

An Investigation of the Relationship between the Electrical Conductivity of the Soil Saturated Paste Extract EC_e with the Respective Values of the Mass Soil/Water Ratios 1:1 and 1:5 ($EC_{1:1}$ and $EC_{1:5}$)[†]

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Abstract: The standard methodology for the soil salinity assessment is provided through the determination of the electrical conductivity (EC) of the soil saturated paste extract, EC_e . This approach is cumbersome and tedious. Instead of this, it appears easier to measure the EC of various soil over water mass ratios, (soil:water), such as 1:1, 1:5. In the present study an attempt is made to compare the EC_e methodology with the methods providing the $EC_{1:1}$ and $EC_{1:5}$. EC_e , and $EC_{1:1}$ or $EC_{1:5}$ values were obtained from 198 soil samples from 5 different locations in Greece. It was shown that the methods providing $EC_{1:1}$ and $EC_{1:5}$ values are linearly correlated to the EC_e methodology with a high correlation coefficient ($R^2 > 0.93$).

Keywords: soil salinity; electrical conductivity; saturated soil paste

1. Introduction

Soil salinity is undoubtedly a basic factor which determines in a large extent soil suitability for the agricultural productivity. The problem of soil salinity makes its early presence in arid and semi-arid regions. Around 995 million hectares world-wise are estimated to suffer from salinity problems [1]. Soil salinity assessment is based on measurements of the electrical conductivity of the saturated paste extract (EC_e), which has been established as the standard method [2]. EC_e is considered as the most appropriate index for the estimation of the crop response to salinity. Unfortunately, this method is tedious, time consuming and requires skills and expertise to reach at saturation percentage (SP) especially in clay soils. In cases where salinity monitoring involves repeated soil sampling during the growing season and in different parts of the field, producing a large number of soil samples for the EC_e to be measured, it appears to be a difficult and laborious method [3].

For these reasons, instead of measuring EC_e a number of researchers find it easier to measure the EC of various soil over water mass ratios, (soil:water), such as 1:1, 1:2, 1:2.5, 1:5, which are more easily attainable. It is to be noted that the soil over water mass ratios are very little correlated with the actual soil conditions. These methods can be practically very useful when one is not interested in the determination of the absolute EC values or the absolute soil salt concentration, but on the relative changes of these. A serious disadvantage of the methods measuring EC of the various soil over water mass ratios, is the effect associated with the larger water quantities on the solubility of the less soluble

salts such as gypsum or lime. For the case of gypsum, for as long as the dilution increases, the concentration of all ions decreases, except those of calcium cations and the SO₄ anions which remain relatively constant. In this respect, as the degree of dilution increases for the cases of soils containing gypsum or lime, there appears a large change in the ion concentration in relation to the natural soil solution due to the presence of less soluble salts [3,4]. The most widely used soil over water mass ratios, (soil:water), are the 1:1 and the 1:5.

Although a strong linear relationship between EC_e and EC_{1:1} or EC_{1:5}, has been reported, the coefficients entering this relationship are not unique but they vary according to the area of interest. The range of their differences and the causes leading to this are not yet clear. In Tables 1 and 2 the respective equations EC_e = f(EC_{1:1}) and EC_e = f(EC_{1:5}) together with the appropriate references are shown. As for the relationship EC_e = f(EC_{1:1}) proposed by [2] this had the form EC_e = 3(EC_{1:1}). In this case the effect of soil particle composition or the organic content presence were not investigated [5]. Sonmez et al. [4], Franzen [5], and Hogg and Henry [6] studied the above relationship in three different soil types and they proposed three different equations corresponding to each separate soil type.

Table 1. The EC_e = f(EC_{1:1}) relationship proposed by several researchers. The indices ^a, ^b, ^c refer to coarse, medium and fine soils respectively.

