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Comparison of Soil EC Values from Methods Based on 1:1 and 1:5 Soil to Water Ratios and EC_e from Saturated Paste Extract Based Method

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Abstract: The present study investigates the effect of three different methods of obtaining 1:1 and 1:5 soil-over-water mass ratios (soil:water) extracts for soil electrical conductivity (EC) measurements ($EC_{1:1}$, $EC_{1:5}$). On the same soil samples, also the electrical conductivity of the saturated paste extract (EC_e) was determined and the relationships between EC_e and each of the three of $EC_{1:1}$ and $EC_{1:5}$ values were examined. The soil samples used were collected from three areas over Greece (Laconia, Argolida and Kos) and had EC_e values ranging from 0.611 to 25.9 dS m^{-1}. From the results, it was shown that for soils with $EC_e < 3$ dS m^{-1} the higher EC values were obtained by the method where the suspension remained at rest for 23 hours and then shaken mechanically for 1 h. On the contrary, no differences were observed among the three methods for soils with $EC_e > 3$ dS m^{-1}. Also, in the case of $EC_{1:5}$, the optimal times for equilibration were much longer when $EC_e < 3$ dS m^{-1}. Across all soils, the relationships between EC_e and each of three methods of obtaining $EC_{1:1}$ and $EC_{1:5}$ were strongly linear ($0.953 < R^2 < 0.991$ and $0.63 < \text{RMSE} < 1.27$ dS m^{-1}). Taking into account the threshold of $EC_e = 3$ dS m^{-1}, different $EC_e = f(EC_{1:5})$ linear relationships were obtained. Although the linear model gave high values of R^2 and RMSE for $EC_e < 3$ dS m^{-1}, the quadratic model resulted in better R^2 and RMSE values for all methods examined. Correspondingly, in the 1:1 method, two of the three methods used exhibited similar slope values of the linear relationships independent of EC_e value ($EC_e < 3$ or $EC_e > 3$ dS m^{-1}), while one method (23 h rest and then shaken mechanically for 1 hour) showed significant differences in the slopes of the linear relationships between the two ranges of EC_e.

Keywords: saturated soil paste; electrical conductivity; salinity

1. Introduction

Soil salinity is one of the basic limiting factors in food production especially in arid and semi-arid regions since most crops are sensitive to increased salt concentration in the soil solution [1]. Soil salinization is particularly acute in arid and semi-arid areas with shallow groundwater as well irrigation water of poor quality.

Soil salinity assessment is based on measurement of the electrical conductivity of soil saturated paste extract (EC_e); this has been established as the standard method [2,3]. Saline soils are considered to be the soils where the saturated paste extract has EC_e values greater than 4 dS m^{-1}. However, this method is laborious and time consuming especially in the case of EC_e determination for a large number of soil samples. Additionally, the method appears to be more difficult and requires skills and expertise to obtain saturation point for clay soils.

For these reasons, many researchers have suggested easier methods to determine EC in various soils over water mass ratios extracts instead of determining EC_e. The most widely used soil over water mass ratios, (soil:water), are the 1:1 and the 1:5. The ratio of 1:5 is used for soil salinity assessment ($EC_{1:5}$) in Australia and China [4,5], while the ratio 1:1 ($EC_{1:1}$) is commonly used in the United States [6]. Therefore, different methods for EC assessment are applied between different regions and organizations.

Many researchers have proposed linear relationships between EC_e and $EC_{1:1}$ or $EC_{1:5}$ [7], (Table 1). However, the coefficients of the linear relationships are different and vary according to the area of interest. These coefficients are affected, among other factors, by the soil texture [8–10], the presence of gypsum and calcite in the soil [3,11], the chemical composition of the soil solution, the cation exchange capacity, etc. It has been documented that in the case of coarse-textured soils the slopes of the abovementioned linear relationships is greater than those of fine-textured soils [8].

The equilibration time and the method of preparation and extraction for determining $EC_{1:1}$ or $EC_{1:5}$ are probably additional factors that have led to the observed differences among various models [6,12]. It is worth to know that the equations $EC_e = f(EC_{1:5})$ and $EC_e = f(EC_{1:1})$ presented in Table 1 are often compared without taking into account these factors even though the equations have been obtained by different methods and at different ranges of EC_e values. More specific, Aboukila and Norton [13] and Aboukila and Abdelaty [14] have used the NRCS method [15], Khorsandi and Yazdi [11] have shaken the suspension for 1 h, Sonmez et al. [10] have used the USDA method [16], while Visconti et al. [3] have applied mechanical shake for 24 h (Table 1). As regards to the EC_e values range, Aboukila and Norton [13] presented their equation for EC_e values up to 10.26 dS m^{-1}, while Zhang et al. [17] and Khorsandi and Yazdi [11] for EC_e values up to 108 and 170 dS m^{-1}, respectively (Table 1). Noted that such extreme EC_e values are related to very specific cases (e.g., dumping of saline water as waste from the oil industry or saline areas for large scale halophyte production). Overall, to obtain the equations $EC_e = f(EC_{1:5})$ and $EC_e = f(EC_{1:1})$ both different methods have been applied to measure $EC_{1:5}$ and $EC_{1:1}$ and different ranges of EC_e values.

