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AVAILABLE SOIL WATER UPPER LIMIT BY MODELING AND DIRECT DETERMINATION IN A GREENHOUSE

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ABSTRACT - Pot capacity (PC) is a direct method of determining field capacity (FC) for experiments with plantings in pots. The objective of this study was to evaluate different laboratory methods to determine field capacity and compare them with the pot capacity method. The experimental design was completely randomized (CRD), with nine treatments (methods of obtaining FC) and four replications, totaling 36 experimental plots. The mean values of moisture contents in the FC of the nine methods were compared, being eight empirically obtained and one directly in the greenhouse, defined as a control treatment (PC). The relative accuracy (RA) for all treatments was determined in relation to the control treatment. The estimation of the upper limit of available water in the soil varies depending on the method, and a decreasing order of moisture levels can be observed at FC: FC-Lab4pts > FC-Labip > FC-Lab8pts > PC > FC-Lab6pts > FC-6KPa > FC-LabSWRC > FC-10KPa > FC-33KPa. The treatment FC-Lab6pts has the relative accuracy closest to 100% and can be a practical alternative to PC. The use of 4, 6, 8 or 10 points for modeling the SWRC does not interfere with the quality of the FC estimated by the Dexter inflection point method, which is much more efficient for experiments of this nature. The use of potentials -10 kPa and -33 kPa is not adequate to estimate FC in tests with pots in a greenhouse.
Keywords: pot capacity, soil water retention curve, inflection point.

LIMITE SUPERIOR DE ÁGUA DISPONÍVEL NO SOLO POR MODELAGEM E DETERMINAÇÃO DIRETA EM CASA DE VEGETAÇÃO

RESUMO - A capacidade de pote (CP) é um método direto de determinação da capacidade de campo (CC) para experimentos com plantios em vasos. O objetivo deste trabalho foi avaliar diferentes métodos laboratoriais de determinação da capacidade de campo e compará-los com o método da capacidade de pote. O delineamento experimental utilizado foi o inteiramente casualizado (DIC), com nove tratamentos (métodos de obtenção de CC) e quatro repetições, totalizando 36 parcelas experimentais. Foram comparados as médias dos teores de umidade na CC dos nove métodos, sendo oito obtidos empiricamente e um diretamente em casa de vegetação, sendo este definido como tratamento controle (CP). Determinou-se a exatidão relativa (ER) para todos os tratamentos em relação ao tratamento controle. A estimativa da capacidade de campo varia dependendo do método, observando uma ordem decrescente de níveis de umidade na CC: CC-Lab4pts > CC-Labpi > CC-Lab8pts > CP > CC-Lab6pts > CC-6KPa > CC-LabCRA > CC-10KPa > CC-33KPa. O tratamento CC-Lab6pts tem a exatidão relativa mais próxima de 100% e pode ser uma alternativa prática à CP. A utilização de 4, 6, 8 ou 10 pontos para modelagem da CRA não interfere na qualidade da CC estimada pelo método do ponto de inflexão de Dexter, este bem mais eficiente para experimentos desta natureza. O emprego dos potenciais de -10 kPa e -33 kPa não é adequado para estimar a CC em ensaios com vasos em casa de vegetação.
Palavras-chave: capacidade de pote, curva de retenção de água no solo, ponto de inflexão.

INTRODUCTION

In pot crops, seedling nurseries and greenhouse experiments, there is a need to know an upper limit of water availability in the soil, to guide water management. In the field, this limit is conceptualized as field capacity (FC) which, despite physical limitations, has an important practical role (REICHARDT, 1988; SILVA et al., 2014).

Methodologies for estimating FC in the laboratory

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have been adopted for Cerrado conditions, based on the soil water retention curve (SWRC) (ANDRADE and STONE, 2011), at the SWRC at inflection point (DEXTER, 2004; SILVA et al., 2014), and propositions for pot experiments (CASAROLI and VAN LIER, 2008).

However, for greenhouse agricultural enterprises that require the determination of FC in vessels or pots, there are few materials available in the literature. Through the methodology proposed by Souza et al. (2000), one of the pioneers in Brazil, frequently called pot capacity (PC), it is possible to obtain the upper limit of water available in the soil for plants in experiments conducted in pots, that is, it can be considered a direct method for the determination of FC.

Most studies related to soil water management consider values of water content retained at potentials of 33 kPa for clay soils and 10 kPa for sandy soils, as an estimate of FC. These values are obtained in the laboratory, according to Richards (1947). However, some methodologies (DEXTER, 2004; ANDRADE and STONE, 2011; SILVA et al., 2014) confirmed that these potentials may not satisfactorily estimate WC.