EC _{1:1}	
USDA [2]	EC _e = 3(EC _{1:1})
Sonmez et al. [4]	EC _e = 2.72(EC _{1:1}) - 1.27 ^a
	EC _e = 2.15(EC _{1:1}) - 0.44 ^b
	EC _e = 2.03(EC _{1:1}) - 0.4 ^c
Franzen [5]	EC _e = 3.01(EC _{1:1}) - 0.06 ^a
	EC _e = 3.01(EC _{1:1}) - 0.77 ^b
	EC _e = 2.96(EC _{1:1}) - 0.95 ^c
Hogg and Henry [6]	EC _e = 1.56(EC _{1:1}) - 0.06
Zhang et al. [14]	EC _e = 1.79(EC _{1:1}) + 1.46
Ozkan et al. [15]	EC _e = 1.93(EC _{1:1}) - 0.57

The possibility of the EC_e prediction from measurements of the EC_{1:5} has been investigated in a number of regions world-wise [3,4,7–10]. In Table 2 these EC_e = f(EC_{1:5}) expressions together with the appropriate references are given. It is to be noted that in these expressions the effect of soil particle composition or the specific kind of salts and the organic content presence were taken into consideration. Less examined was the subject of EC_{1:5} measurement in relation to the methodology followed for the acquisition of the soil over water mass ratio [9].

Slavich and Petterson [10] gave an expression for the multiplicative *f* factor in the EC_e = *f*EC_{1:5} relationship according to the Equation (1) below, where θ_{SP} denotes the saturation percentage.

$$f = 2.46 + \frac{3.03}{\theta_{SP}} \tag{1}$$

Moreover, they presented the range and the mean values of *f* as a function of the clay content. From Equation (1) the increase of θ_{SP} leads to a decrease of *f*.

Visconti et al. [11] presented EC_e = f(EC_{1:5}) relationships for soils with gypsum mass percentage between 0.2–1.5% and >1.5%. For the case where gypsum mass percentage is less than 0.2% the EC_e = f(EC_{1:5}) is strongly linear.

Khorsandi and Yazdi [3] from the comparison between measured EC_e and EC_{1:5} in soils from Iran reached to the conclusion that, it seems that gypsum concentration has greater impact by far on the accuracy of models in predicting EC_e than texture.

He et al. [9,12] tested other different methods for the determination of the EC_{1:5} and concluded that the way of preparing the 1:5 soil over water mass ratio, regarding shaking the mixture and the time for equilibrium could end up in different EC_{1:5} values. More specifically the time for equilibrium depends on the value of EC_e. In this respect for EC_e < 4 dS m⁻¹ the required time for equilibrium is

larger than that for the case where $EC_e > 4 \text{ dS m}^{-1}$. He et al. [12] presented $EC_e = f(EC_{1:5})$ models for each different method of acquiring values of $EC_{1:5}$. The ln-transformed model was shown to be better than the non-transformed and the exponential one for the whole lot of soil samples. Moreover, very good results were obtained from the curvilinear model for the range of $EC_e < 4 \text{ dS m}^{-1}$. Present work aims at investigating the relationship $EC_e = f(EC_{1:1})$ or $EC_e = f(EC_{1:5})$ in soil samples collected from five areas of Greece and to compare those values with EC_e values derived from models developed for other regions in the world.

Table 2. The $EC_e = f(EC_{1:5})$ relationship proposed by several researchers. The indices ^a, ^b, ^c refer to coarse, medium and fine soils respectively. The indices ^d and ^e refer to the cases where gypsum is present and not present respectively. The equation of [11] refers to a gypsum mass percentage <0.2%. Chi and Wang [8] presented cases considering the range of θ_{SP} variation. Their first equation corresponds to a range of θ_{SP} between 20% and 45% while their second equation between 45 and 63%. The third equation corresponds to the full range of θ_{SP} of variation i.e., between 20% and 63%.