He et al. [6] reported that the $EC_{1:5}$ was affected by both agitation method and agitation time. Specifically, significant differences existed within three agitation methods when EC_e values ranged between 0.96 and 21.2 dS m^{-1}. Equilibration times were significantly greater for soils having $EC_e < 4$ dS m^{-1} compared to soils having $EC_e > 4$ dS m^{-1}. The agitation method of shaking plus centrifuging showed the greatest values of $EC_{1:5}$ while the stirring method showed the smallest ones for the same soil examined. Also, Vanderheynst et al. [12], conducting an experiment with compost using various dilutions, found that as agitation time increased the EC values increased—especially when agitation time increased from 3 to 15 h. The above results showed the important role of agitation time among the different agitation methods on EC measurement, irrespective of the porous medium (e.g., soil, compost).

Among the various methods widely used—especially in the case of 1:5 ratio—there are the following three methods:

(i) Loveday [18]: the suspension is mechanically shaken for 1 h and then kept at rest for 20 min.
(ii) NRCS [15]: the suspension remains at rest in complete shade for 23 h and then shaken mechanically for 1 h.
(iii) USDA [2]: the suspension is shaken by hand, 4 times, every 0.5 h for 30 s.

The difference between methods (i) and (ii) lies in the different rest times of the suspension, while methods (i) and (ii) differ from (iii) in both the shaking mode and the rest time.

Table 1. Relationships between soil saturated paste extract electrical conductivity (EC_e) and 1:1 and 1:5 soil to water extract electrical conductivities ($EC_{1:1}$, $EC_{1:5}$) as proposed by several researchers, as well as the extraction method and the corresponding range of EC_e values.

Reference	Expression	Method	EC_e Values Range ($dS\ m^{-1}$)
USDA [16]	$EC_e = 3\ (EC_{1:1})\ ^{f}$		
Khorsandi and Yazdi [11]	$EC_e = 7.94\ (EC_{1:5}) + 0.27\ ^{d}$ $EC_e = 9.14\ (EC_{1:5}) - 15.72\ ^{e}$	Shake 1 h	1.04–170
Sonmez et al. [10]	$EC_e = 2.03\ (EC_{1:1}) - 0.41\ ^{c}$ $EC_e = 7.36\ (EC_{1:5}) - 0.24\ ^{c}$	Rhoades [19]	0.22–17.68
Frazen [9]	$EC_e = 2.96\ (EC_{1:1}) - 0.95\ ^{c}$	N/A	N/A
Aboukila and Norton [13]	$EC_e = 5.04\ (EC_{1:5}) + 0.37\ ^{c}$	NRCS method [15]	0.624–10.26
Chi and Wang [20]	$EC_e = 11.74\ (EC_{1:5}) - 6.15\ ^{b}$ $EC_e = 11.04\ (EC_{1:5}) - 2.41\ ^{c}$ $EC_e = 11.68\ (EC_{1:5}) - 5.77\ ^{f}$	USDA method [16]	1.02–227
Slavich and Petterson [8]	$EC_e = f(EC_{1:5})$	Loveday [18]	0–38
Ozcan et al. [21]	$EC_e = 1.93\ (EC_{1:1}) - 0.57\ ^{f}$ $EC_e = 5.97\ (EC_{1:5}) - 1.17\ ^{f}$	N/A	N/A
Aboukila and Abdelaty [14]	$EC_e = 7.46\ (EC_{1:5}) + 0.43\ ^{a}$	NRCS method [15]	0–18.3
Hong and Henry [22]	$EC_e = 1.56\ (EC_{1:1}) - 0.06\ ^{f}$	Shake 1 h	0.25–42.01
Zhang et al. [17]	$EC_e = 1.79\ (EC_{1:1}) + 1.46\ ^{f}$	Equilibrate 4 h	0.165–108
Visconti et al. [3]	$EC_e = 5.7\ (EC_{1:5}) - 0.2$	Shake 24 h	0.5–14
Kargas et al. [7]	$EC_e = 1.83\ (EC_{1:1}) + 0.117\ ^{c}$ $EC_e = 6.53\ (EC_{1:5}) - 0.108\ ^{c}$	USDA [16]	0.47–37.5

The indices a, b and c refer to coarse, medium and fine soils, respectively. The indices d and e refer to the presence or absence of gypsum, respectively. The index f refers to combined soil texture.

Still now, no comparison has been made among the three abovementioned widely spread EC methods. Also, from international literature, it seems that there is no research work referred on the effect of different methods on the $EC_{1:1}$, although different methods have been used on the $EC_{1:1}$ measurement [16,17].

The objectives of present work are: (i) The comparison of EC values derived from the three most commonly used methods of 1:1 and 1:5 extracts; to investigate whether the differences between these methods are maintained across a range of soil EC_e and (ii) the investigation of the relationship between EC_e and EC values derived from the three methods.

2. Materials and Methods

2.1. Sample Collection Areas

The soil samples examined were collected from three areas in Greece, and more specifically, from the Prefectures of Lakonia, Argolida and from the island of Kos. Specifically, 50 soil samples were collected from Laconia from irrigated olive groves. The sampling procedure was carried out in September after the irrigation period. In Argolida, 12 samples were collected from various irrigated crops at the end of the irrigation period, while in Kos, 27 samples were collected from a horticultural greenhouse. The depth of soil samples collection was up to 30 cm.

