SCAP
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Study of the influence of the standing time in the electrical conductivity of the saturated soil paste in three soils

Análise da influência do tempo de repouso na condutividade elétrica da pasta saturada de três solos

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ABSTRACT

The electrical conductivity of the saturated soil paste extract (EC_e) is a reference measurement for soil salinity because it allows comparison among soils regardless of the water content under field conditions. The saturated soil paste is obtained by saturating a soil sample with deionized water, according to a method published about seven decades ago that has been recently updated with the inclusion of an extra standing time of 24 hours. This study analyses the influence of three standing times in the determination of EC_e, the saturation percentage (*SP*), and the electrical conductivity of the soil solution (EC_{sw}), in three soils with different textures (sand, loam, and silty clay). The results show highly significant differences in EC_e and significant differences in EC_{sw} in the sandy soil, when including a standing time of 2 hours compared to no standing time. No significant differences were found when including an additional standing time of 24 hours.

Keywords: saturated soil paste, soil salinity, electrical conductivity, saturation percentage.

RESUMO

A condutividade elétrica do extrato pasta saturada do solo (EC_e) é amplamente usada como medida de referência para a salinidade do solo, pois permite a comparação da salinidade entre solos independentemente de seu teor de água em condições de campo. Ao mesmo tempo, a EC_e é mais comparável com condutividade da solução do solo (EC_{sw}) do que a dos extratos de outras razões solo-água (1:1, 1:2 ou 1:5). A pasta saturada do solo é obtida através da saturação de uma amostra de solo com água desionizada, segundo um método publicado há cerca de sete décadas, e que foi recentemente atualizado com a inclusão um tempo de repouso de 24 horas. O presente estudo analisa a influência de três diferentes tempos de repouso na obtenção da pasta saturada de solo e sua influência na EC_e, percentagem de saturação (*SP*) e EC_{sw} em três solos com diferentes texturas (arenoso, franco e argilo-limoso) Os resultados mostram diferenças altamente significativas na EC_e e diferenças significativas na EC_{sw}, apenas no caso do solo arenoso, quando se inclui um tempo de repouso de 2 horas face à ausência de tempo de repouso.

Palavras-chave: pasta saturada do solo, salinidade do solo, condutividade elétrica, percentagem de saturação

INTRODUCTION

Soil salinity is an important factor in productivity loss of agricultural soils and land degradation. The electrical conductivity of the saturated soil paste extract (EC_e) is widely used as a reference measurement for soil salinity. The soil is generally considered to be saline when EC_e is above 4 dSm^{-1}, a threshold initially defined by Richards (1954). Sensitive crops can start having growth limitations for EC_e above 1.5 dSm^{-1}, while highly tolerant plants grow well until EC_e of about 12 dSm^{-1} (Weil & Brady, 2017). EC_e is an advantageous measurement because it allows comparison among soil samples regardless of their water content under field conditions. EC_e is also widely used as a reference because it is more comparable to the electrical conductivity of the soil solution (EC_{sw}) than the electrical conductivity measured in aqueous extracts obtained from soil-water ratios such as 1:1, 1:2, and 1:5. EC_e is measured in the aqueous extract from the saturated soil paste which is also used for determination of the concentrations of dissolved salts in the soil and to determine the Sodium Adsorption Ratio (SAR) (Paz *et al*., 2023).

The method for obtaining the saturated soil paste has been initially published by Richards (1954), and consists of adding distilled water to a soil sample while stirring with a spatula, until obtaining a paste that 1) "glistens as it reflects light", 2) "flows slightly when the container is tipped", and 3) "slides freely and cleanly off the spatula for all soils but those with a high clay content".

The protocol includes a standing time of "one hour or more" before rechecking the three criteria for saturation. After the standing time, more water can be added if the paste stiffens or loses glisten or more soil can be added if there is free water at the soil surface. The method for preparation of the saturated soil paste has been recently updated by FAO (2021), which added another standing time of 24 hours and a further checking of the saturation criteria, but without providing support data regarding the relevance of this additional standing time.

