicos na obtenção da curva de retenção da água pelo solo. *Scientia Agricola*, Piracicaba, v. 50, n. 3, p. 383-392, 1993.

OLIVEIRA, L. B. Determinação da macro e microporosidade pela "mesa de tensão" em amostras de solo com estrutura indeformada. *Pesquisa Agropecuária Brasileira*, v. 3, p. 197-200, 1968.

REINERT, D. J.; REICHERT, J. M. Coluna de areia para medir a retenção de água no solo – protótipos e teste. *Ciência Rural*, v. 36, n. 6, p. 1931-1935, 2006. http://dx.doi.org/10.1590/S0103-84782006000600044

ROMANO, S.; SANTINI, A. Water Retention and Storage. In: DANE, J. H.; TOPP, G. C. (Eds.). *Methods of Soil Analysis*. Madison: Soil Science Society of America, 2002. p. 721-738.

SEVERIANO, E. C.; OLIVEIRA, G. C.; DIAS JÚNIOR, M. S.; COSTA, K. A. P.; SILVA, F. G.; FERREIRA FILHO, S. M. Structural changes in Latosols representative of the Cerrado Region: I - Relationships between soil physical attributes and least limiting water range. *Revista Brasileira de Ciência do Solo*, v. 35, p. 773-782, 2011. http://dx.doi.org/10.1590/S0100-06832011000300013

SOUZA, Z. M.; MARQUES JÚNIOR, J.; COOPER, M.; PEREIRA, G. T. Micromorfologia do solo e sua relação com atributos físicos e hídricos. *Pesquisa Agropecuária Brasileira*, v. 41, n. 3, p. 487-492, 2006. http://dx.doi.org/10.1590/S0100-204X2006000300016

STAKMAN, W. P.; VALK, G. A.; VAN DER HARST, G.G. *Determination of moisture retention curves. I. Sandbox apparatus, range pF 0 and 2.7* . 3rd ed. Wageningen: Institute for Land and Water Management Research, 1969.

TOWNEND, J.; REEVE, M. J.; CARTER, A. Water release characteristic In: SMITH, K. A. (Ed.). *Soil and environmental analysis: Physical methods*. 2nd ed. New York: Marcel Dekker Incorporated, 2000. p. 95-140. http://dx.doi.org/10.1201/9780203908600.ch3