2.2. Methods of Determining the Soil Properties

After sampling, the samples were transferred to the laboratory for air-drying and sieving through a 2 mm sieve and the soil texture, pH and calcium carbonate were determined. Soil texture was determined by means of the Bouyoucos hydrometer method [23], pH values were measured using standard glass/calomel electrodes in 1:2.5 w/v soil–water suspension [24]; $CaCO_3$ equivalent percentage was estimated by measuring the eluted CO_2 following the addition of HCl (calcimeter Bernard method).

2.3. Methods of Various Soil Extraction and Measurements

2.3.1. EC_e Method

350 g of soil was used to prepare the soil saturated paste and then the paste was allowed to stand for 24 h (USDA, 1954). Subsequently, the vacuum extracts were collected and EC_e was measured by a conductivity meter (WTW, Cond 315i). For the saturation percentage (SP) determination, a subsample of each paste was oven dried at 105 °C for 24 h.

2.3.2. $EC_{1:5}$ Method

For the 1:5 suspension, 50 g of soil and 250 mL of distilled water were used. Three alternative methods were applied: the method of Loveday [18], the NRCS [15] and the USDA [2].

In the Loveday method, the suspension was shaken by a mechanical shaker for exactly one hour and then kept at rest for 20 min. After the rest time, the extract was obtained, and the EC was determined. For the NRCS method, the suspension remains at rest in complete shade for 23 h and then shaken mechanically for one hour. After the shaking, the extract was obtained, and the EC was determined. Finally, in the USDA method the suspension was shaken by hand, 4 times, every half hour for 30 s. After, the extract was obtained, and the EC was determined. The method of vacuum filtration in all the three methods is the same and common, followed by the measurement of EC with a conductivity meter. All the methods and EC readings were conducted at 25 °C.

In two soil samples, one from Laconia (sample L) and one from Argolida (sample A) with EC_e values of 0.793 and 13.78 dS m^{-1}, respectively, the $EC_{1:5}$ values were measured after the suspensions were agitated with mechanical shaker for times 1, 2, 3, 4, 6, 24 and 48 h. After each agitation time the extraction was obtained, and the EC was determined. This process can better evaluate the role of shaking time on the $EC_{1:5}$ values for the two very different EC_e values.

2.3.3. $EC_{1:1}$ Method

In the 1:1 method, the three above mentioned methods (Loveday, NRCS and USDA) were also applied as described in the 1:5 method. For each of the above methods, 50 g of soil was weighed and then each procedure was performed in the same way as above.

2.3.4. Statistical Analysis

For the relationships $EC_e = f(EC_{1:1})$ and $EC_e = f(EC_{1:5})$, a least-squared linear regression was applied and the coefficient of determination R^2 was evaluated. The R^2 coefficient is used to assessing the correlation between two independent methods. Also, the values of root mean square errors (RMSE) were determined. Analysis of variance (ANOVA) was applied to test the significant difference among the applied $EC_{1:5}$ or $EC_{1:1}$ methods using SPSS Statistical Software v. 17.0 (SPSS Inc., Chicago, IL, USA); the means of each method were compared using t-test at a probability level $P = 0.05$.

3. Results and Discussion

3.1. Soil Properties

Samples from Laconia and Argolida are characterized as clay-clay loam soils and from Kos as sandy clay soils. All soil samples presented negligible gypsum content. As regards to $CaCO_3$, samples from Laconia presented a content lower than 2.5%, from Argolida 5–8% and from Kos 8.5–11%. The pH values ranged from 7.69 to 8.06 for soil samples from Laconia and from 7.5 to 7.7 for soil samples from Argolida and Kos.

Additionally, the soil texture analyses of the two soil samples examined separately resulted as follows: (i) soil sample L—clay soil (23.5% sand, 16% silt, 60.5% clay) and (ii) soil sample A—clay loam/loam soil (39% sand, 32% silt, 29% clay). The $CaCO_3$ content was 0.2% and 7.66% and pH values were 7.75 and 7 for sample L and A, respectively.

3.2. Estimation of Soil Salinity

The EC_e values ranged from 0.611 to 25.9 dS m^{-1}. It should also be noted that the EC_e variation range of the soil samples from Laconia is much lower than that of the other two regions (Argolida and Kos). Specifically, EC_e values of the samples from Laconia ranged from 0.611 to 1.664 dS m^{-1}, while in the other two regions they ranged from 2.32 to 25.9 dS m^{-1}. From the measured EC_e values, it appears that a relatively wide range in salinity levels was obtained for both comparing the different $EC_{1:5}$ and $EC_{1:1}$ methods, as well as evaluating the relationship between the EC_e and each of $EC_{1:5}$ or $EC_{1:1}$ methods.

As regards to SP all soil samples examined (with exception of the two separated samples) have values greater than 43%, percentage which indicates that the soils are classified in fine textured soils [20]. More specifically, SP values ranged from 50.5% to 72.5% for soils from Laconia, 52–70% for soils from Argolida and 43–53% for soils from Kos.