The gravimetric water content of the saturated soil paste is called the saturation percentage (*SP*), which can be used to calculate EC_{sw} according to the following equation, where θ is the gravimetric water content of the soil (Rhoades *et al*., 1989):

$$EC_{sw} = EC_e \frac{SP}{\theta} \; [\mathrm{dSm^{-1}}] \qquad \text{eq. (1)}$$

This study aimed to analyse the influence of the standing time used for the preparation of the saturation soil paste in the determination of EC_e, *SP*, and EC_{sw}. Considering that the soil solids determine the release of ions to the soil solution, the impact of the standing time might be related to the soil's particle size distribution (Weil & Brady, 2017; Sparks *et al*., 2024). As a result, the analysis was carried out by preparing the saturation soil paste in three soils with different textural classes and using three different standing times.

MATERIAL AND METHODS

Soil samples

Soil samples from three soils with different textural classes, were collected at three locations in Portugal (Alenquer, Torres Vedras, and Lezíria Grande de Vila Franca de Xira), at a depth of 0-20 cm. The particle size distribution was determined using the pipette method and the Atterberg scale and the soil organic carbon was determined using the Walkey-Black method. Table 1 shows the soil textural class according to the diagram by (Gomes & Antunes, 1962), the particle size distribution, soil organic carbon and the corresponding organic matter, using the van Bemmelen factor. The studied soils are classified as sand, loam, and silty clay and have a medium level of organic matter in the case of the sand and silty clay, and a low level of organic matter in the case of the loam.

Table 1 - Characterization of the three studied soils

Soil textural class	Coarse sand [%] (200-2000 μm)	Fine sand [%] (20-200 μm)	Silt [%] (2-20 μm)	Clay [%] (<2 μm)	Soil organic carbon [%]	Organic matter [%]
Sand	66.4	26.6	3.0	4.0	1.03	1.8
Loam	15.7	38.6	20.4	25.2	0.61	1.1
Silty Clay	1.3	5.7	43.1	49.9	1.32	2.3

Preparation of the saturated soil paste

Soil samples were air-dried, ground, and homogenized through a 2 mm sieve. A mass of 300 g of air-dried fine earth was initially used for the preparation of the pastes. Three replicates were performed for each soil and treatment. Deionised water was added to the soil samples, while stirring with a spatula, until the three criteria for definition of the endpoint of the saturation paste were met. The amount of water added was decided independently for each replicate and was carried out always by the same operator. The rechecking of the criteria after the standing times may result in the addition of water or soil, as described in the introduction. When the endpoint of the saturated soil paste was reached, the mass was registered and the paste was placed in a Büchner funnel to which a negative pressure was applied, in order to collect the aqueous extract. This study carried out three treatments considering different standing times to define the endpoint of the saturated soil paste:

- Treatment I – the saturated soil paste is directly placed in the Büchner funnel for extracting the extract;
- Treatment II – the saturated soil paste stands for 2 hours after which the saturation criteria were rechecked and more deionised water or soil were added;
- Treatment III - the saturated soil paste stands for 2 hours after which the saturation criteria were rechecked and more deionised water or soil were added, followed by an additional standing time of 24 h after which the criteria were again confirmed and again corrected, if needed.

EC_e was measured in the aqueous extract of the saturation soil paste with a conductivity meter (WTW 1C20-0211 inoLab), which performs a temperature correction for obtaining the electrical conductivity to 25°C. EC_e was measured simultaneously, at the same room temperature, for all the treatments within the same soil. *SP* was calculated considering the added water and the water already present in the air-dried soil, according to the following equation, where M_{soil} is the mass of air-dried soil, M_{paste} is the mass of the saturated soil paste, and θ is the gravimetric water content of the air-dried soil in %:

$$SP = \frac{M_{paste} - M_{soil}\left(\frac{100}{100+\theta}\right)}{M_{soil}\left(\frac{100}{100+\theta}\right)} \cdot 100\ [\%] \quad \text{eq. (2)}$$

Statistical analysis

The analysis of variance was used to study the results for the determination of EC_e, *SP*, and EC_{sw}. In this analysis the variance between results obtained with the three treatments was compared to the variance within each treatment (F-test). It was tested if the differences between the treatments were statically significant at different significance levels.

RESULTS AND DISCUSSION

Rechecking of the saturation criteria

In treatments II and III the saturation criteria were checked after each standing time. Table 2 shows the mass of added water or soil for each replicate.