In addition, some differences have been observed among the different laboratory methods for determining FC, when compared with the direct method in the field, reference of accuracy, according to Reichardt (1988). Unlike the permanent wilting point (PWP), in which changes in the potential result in small changes in the associated moisture, field capacity is considered dynamic (SOUZA and REICHARDT, 1996), a fact that interferes with its analysis and the reliability of the obtained values.

Taking into account the probable variations in soil moisture when it is found at FC, according to the determination method, the upper limit of available water in the soil will be changed, with reflections in the calculations of water levels for irrigation management and in the possible deficit of potential crop yield. In view of the above, the objective of this study was to evaluate different laboratory methods for determining the upper limit of water availability in the soil and compare them with the direct method for determining pot capacity (PC).

MATERIAL AND METHODS

Treatments and sampling

The experiment was conducted in a greenhouse, belonging to the Post-graduation Program in Agricultural Sciences (PPGCA) of Universidade Federal de São João Del Rei (UFSJ), Sete Lagoas *Campus* (CSL), Minas Gerais State, Brazil. In this local was controlled temperature and moisture, for the obtaining of pot capacity (PC) and in the Soil Physics Laboratory of CSL, for the indirect determination of FC, through a Richards extractor and modeling in a specific software for building a soil water retention curve (SWRC). An Oxisol, a pedological unit representative of the Cerrado region, where the municipality of Sete Lagoas (MG) is inserted, was used in all treatments, with a very clay texture (14% sand, 16% silt and 70% clay), collected at a depth of 0-20 cm, from the CSL (Table 1).

TABLE 1 - Physical analysis of the soil collected in the Cerrado area, in the municipality of Sete Lagoas (MG), used for the obtaining of pot capacity (PC).

Soil density (g cm^{-3})	TP* (m^3 m^{-3})	Granulometric composition			Textural classification
		Sand (g kg^{-1})	Silt (g kg^{-1})	Clay (g kg^{-1})	
1.03	0.677	140	160	700	Very clayey
Moisture (g g^{-1})		Ψmpi* (kPa)			AWCip* (m^3 m^{-3})
Soil Initial	PWP	3.80			0.257
0.324	0.258				

*TP = total porosity, PWP = permanent wilting point estimated at -1500 kPa, Ψmpi = matrix potential at the inflection point, AWCpi = available water capacity between FC-Labip and PWP.

Each treatment corresponded to a method for obtaining FC, one directly in the greenhouse and eight carried out in the laboratory, where:

PC = pot capacity, obtained directly in pots filled with 3.5 kg of soil,

FC-Labip = estimated in the laboratory by the inflection point (ip) of the SWRC (DEXTER, 2004), adopting water content (U) at FC (g g^{-1}),

FC-Lab8pts = estimated by the ip of the SWRC, modeled with eight points of the curve (saturation = -4; -6; -10; -33; -100; -500 and -1500 kPa),

FC-Lab6pts = estimated by the ip of the SWRC, modeled with six points of the curve (saturation = -4; -6; -10; -33 and -1500 kPa),

FC-Lab4pts = estimated by the ip of the SWRC, modeled with four points of the curve (saturation = -6; -33 and -1500 kPa),

FC-LabSWRC = FC estimated by the SWRC in the laboratory (ANDRADE and Stone, 2011),

FC-6kPa, FC-10kPa and FC-33kPa = determined in the laboratory by the water content retained, at their respective potentials.

PC was determined according to the method proposed by Souza et al. (2000), adopted with the water content retained by the soil after suffering saturation and consequent gravity action, until the visual cessation of drainage. Four pots containing 3.5 kg of the soil mentioned above were used for the determination of PC, using Equation 1:

$$FM_{pc} = DM \times (1 + M_{PC}) \text{ (Equation 1)},$$

Where:

FM_{PC} = fresh matter (kg), at pot capacity, obtained by the average weight of four pots (SOUZA et al., 2000),

DM = dry matter (kg), determined for the pots (N = 4) and

M_{PC} = soil moisture (g g^{-1}), at pot capacity, obtained in the laboratory, by the standard greenhouse method (EMBRAPA/CNPS, 2011).

After estimating the dry matter and, with the moisture value obtained, the weight of each pot (FM_{PC}) was defined.

For the determination of M_{PC}, 24 samples were collected from the four pots used to obtain PC. In each pot, three subsurface samples and three samples were collected in the deepest region of the pot, around 50 g of soil/sample. Subsequently, 10 g of each sample were weighed and dried in a drying and sterilization oven at 105ºC, until reaching constant weight (EMBRAPA/CNPS, 2011).