3.3. Comparison of 1:1 and 1:5 Soil to Water Extract Electrical Conductivity Methods

In Table 2 the slope of the linear relationship (y = ax) between 1:5 soil to water extract electrical conductivity methods for $EC_e < 3$ dS m^{-1} and $EC_e > 3$ dS m^{-1} and R^2 are presented.

Table 2. Slopes of the linear equations describing the relation between 1:5 soil to water extract electrical conductivity methods for $EC_e < 3$ dS m^{-1} and $EC_e > 3$ dS m^{-1} and coefficient of determination R^2.

$EC_{1:5}$		
Methods	**Slope**	**R^2**
$EC_e < 3$ dS m^{-1}		
NRCS–Loveday method	1.166	0.872
NRCS–USDA	1.047	0.797
USDA–Loveday method	1.108	0.812
$EC_e > 3$ dS m^{-1}		
NRCS–Loveday method	1.01	0.990
NRCS–USDA	1.00	0.960
USDA–Loveday method	1.00	0.976

Similarly, the slope and R^2 of the linear relationship between 1:1 soil to water extract electrical conductivity methods for $EC_e < 3$ dS m^{-1} and $EC_e > 3$ dS m^{-1} are presented in Table 3.

Table 3. Slopes of the linear equations describing the relation between 1:1 soil to water extract electrical conductivity methods for $EC_e < 3$ dS m^{-1} and $EC_e > 3$ dS m^{-1} and coefficient of determination R^2.

$EC_{1:1}$		
Methods	**Slope**	**R^2**
$EC_e < 3$ dS m^{-1}		
NRCS–Loveday method	1.185	0.800
NRCS–USDA	1.161	0.781
USDA–Loveday method	1.012	0.817
$EC_e > 3$ dS m^{-1}		
NRCS–Loveday method	1.01	0.984
NRCS–USDA	0.97	0.945
USDA–Loveday method	1.09	0.952

From the results presented in Tables 2 and 3, it is obvious that each of the three methods examined resulted in different values of both $EC_{1:1}$ and $EC_{1:5}$ when $EC_e < 3$ dS m^{-1}. Analysis of variance (ANOVA) showed that the three methods are significantly different at a probability level P = 0.05. Furthermore, the t-test analysis (P = 0.05) showed that the NRCS and Loveday methods as well as the USDA and Loveday methods resulted in significantly different $EC_{1:5}$ values, while $EC_{1:5}$ values between NRCS and USDA were not significantly different. The mean value with standard deviation for NRCS, USDA and Loveday methods were 0.177 ± 0.029, 0.169 ± 0.029 and 0.151 ± 0.027 dS m^{-1}, respectively. In the case of 1:1 ratio, the EC values between NRCS and USDA as well as NRCS and Loveday methods were also significantly different (P = 0.05). The mean value with standard deviation for NRCS, USDA and Loveday methods were 0.5 ± 0.070, 0.43 ± 0.100 and 0.423 ± 0.086 dS m^{-1}, respectively.

The NRCS method resulted in greater EC values compared to the other two methods for both 1:1 and 1:5 ratios, whereas the Loveday method resulted in lower EC values. From these results, it appears that at low values of EC_e ($EC_e < 3$ dS m^{-1}) the rest time seems to play an important role since the difference between the NRCS and the Loveday method is only in the duration of rest time. As regards to the NRCS and USDA methods, the slope of the linear regression between the NRCS and USDA at 1:5 ratio is 1.047, while at 1:1 is 1.161.

The $EC_{1:5}$ values of the soil sample L (with $EC_e = 0.793$ dS $m^{-1} < 3$ dS m^{-1}) obtained by mechanical shaking for 1, 2, 3, 4 and 6 h was approximately 0.142 dS m^{-1} while $EC_{1:5}$ values for 24 and 48 h were 0.218 and 0.274 dS m^{-1}, respectively. Practically, after 48 h shaking the $EC_{1:5}$ value was approximately doubling. The corresponding EC values obtained by the three methods used were 0.141, 0.127 and 0.158 dS m^{-1} for USDA, Loveday and NRCS methods, respectively. Therefore, it appears that the agitation time plays a dominant role to obtain equilibrium since the difference between the NRCS method ($EC_{1:5} = 0.158$ dS m^{-1}) and the method with 24 h shaking ($EC_{1:5} = 0.218$ dS m^{-1}) is in the shaking time. These results are similar to those of He et al. [6] in terms of the long shaking time required to equilibration but differ in the fact that in our experiments did not show differences in EC values obtained by shaking of at least up to 6 h. He et al. [6] explained that the higher values of EC obtained by the long shaking time method compared to other methods may be due to the fact that the mechanical shaking destroys micro-aggregates, as well as increase dissolution of salts because the dynamic concentration gradient between solid and liquid phases. Also, Vanderheynst et al. [12] found that differences occur for shaking time greater than a threshold value of 3 h.

In the case of soils with $EC_e > 3$ dS m^{-1} there is no significant differences between agitation methods since all methods gave almost the same results and the slope of the linear relationship is almost 1 (Tables 2 and 3). In addition, it is noted that the R^2 values for soils with $EC_e > 3$ dS m^{-1} are higher for all methods examined, in both 1:5 and 1:1 ratios, compared to R^2 values for $EC_e < 3$ dS m^{-1} (Tables 2 and 3).