	$EC_{1:5}$
Khorsandi and Yazdi [3]	$EC_e = 5.37(EC_{1:5}) + 0.57^d$
	$EC_e = 5.60(EC_{1:5}) - 4.37^e$
Sonmez et al. [4]	$EC_e = 8.22(EC_{1:5}) - 0.33^a$
	$EC_e = 7.58(EC_{1:5}) + 0.06^b$
	$EC_e = 7.36(EC_{1:5}) - 0.24^c$
Aboukila and Norton [7]	$EC_e = 5.04(EC_{1:5}) + 0.37^c$
Chi and Wang [8]	$EC_e = 11.74(EC_{1:5}) - 6.15$
	$EC_e = 11.04(EC_{1:5}) - 2.41$
	$EC_e = 11.68(EC_{1:5}) - 5.77$
Slavich and Petterson [10]	$EC_e = f(EC_{1:5})$
Visconti et al. [11]	$EC_e = 5.7(EC_{1:5}) - 02$
Ozkan et al. [15]	$EC_e = 5.97(EC_{1:5}) - 1.17$

2. Materials and Methods

Soil samples were collected from five areas over Greece and more specifically from the Prefectures of Evia (49 samples), Lakonia (12 samples), Preveza (7 samples), Argolida (90 samples) and from the island of Kos (40 samples) at the depths of 0 to 15 cm (Figure 1). The soils were under different crop cultivations or non-cultivated and represent soils of different soil salinity levels. Also considered to be representative of irrigated soils.

After the collection, soil samples were taken to the Agricultural Hydraulics Laboratory where they were left for air-drying. After this, samples were ground and sieved in 2 mm sieves. For the preparation of the saturated pastes, the standard method was followed [13]. According to this, 350 g of air dried soil were used. The soil paste was left 24 h for the equilibration. Subsequently, using Buchner funnel and applying suction to the saturated paste, the saturated paste extract was collected and its electrical conductivity EC_e was measured by a conductivity meter. For the SP determination, a small portion of the paste was oven dried at 104 °C for 24 h and the standard gravimetric procedure was applied.

For the 1:1 soil over water ratio in a 100 g of soil, a 100 g distilled water were added and the mixture was shaken for 1 min by hand 4 times at 30 min-intervals, left afterwards to reach equilibrium for 4 h and soon after the extract was obtained [13]. For the 1:5 soil over water ratio in a 50 g of soil, a 250 g distilled water were added and the same process described above was followed.

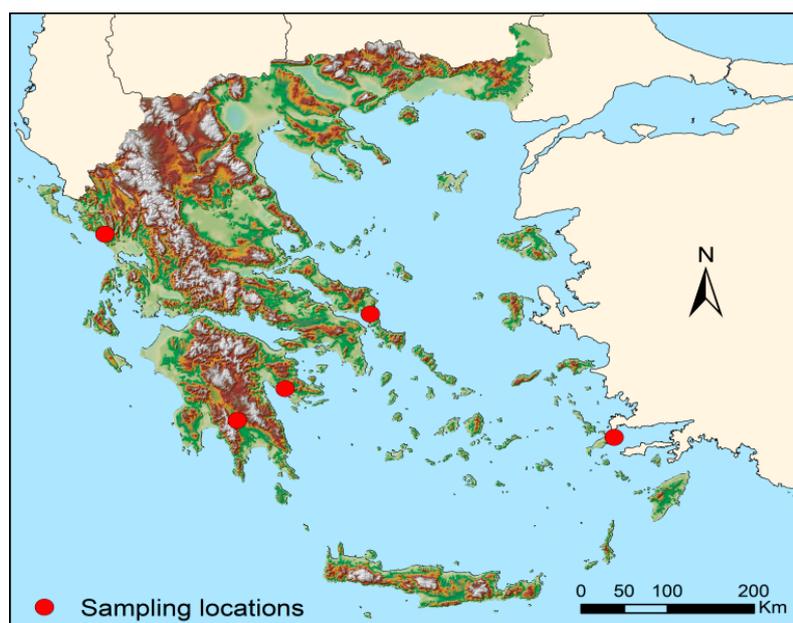


Figure 1. The sampling locations as shown in the map.