The treatment FC-Labip was obtained at the Soil Physics Laboratory (CSL), using an automated tension table (Ecotech®, up to 75 kPa tension) and medium- and high-pressure Richards extractor, containing the samples taken from the same soil used in PC pots; 25 g of each of the four soil samples with a deformed structure were weighed in a PVC ring assembly (25 mm high), mesh and rubber gum. After this procedure, the samples were placed in a tray and saturated by capillarity (gradual elevation of the water level) with distilled water for 24 hours, until saturation was reached.

Subsequently, the samples were weighed to estimate the saturation moisture and taken for the determination of the equilibrium water at potentials (Ψ): -4, -6, -8, -10, -33, -100, -300, -500 and -1500 kPa (KLUTE, 1986). After the last potential, the four samples were dried in a drying oven at 105ºC, to quantify the water content (U), associated with each Ψ for the obtaining of the SWRC.

The SWRC was modeled using the van Genuchten (1980) model, with Mualem restriction [m = 1- (1/n)], using the RETC software (VAN GENUCHTEN et al., 1991), and then elaborated in an Excel spreadsheet. At the inflection point of the modeled curve, U (g g^{-1}) was obtained, which was used as the water content at FC for the treatment FC-Labip, determined according to Dexter (2004) and Silva et al. (2014).

For the treatments FC-Lab8pts, FC-Lab6pts and FC-Lab4pts, the same procedures as those of FC-Labip were adopted, using the number of SWRC points, respective for each treatment. For the treatment FC-LabSWRC, the same potentials as those of treatment CC-Labpi were adopted. However, U (g g^{-1}) was determined according to Andrade and Stone (2011), with no need for modeling the SWRC for this treatment.

At potentials -6; -10 and -33 kPa, the retained water contents were recorded as the U values at FC, for the last three treatments (FC-6 kPa, FC-10 kPa and FC-33 kPa), respectively. The treatment PC was defined as a control, to enable the calculation of relative accuracy (RA), in percentage (%), in relation to the other treatments.

Statistical analysis

The experimental design was completely randomized (CRD), with nine treatments and four replications, totaling 36 sample units (N = 36). To assess the effect of treatments, analysis of variance (ANOVA) was performed and the means were compared by the Tukey test, at 5% probability, using the R software, ExpDes package (FERREIRA et al., 2014).

RESULTS AND DISCUSSION

The water retention curves for the treatments modeled according to Dexter (2004), are presented in Figure 1, showing the efficiency of this empirical method with the use of fewer points (matrix potentials) on the curve (data in hPa or cm), or with all possible points, as done in treatment FC-Labip. In addition, it was observed that the four treatments adjusted their observed points (matrix potentials) equally to the modeled SWRC. The same behavior was observed by Silva et al. (2014) in similar treatments after adjusting them to the retention curve.

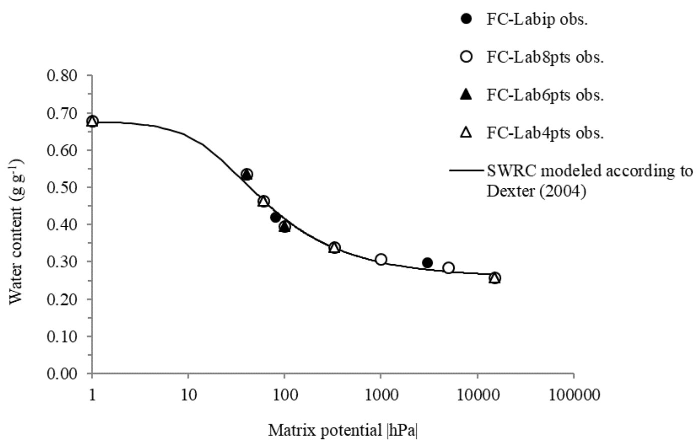

FIGURE 1 - Soil water retention curve (SWRC) in the soil of Cerrado, municipality of Sete Lagoas (Minas Gerais State, Brazil) according to the inflection point model proposed by Dexter (2004) and adjustments of the determined points (obs = observed data) for each treatment to obtain the field capacity (FC) that used the aforementioned model.

Table 2 shows the average water content values (g g^{-1}) for the nine FC determination methods and the relative accuracy (RA) values for each method in relation to the direct FC determination method, the standard PC treatment, defined as a control in this study. Accuracy values are relative, thus representing the percentage of U (g g^{-1}) at FC in relation to the value of Ucc = 0.510 g g^{-1}, corresponding to the control treatment.