The $EC_{1:5}$ values of the soil sample A (with $EC_e = 13.8$ dS $m^{-1} > 3$ dS m^{-1}) obtained by mechanical shaking for 1, 2, 3, 4, 6, 24 and 48 h ranged from 1.683 to 1.751 dS m^{-1}. It is obvious that for soils with $EC_e > 3$ dS m^{-1} the shaking times required to obtain equilibration are significantly lower compared to soils with $EC_e < 3$ dS m^{-1}

The different behavior depending on the EC_e value shows that the solid and liquid phases is far from considered a simple system where the only process carried out is dissolution and that the concentration of ions is inversely proportional to dilution. Such situations may exist only in sandy or sandy loam soils in semi-arid areas with high salinity [25]. However, the soils are characterized by a cation exchange capacity value depending on the type and quantity of clay, the presence of slightly soluble minerals but also ion exchanges between solid and liquid phase. In the present experimental work, the existence of a relatively high clay percentage combined with the existence of slightly soluble minerals may be led to different EC values among various methods, especially when $EC_e < 3$ dS m^{-1}. This phenomenon may be even more pronounced in the case of clay soils where there are high content of slightly soluble minerals but less pronounced in the coarse-textured soils without slightly soluble minerals.

3.4. Relationship between EC_e and 1:5 Soil to Water Extract Electrical Conductivity Methods

In Table 4, the linear relationships between EC_e and $EC_{1:5}$, for all soil samples, determined by the three different methods are presented. Analysis of the results showed that each 1:5 soil to water extract electrical conductivity method is strongly related with EC_e since R^2 values are high ($0.953 < R^2 < 0.972$) and RMSE are low (1.02 dS m^{-1} < RMSE < 1.27 dS m^{-1}). It also appears that the linear equations showed small differences regardless of the $EC_{1:5}$ methods for all soils examined. These data confirm the existence of a strong linear relationship when the range of EC_e is relatively great (Table 1).

Table 4. Regression equations describing the relation between saturated paste extracts EC_e and $EC_{1:5}$ determined by three different methods with the coefficients of determination (R^2) and root mean square errors (RMSE) for all soil samples examined.

	$EC_{1:5}$		
Methods	**$EC_e = fEC_{1:5}$**	**R^2**	**RMSE (dS m^{-1})**
EC_e–NRCS	$EC_e = 6.58\ EC_{1:5}$	0.973	1.09
EC_e–USDA	$EC_e = 6.61\ EC_{1:5}$	0.953	1.27
EC_e–Loveday method	$EC_e = 6.71\ EC_{1:5}$	0.971	1.02

As shown in Table 4, the relationship $EC_e = fEC_{1:5}$ using the USDA method is similar to the corresponding one reported by Kargas et al. [7], (Table 1) for Greek soils since both the two equations have almost the same slope (6.61 and 6.53, respectively).

However, analysis of the results for soils with $EC_e < 3$ dS m^{-1} showed that a percentage of 70% of experimental EC_e values were lower than those calculated by the equations presented in Table 4. For this reason, the data were separated into two ranges based on the threshold value $EC_e = 3$ dS m^{-1} to evaluate whether the relationship $EC_e = fEC_{1:5}$ is described by different equations as reported by other researchers [26,27].

The slopes of linear equation describing the relation between EC_e and $EC_{1:5}$ determined by three different methods, as well as the R^2 and RMSE for all soil examined for $EC_e < 3$ dS m^{-1} and $EC_e > 3$ dS m^{-1}, are presented in Table 5.

Table 5. Regression equations describing the relation between saturated paste extracts EC_e and $EC_{1:5}$ determined by three different methods with the coefficients of determination (R^2) and root mean square errors (RMSE) for all soil examined for $EC_e < 3$ dS m^{-1} and $EC_e > 3$ dS m^{-1}.

	$EC_{1:5}$		
Methods	**$EC_e = fEC_{1:5}$**	**R^2**	**RMSE (dS m^{-1})**
	$EC_e < 3$ dS m^{-1}		
EC_e–NRCS	$EC_e = 4.68\ EC_{1:5}$	0.718	0.189
EC_e–USDA	$EC_e = 4.89\ EC_{1:5}$	0.537	0.130
EC_e–Loveday method	$EC_e = 5.46\ EC_{1:5}$	0.647	0.123
	$EC_e > 3$ dS m^{-1}		
EC_e–NRCS	$EC_e = 6.60\ EC_{1:5}$	0.934	1.710
EC_e–USDA	$EC_e = 6.60\ EC_{1:5}$	0.917	1.800
EC_e–Loveday method	$EC_e = 6.71\ EC_{1:5}$	0.942	1.580

As shown in Table 5, for soils with $EC_e < 3$ dS m^{-1}, the slope of the linear equation between EC_e and $EC_{1:5}$ has different value depending on $EC_{1:5}$ determination method used with the smallest and the highest values obtained by the NRCS and Loveday method. Also, the values of the slopes of linear relationships, for both $EC_e < 3$ dS m^{-1} and $EC_e > 3$ dS m^{-1}, differ significantly from each other since in the case of $EC_e < 3$ dS m^{-1} these values ranged from 4.68 to 5.46, while they ranged from 6.60 to 6.71 in the case of $EC_e > 3$ dS m^{-1}. In addition, for $EC_e < 3$ dS m^{-1} R^2 values are lower ($0.537 < R^2 < 0.718$)

than those ones ($0.917 < R^2 < 0.942$) observed for $EC_e > 3$ dS m^{-1} indicating a strong linear relation between EC_e and each $EC_{1:5}$ determination method.