Table 2 - Addition of deionised water (w) [g] or soil (s) [g] after each standing time in treatments II and III

Treatment II	After 2 h					
	Rep. 1	Rep. 2	Rep. 3			
Sand	9.9 (s)					
Loam						
Silty Clay	10.3 (w)	11.0 (w)	8.9 (w)			
Treatment III	**After 2 h**			**After 24 h**		
Soil	**Rep. 1**	**Rep. 2**	**Rep. 3**	**Rep. 1**	**Rep. 2**	**Rep. 3**
Sand				10.3 (w)	6.8 (w)	7.4 (w)
Loam				16.2 (w)	20.1 (w)	22.0 (w)
Silty clay	15.3 (w)	9.7 (w)	7.8 (w)	6.8 (w)	11.6 (w)	11.5 (w)

After standing times of 2 hours, there was the need to add soil in one replicate of sand and to add deionised water in all replicates of silty clay. After the standing time of 24 hours, there was the need to add deionised water in the replicates of all the soils.

EC_e and SP obtained with the different treatments

Table 3 shows the mean and standard deviation of the three replicates for each treatment and soil. Table 3 shows that even if more water was added to silty clay in Treatments II and III and to all the soils in Treatment III (Table 2), it did not necessarily lead to higher *SP* mean in these treatments when compared to Treatment I. This was likely because the amounts of added water were similar to the evaporation that occurred during the corresponding standing time. The addition of soil to one replicate of sand in Treatment II, did not increase the standard deviation. This can indicate that the addition of soil contributed to a good repeatability in EC_e determination. Table 3 shows that there was no clear trend in either EC_e or *SP* with increasing standing times. Furthermore, there was no consistent variation between the mean of EC_e and the mean of *SP*, although it could be initially expected that higher *SP* could result in lower EC_e, due to a dilution effect. Table 3 also shows that there was a decrease in the standard deviation of EC_e from treatment I to III, which could indicate a higher repeatability of results in Treatments II and III. Considering *SP*, it was not possible to identify such trend in the standard deviation, which decreased for sand but increased for the other soils.

Figures 1 and 2 show the measured EC_e and *SP* and the mean of the three replicates for each treatment and soil. For EC_e, the analysis of variance showed that there were significant differences between treatments I and III ($p<0.05$) and highly significant differences between treatments I and II ($p<0.01$), in the case of the sandy soil. Considering the *SP*, statistically significant differences occurred between treatments I and II in the sandy soil and between treatments I and III ($p<0.01$) and treatments II and III ($p<0.05$) in the silty clay.

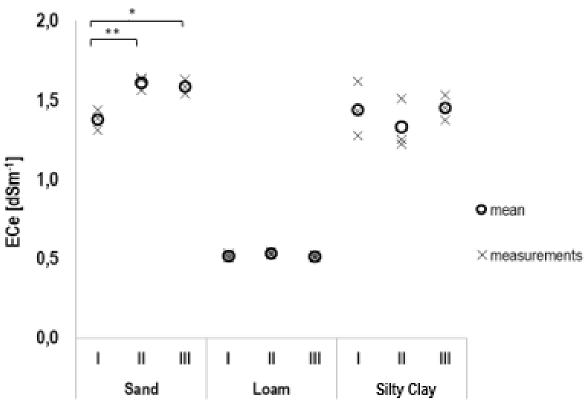

Figure 1 - Measured EC_e and mean for each treatment (I, II, and III) and soil (sand, loam, and silty clay). Statistically significant differences between groups are identified with * for $p< 0.05$ or ** for $p<0.01$, lower ***p-value*** means a higher statistical significance.

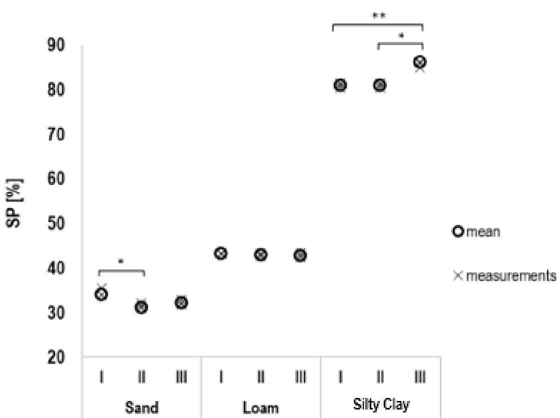

Figure 2 - Measured ***SP*** and mean for each treatment (I, II, and III) and the three soils (sand, loam, and silty clay). Statistically significant differences between groups are identified with * for $p< 0.05$ or ** for $p<0.01$, lower ***p-value*** means a higher statistical significance.