3. Results and Discussion

In Table 3 a general classification of the values EC_e , $EC_{1:1}$ and $EC_{1:5}$ of the 198 soil samples in three classes 0–2, 2–4 and >4 $dS\ m^{-1}$ together with their percentage in each class are shown. The soil samples electrical conductivity varies between 0.47 and 37.5 $dS\ m^{-1}$ for the saturation extract, from 0.16 to 20.1 $dS\ m^{-1}$ for the 1:1 extract and from 0.1 to 5.08 for the 1:5 extract. From these findings it is obvious that a quite large range of EC values are examined when the SP method e.g., EC_e is compared to the $EC_{1:1}$ and the $EC_{1:5}$.

Table 3. The numbers of EC_e , $EC_{1:1}$ and $EC_{1:5}$ values are shown in three classes together with their respective mean and median values of the whole lot of soil samples.

Range of $EC\ (dSm^{-1})$	EC_e		$EC_{1:1}$		$EC_{1:5}$	
	No of Samples	% of Samples	No of Samples	% of Samples	No of Samples	% of Samples
0–2	99	50	123	62.1	176	88.9
2–4	22	11.1	27	13.6	20	10.1
>4	77	38.9	48	24.3	2	1
Mean value	4.89		2.61		0.76	
median	2.26		1.04		0.34	

The mean EC value for the saturation extract is about two times larger than the value of EC for the 1:1 extract and 6.5 times larger than for the 1:5 extract. Our expression for the relationship $EC_e = f(EC_{1:1})$ are almost identical to those of Sonmez et al. [4] and of Zhang et al. [14] who reported approximately twofold dilution when they compared the SP result with 1:1 soil/water extract. For the relationship $EC_e = f(EC_{1:5})$ our results are almost the same with those of Aboukila and Norton [7] who reported that mean EC_e value was 5.7 times larger than $EC_{1:5}$ while Sonmez et al. [4] reported that mean EC_e value was 8 times larger.

According to the measured SP it seems that 30 samples (15.1%) have SP values between 20–45% and 168 samples (84.9%) have SP > 45%. From these findings it is shown that the large majority of the soil samples corresponds to fine soil texture [8].

In Figure 2 the linear relationship between EC_e and $EC_{1:1}$, $EC_e = 1.83 EC_{1:1} + 0.1168$, for the whole lot of soil samples is presented ($R^2 = 0.972$).

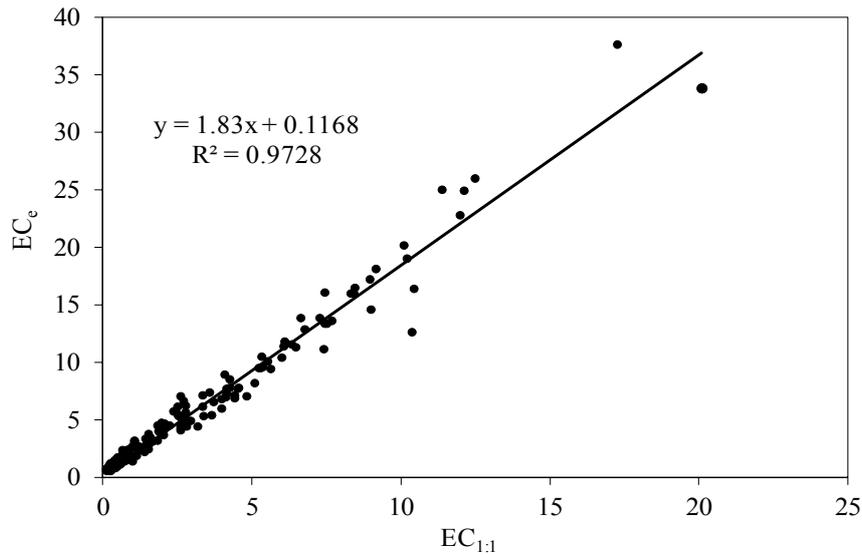


Figure 2. The $EC_e = f(EC_{1:1})$ relationship for all soil samples collected.