Comparison between the same methods for both $EC_e < 3$ dS m^{-1} and $EC_e > 3$ dS m^{-1} showed a difference between slopes ranging from 18.5% to 28.9%. Thus, in order to compare various equations describing the relationship between EC_e and $EC_{1:5}$, both the agitation method of $EC_{1:5}$ determination and the range of EC_e for which the equation has been proposed should be taken into account. Specifically, as shown in Table 5 and Figure 1, the relationship between EC_e and $EC_{1:5}$ determined by the NRCS method has a slope of 4.68 for $EC_e < 3$ dS m^{-1} and 6.60 for $EC_e > 3$ dS m^{-1}. The differences among the methods may be even greater if the soil contains gypsum or larger amounts of calcite than those observed in the soil samples examined.

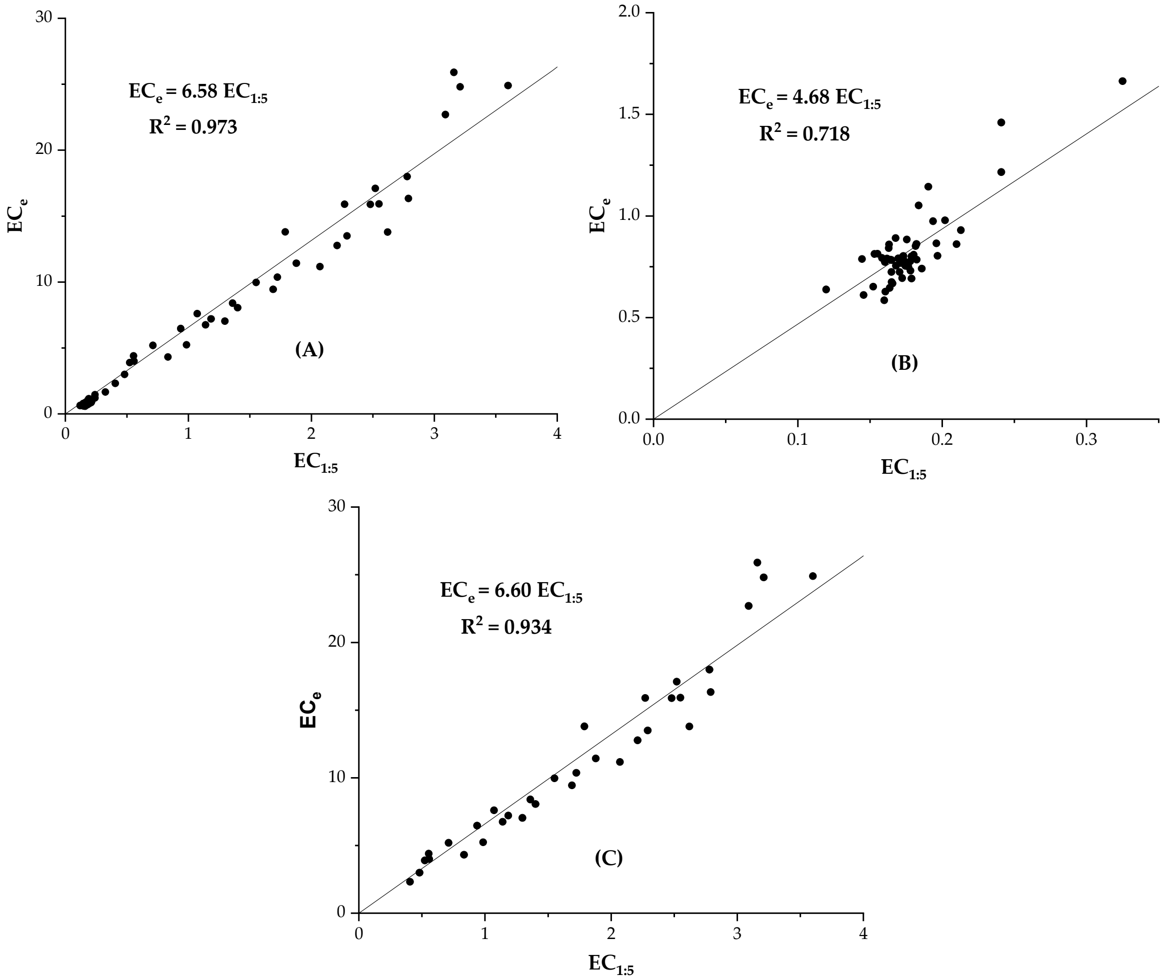

Figure 1. Relationship between EC_e and $EC_{1:5}$ for NRCS extraction method. A: all soil samples, B: soil samples range $EC_e < 3$ dS m^{-1}, C: soil samples range $EC_e > 3$ dS m^{-1}.