Table 3 - Mean and standard deviation for EC_e and ***SP*** for each treatment and soil

Treatment	Sand				Loam				Silty clay			
	EC_e [dSm^{-1}]		SP [%]		EC_e [dSm^{-1}]		SP [%]		EC_e [dSm^{-1}]		SP [%]	
	mean	StDev	mean	StDev	mean	StDev	mean	StDev	mean	StDev	mean	StDev
I	1.4	0.07	34.0	1.32	0.5	0.01	43.1	0.19	1.4	0.17	80.9	0.52
II	1.6	0.04	31.1	1.13	0.5	0.01	42.9	0.33	1.3	0.16	80.9	0.52
III	1.6	0.05	32.1	0.66	0.5	0.01	42.8	0.53	1.4	0.08	86.2	1.49

Differences in the *SP* of the replicates can determine differences in EC_e, because a higher *SP* might contribute to a dilution of the ions in the extract. In order to verify the significance of the results considering the influence of *SP* in EC_e, EC_{sw} was determined according to equation (1), assuming a hypothetical value of θ = 20%. EC_{sw} is also an important variable as it is mostly used for modelling the water and solute transport in soils.

Figure 3 shows the calculated EC_{sw} and the mean for each treatment and soil. The figure shows that there were significant differences between treatment I and treatment II, and between treatment I and treatment III for the sandy soil. This was also the case for of EC_e (Figure 2), but the significant level between treatment I and treatment II decreased in the case of EC_{sw}

The significant differences in EC_e and EC_{sw} in the case of sandy soil were rather surprising as it was initially expected that increased standing times could have a larger impact on the saturated soil paste of heavier textures. Although, the results could be partly explained by the relatively high EC_e of the sandy soil (Table 3) and its relatively appreciable level of organic matter (Table 1).

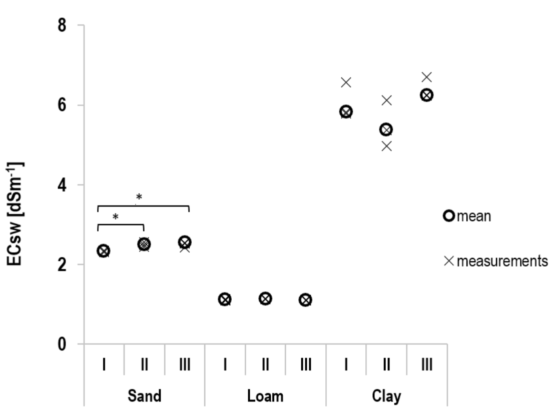

Figure 3 - ***EC_{sw}*** calculated from measurements and mean of ***EC_e***, considering a hypothetical θ_w of 20%, for each treatment (I, II, and III) and soil (sand, loam, and silty clay). Statistically significant differences between groups are identified with * for p< 0.05 or ** for p<0.01, lower ***p-value*** means a higher statistical significance.

CONCLUSIONS

Considering the determination of EC_e, the results obtained with the three studied soils indicate that:

- there was a highly significant difference of a standing time of 2 hours (treatment II) compared to no standing time (treatment I) in the case of the sandy soil.
- there was no significant influence of an additional standing time of 24 hours (treatment III).
- The standard deviation of EC_e replicates decreases from Treatment I to Treatment III, which can indicate a that the standing times and rechecking of the saturation criteria, can result in higher repeatability.

Considering *SP*:

- there were significant differences between treatments I and II for sand. In the case of silty clay there were highly significant differences and between treatments I and III and significant differences between treatments II and III.
- using *SP* and EC_e to calculate EC_{sw}, the differences were significant between I and II between I and III, only for the sandy soil.

The results obtained with the three studied soils indicate the importance of including a standing of 2 hours in the method for obtaining of the extract from the saturated soil paste, due to highly significant differences in EC_e and to significant differences in EC_{sw} only in the case of the sandy soil. No significant differences were found from including an additional standing time of 24 hours.

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DATA AVAILABILITY

The data that support the findings of this study are openly available in Zenodo at https://doi.org/10.5281/zenodo.10352934 (Antunes & Paz, 2023).

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