These results are similar with the findings of other researchers in the sense that they too found a strong linear relationship between EC_e and $EC_{1:1}$. The slope (1.83) is close to what it was found by Hogg and Henry [6], (1.56) and by Zhang et al. [14], (1.79) as well as by Sonmez et al. [4], (2.03) for the fine texture soils. Nonetheless our findings differ much from the findings of [5] who found a value for the slope 2.96, or from those of the [2] who found a value for the slope 3. Also, the values of their slopes do not change if the curve fitting linear correlation is with an intercept equal to zero, in other words if the line is forced to pass from the origin. More specifically the slope has a value equal to 1.847 and the $R^2 = 0.97$.

If our soil samples are separated according to their SP values, for the $EC_e = f(EC_{1:1})$ linear curve fitting prediction, then one can see that the slope for SP values lying in the range 20–45% is larger than for the SP values larger than 45% (Figure 3). More specifically the slope for the first case is 2.11 while for the second case is 1.79. This fact indicates that EC_e versus $EC_{1:1}$ relationship is affected from the soil mechanical analysis, since the saturation percentage SP depends strongly on the clay content, as well as, the type of the clay. When the soil texture is changing from coarse to fine, a decreasing trend in the slopes are observed both in our results and the results of [4,5].

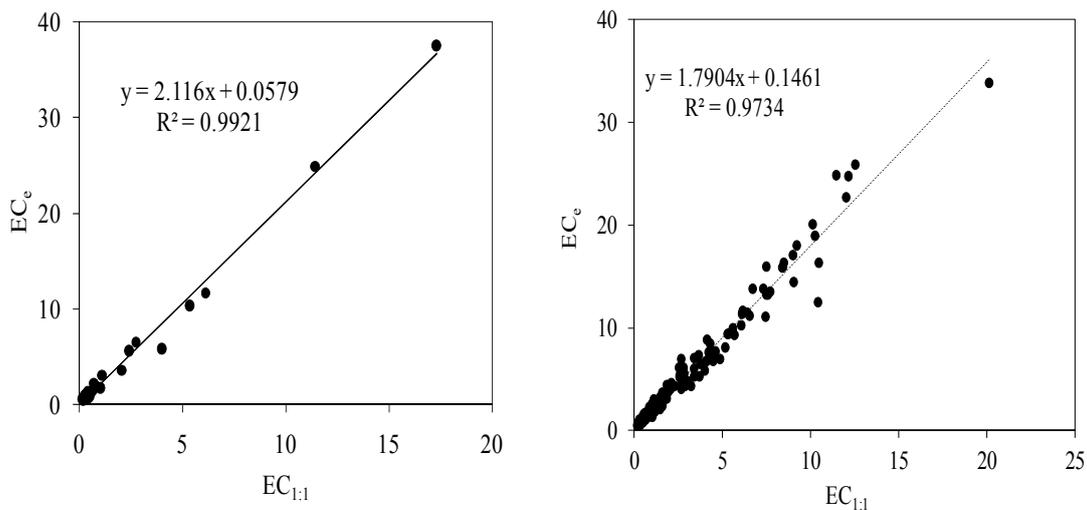


Figure 3. The $EC_e = f(EC_{1:1})$ relationship according to the value of SP. In the left, values of SP are between 20–45% and in the right for $SP > 45\%$.