Similar results regarding to the effect of agitation method, the range of EC_e and the gypsum content on equation describing the relationship between EC_e and $EC_{1:5}$ have been presented by other researchers [3,26,27].

He et al. [27] proposed a quadratic equation as a more appropriate equation to describe the relationship between EC_e and $EC_{1:5}$ when EC_e values are lower than 4 dS m^{-1}. The fitting of a quadratic equation to the data of this study for $EC_e < 3$ dS m^{-1} gave R^2 values of 0.74, 0.57 and 0.66 and RMSE values 0.096 (NRCS), 0.124 (USDA) and 0.115 dS m^{-1} (Loveday method), respectively. A comparison between these RMSE values and those of the linear relationships presented in Table 5, showed a significant improvement only in the case of the NRCS method. It should be noted that there is a significant difference in RMSE values presented in Table 4 compared to RMSE values whether we use the linear equation or quadratic equation to EC_e estimation for $EC_e < 3$ dS m^{-1}.

3.5. Relationship between EC_e and 1:1 Soil to Water Extract Electrical Conductivity Methods

Table 6 shows the relationship between EC_e and the three methods of determining $EC_{1:1}$ for all soil samples examined. The results showed that the relationship is strongly linear in all methods examined ($R^2 > 0.986$) and RMSE values are low ($0.63 < \text{RMSE} < 0.74$ dS m^{-1}). The values of both R^2 and RMSE indicate that this linear relationship reliably estimates the EC_e. However, $EC_e = fEC_{1:1}$ linear relationships have different f coefficient for each method.

Table 6. Regression equations describing the relation between saturated paste extracts EC_e and $EC_{1:1}$ determined by three different methods with the coefficients of determination (R^2) and root mean square errors (RMSE) for all soil examined.

	$EC_{1:1}$		
Methods	**$EC_e = fEC_{1:1}$**	**R^2**	**RMSE (dS m^{-1})**
EC_e–NRCS	$EC_e = 2.07\ EC_{1:1}$	0.986	0.63
EC_e–USDA	$EC_e = 1.93\ EC_{1:1}$	0.991	0.74
EC_e–Loveday method	$EC_e = 2.12\ EC_{1:1}$	0.988	0.68

In Table 7, regression equations describing the relation between EC_e and $EC_{1:1}$ determined by three different methods are presented taking into consideration the threshold of EC_e value 3 dS m^{-1}. The results showed that the same trends were observed for R^2 and RMSE values as in the case of the results of 1:5 ratio presented in Table 5. As regards to differences observed in the slope of linear relationships between the two areas of EC_e values, a notable difference was observed in the NRCS method since it resulted to a slope 1.65 for $EC_e < 3$ dS m^{-1} and 2.08 for $EC_e > 3$ dS m^{-1}. Furthermore, the quadratic equation for the NRCS method, for $EC_e < 3$ dS m^{-1}, resulted almost to the same RMSE values (0.099 dS m^{-1}) with those of linear equation. Therefore, for this method with EC_e <3 dS m^{-1} the simple linear equation gave quite reliable results to EC_e estimation. The other two methods showed similar slope values regardless of the EC_e value. In particular, the EC_e-USDA relationship had almost the same slope value regardless of the EC_e.

Table 7. Regression equations describing the relation between saturated paste extracts EC_e and $EC_{1:1}$ determined by three different methods with the coefficients of determination (R^2) and root mean square errors (RMSE) for all soil examined for $EC_e < 3$ dS m^{-1} and $EC_e > 3$ dS m^{-1}.

	$EC_{1:1}$		
Methods	**$EC_e = fEC_{1:1}$**	**R^2**	**RMSE (dS m^{-1})**
	$EC_e < 3$ dS m^{-1}		
EC_e–NRCS	$EC_e = 1.65\ EC_{1:1}$	0.551	0.102
EC_e–USDA	$EC_e = 1.93\ EC_{1:1}$	0.566	0.254
EC_e–Loveday method	$EC_e = 1.96\ EC_{1:1}$	0.624	0.091
	$EC_e > 3$ dS m^{-1}		
EC_e–NRCS	$EC_e = 2.08\ EC_{1:1}$	0.985	1.62
EC_e–USDA	$EC_e = 1.90\ EC_{1:1}$	0.991	1.06
EC_e–Loveday method	$EC_e = 2.12\ EC_{1:1}$	0.984	1.62

The relationships between EC_e and $EC_{1:1}$ determined by the NRCS method taking into consideration the threshold of EC_e value 3 dS m^{-1} are also presented in Figure 2.