In this study, five treatments showed statistically equal mean Ucc values, four of which were obtained in the laboratory with later modeling, adopting the inflection point as the moisture value at FC (Table 2). This proves that the model proposed by Dexter (2004) is robust enough to estimate moisture at FC using only four points in the SWRC in the soil (Figure 1). However, the treatment FC-Lab6pts yielded the RA closest to the PC treatment, with 0.39% less accuracy (Table 2).

TABLE 2 - Mean values of water content (U_{FC}), relative accuracy (RA) and matrix potential at field capacity (Ψ_{FC}) for the different methods for determining field capacity (FC).

Treatments	U_{FC} (g g^{-1})	RA (%)	Ψ_{FC} (kPa)
FC-Lab4pts	0.516 a*	101.18	-3.8
FC-Labip	0.515 a	100.98	-3.8
FC-Lab8pts	0.513 a	100.59	-4.2
PC	0.510 a	100.00	-4.0
FC-Lab6pts	0.508 a	99.61	-4.5
FC-6kPa	0.464 b	90.98	-6.0
FC-LabSWRC	0.447 b	87.65	-7.7
FC-10kPa	0.396 c	77.65	-10.0
FC-33kPa	0.340 d	66.67	-33.0
CV (%)	1.86		

*Means followed by the same letter in the column do not differ, according to the Tukey test, at 5% probability.

The result obtained for treatment FC-Lab4pts will allow to reduce the analysis time of the soil samples in the Richards extractor, increase the efficiency of laboratory work and speed up the modeling of the SWRC (Figure 1). Besides, all treatments that used the inflection point methodology (DEXTER, 2004) can be an alternative to the PC method, which requires pots and a considerable amount of soil to obtain them. Therefore, when dealing with a large scale seedling or flower production company, in a greenhouse, with the need for good precision and the shortest possible time to define FC, treatment FC-Lab4pts can be a practical and efficient alternative for the producer or entrepreneur.

According to Andrade and Stone (2011), in a study using 2242 Cerrado soil samples, by modeling from information on water retention in the soil and considering the drainage rate equivalent to 1% of the value of the saturated hydraulic conductivity of the soil, a potential for FC between -6.5 and -7.5 kPa was obtained. For this study, a potential value at FC was found to be higher than that in the interval predicted by the model of the authors mentioned (Table 2). The RA value for treatment FC-LabSWRC showed a moisture deficit at FC or a reduction in the potential yield of a hypothetical culture, in the amount of 12.35%, compared to the control treatment. In this context, for experiments conducted in pots, the model of Andrade and Stone (2011) showed less accuracy, with an underestimation of FC.

In a study using the potentials of -6 kPa, -10 kPa, -33 kPa and the inflection point to determine the U_{FC}, Silva et al. (2014) obtained the worst results at potentials of 10 and 33 KPa in relation to the ip of the SWRC, with Ψpi = 4.015 kPa, at a depth of 0.20 m of an Oxisol. In addition, depending on the method chosen to estimate FC, there was a 336% variation in available water capacity (AWC).

Therefore, it is not recommended to estimate pot capacity, equivalent to FC for pot cultures, based on “traditional” matrix potential values (-10 or -33 kPa), as the values obtained are overestimated and correspond to high reduction rates in water content (> 1% per day) (CASAROLI; VAN LIER, 2008). The conclusions obtained by the authors mentioned above confirm the results of this study, regarding the inappropriate use of the potentials of -10 kPa and -33 kPa to estimate FC (Table 2).

Based on these results, we can encourage the use of only eight or six points in the obtaining of the SWRC and compare it to the direct determination method (PC). The results obtained in this study and confirmed by Silva et al. (2014) will be extremely useful for agricultural enterprises that aim to manage the amount of irrigation needed for developing seedlings and/or plants.

CONCLUSIONS

The estimation of field capacity varies as a function of the method, and a decreasing order of moisture levels can be observed at FC: FC-Lab4pts > FC-Labip > FC-Lab8pts > PC > FC-Lab6pts > FC-6KPa > FC-LabSWRC > FC-10KPa > FC-33KPa.

The treatment FC-Lab6pts has the relative accuracy closest to 100% and can be a practical alternative to PC.

The use of 4, 6, 8 or 10 points for modeling the SWRC does not interfere with the quality of the FC estimated by the Dexter inflection point method (2004), which is much more efficient for experiments of this nature.

The use of potentials -10 kPa and -33 kPa is not adequate to estimate FC in tests with pots in a greenhouse.

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