In Figure 4 the results of the comparison between EC_e and $EC_{1:5}$ are shown. The $EC_e = f(EC_{1:5})$ relationship is given by the expression $EC_e = 6.5318 EC_{1:5} - 0.1088$. Also shown is $R^2 = 0.931$, indicating a strong linearity. The value of the slope when it is imposed the line to pass from the origin is practically unaffected, becoming $EC_e = 6.47 EC_{1:5}$. These findings are similar to the findings of other researchers [3,4,7,8,15] who also found strong linearity for the relationship $EC_e = f(EC_{1:5})$. It is to be mentioned that our results do not match exactly with the other researchers' findings but lie in between them. To be more specific the slope is less than the one found by [4] but it is larger than the one obtained by [3] or [7].

These differences may be attributed to the clay content and the clay type of the soils examined, but most seriously to the methodologies applied for the $EC_{1:5}$ measurements. The last factor seems to play the most serious role in the relationship between EC_e and $EC_{1:5}$ [12]. This could be supported because in this present work there is no gypsum in the soils examined and the soils were fine-textured as those in the works used for comparison. In this respect the methodology applied for the acquisition of the $EC_{1:5}$ values appears to be the basic different factor considering present work and the work of other scientists. Apart from this factor, concerning the acquisition of $EC_{1:5}$, another probable factor could be the range of the EC_e values from which the $EC_e = f(EC_{1:5})$ relationship in this work, in relation to the other similar works, was estimated. We consider that these two factors were responsible for the fact that our findings gave values of the slope in the $EC_e = f(EC_{1:5})$ expression close but not identical to similar findings of other scientists presented in the literature.

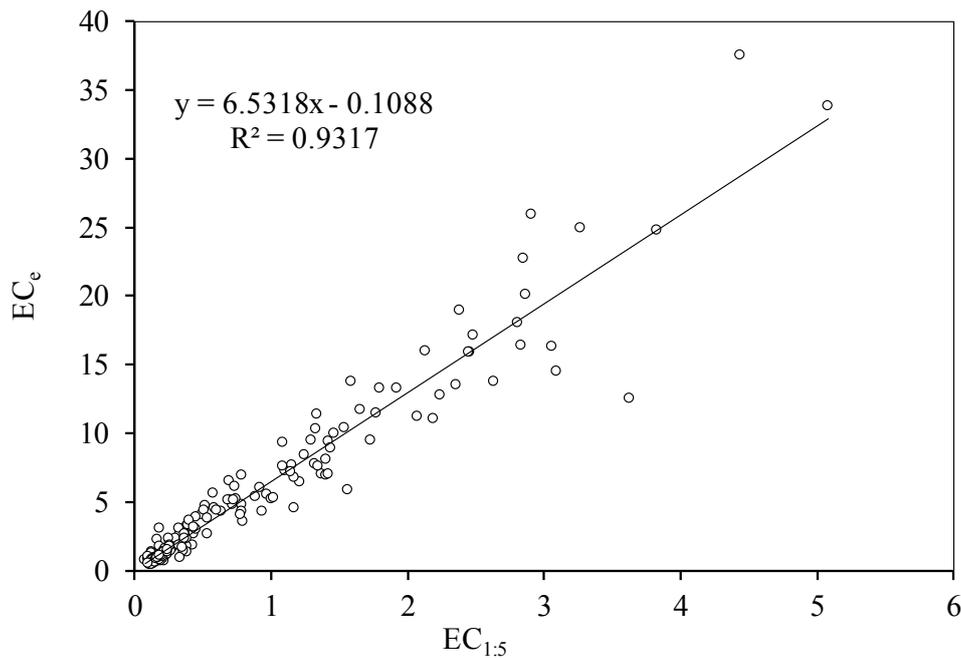


Figure 4. The relationship of EC (dS m⁻¹) as this was measured by the methods for EC_e and $EC_{1:5}$ for soil samples collected.