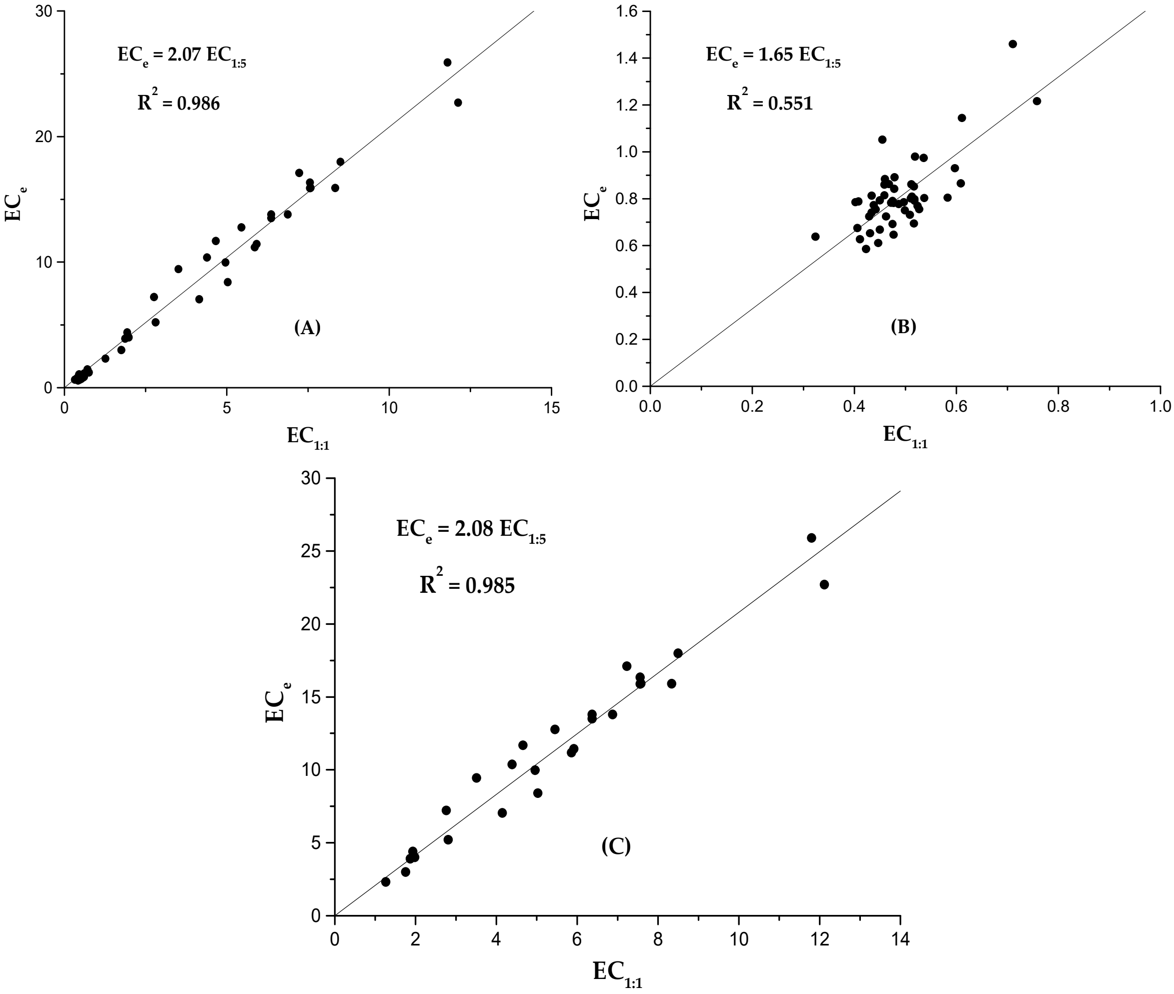

Figure 2. Relationship between EC_e and $EC_{1:1}$ for NRCS extraction method. A: all soil samples, B: soil samples range $EC_e < 3$ dS m^{-1}, C: soil samples range $EC_e > 3$ dS m^{-1}.

4. Conclusions

The $EC_{1:5}$ was affected by both agitation method and time, especially for EC_e values lower than 3 dS m^{-1}. Generally, the NRCS method resulted in the highest EC values compared to the other two methods examined. The differences among agitation methods are essentially eliminated for EC_e values greater than 3 dS m^{-1}. For soil having EC_e values lower than 3 dS m^{-1}, equilibration time was very greater than the soils having EC_e values above 3 dS m^{-1}. The most appropriate equation for EC_e estimation using $EC_{1:5}$ values for soils having $EC_e < 3$ dS m^{-1} is a quadratic equation—especially in the case of the NRCS method—while for soils having $EC_e > 3$ dS m^{-1} is the linear equation. However, if soils have a wide range of salinization levels, the linear model are recommended.

The present study shows that the shaking method and the equilibration time are additional contributing factors to the observed differences of the proposed equations for the EC_e estimation by $EC_{1:5}$. Therefore, in order to select each time, the appropriate method and equilibration time for measuring $EC_{1:5}$, during laboratory studies, the EC_e value of some samples, as well as the soil characteristics (e.g., gypsum and calcium carbonate content) should be examined in advance.

The $EC_{1:1}$ was affected by EC_e values only in the case of the NRCS method where the estimation of the EC_e can be conducted by simple but different linear relationships whose slopes depend on EC_e values. In the other two methods, the linear relationship $EC_e = f(EC_{1:1})$ was not affected by EC_e values.

Overall, it is necessary to describe in detail the method of preparation and extraction for determining $EC_{1:1}$ or $EC_{1:5}$ and the range of EC_e in order to properly evaluate and compare the proposed equations of $EC_e = f(EC_{1:5})$. Additionally, the study of soils with different characteristics than those of the group of soils examined in this work is needed.

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