In Figure 5 the comparison is shown between the predicted EC_e values, as these were obtained by an ln-transformed model ($\ln(EC_e) = f(\ln(EC_{1:5}))$) and the predicted EC_e values, as these were obtained by the linear model ($EC_e = f(EC_{1:5})$), against the actually measured EC_e values. From Figure 5 it is shown that the predicted EC_e values, as these were obtained by an ln-transformed model are very close to the 1:1 line and give better results than those obtained by the linear model. It is to be noted that a strong linearity was obtained in the ln-transformed model, as this was also reported by He et al. [12] for each one out of the four examined cases of equilibrium, concerning $EC_{1:5}$ determination (data not shown). It is to be reminded that in their work the majority of their soil samples (67%) had SP values in the range 20–45% while in the present work in this range only the 15.1% were included.

Therefore, the ln-transformed model seems to have a general validity for all soil types and in this sense, it is a reliable methodology for the estimation of EC_e from the $EC_{1:5}$ measurements.

It is to be noted again that if, soil samples are separated according to their SP values, for the determination of the $EC_e = f(EC_{1:5})$ relationship, then one can see that the slope, for SP values lying in the range 20–45%, is larger than for the SP values larger than 45%

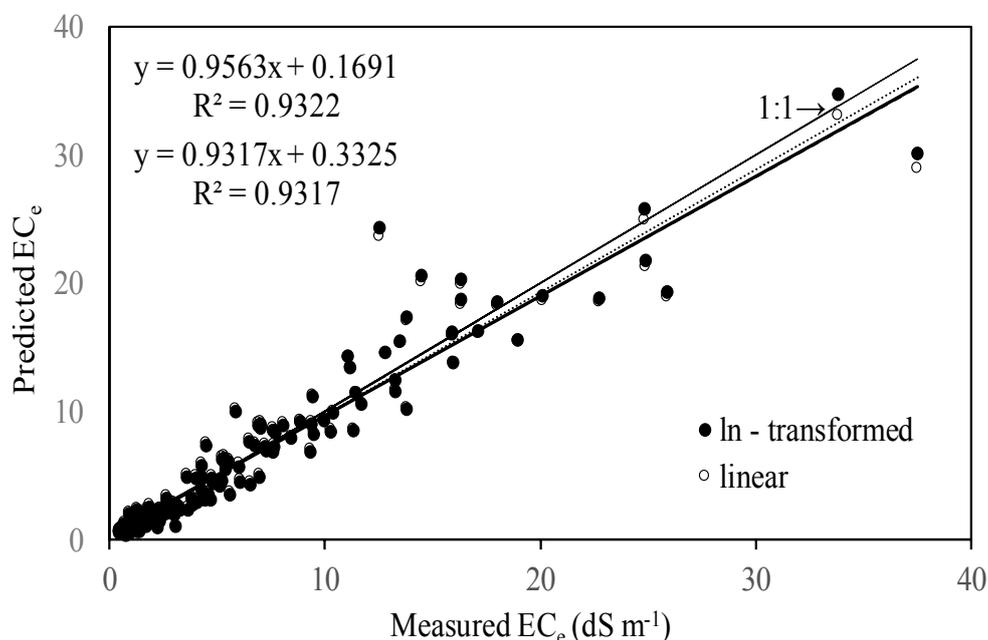


Figure 5. The relationship between measured values of EC_e and the estimated EC_e from the ln-transformed model ($Pred\ EC_e = 0.9563EC_e + 0.1691$) and the linear expression $Pred\ EC_e = 0.9319EC_e + 0.3339$.

4. Conclusions

From the above results it seems that it is possible to get a high degree of accuracy in the EC_e prediction for the fine-textured, mainly, soils, from the more easily measured values of the EC of the 1:1 and 1:5 soil/water mass ratios extracts using the relationship generated by this study. Differences in the value of the slope in the relationship $EC_e = f(EC_{1:5})$ as these were found here in comparison with similar relationships reported by other researchers could mainly be attributed to the differences in the methodologies used for the $EC_{1:5}$ measurements as well as to the wider range of the EC_e values used in this work. For the estimation of EC_e from the $EC_{1:5}$ measurements, quite accurate results were also obtained, through the ln-transformed model.

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