Assessment of Saturated Soil Paste Salinity from 1:2.5 and 1:5 Soil-Water Extracts for Coarse Textured Soils

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ABSTRACT

It is important to determine soil salinity with an accurate and simple method. Electrical conductivity (EC) of soil-water extracts is commonly used to assess soil salinity because it is an easier method than the standard saturated paste extract (EC_e). However, it is essential to convert EC of soil-water extracts to EC_e because plant response and salinity remediation are based mainly on EC_e values. Our objectives were to develop and validate models to predict EC_e from EC of 1:2.5 and 1:5 soil-water extracts ($EC_{1:2.5}$, $EC_{1:5}$). One hundred thirty-six coarse textured soil samples were collected from El Beheira Governorate, Egypt, of which 115 were used to develop models and 21 were used to validate these models. Electrical conductivity was determined using 1:2.5 and 1:5 soil-water extracts and saturated paste extracts (EC_e). Linear regression models were established for the two methods. The results showed that EC_e was highly significant correlated ($R^2 = 0.96$ to 0.97, $P < 0.001$) with $EC_{1:2.5}$ and $EC_{1:5}$ for EC_e values ranging between 0.3 and 18.3 dS m^{-1}. An independent validation set of 21 soil samples showed that the R^2 and slopes of the regressions between predicted EC_e from both $EC_{1:2.5}$ and $EC_{1:5}$ values and direct EC_e values were very close to 1.0. Additionally, these new models reduced EC_e prediction errors by 2.4 to 7 times when compare with 8 predictive models reported in the literature. Confirming that the regressions developed can reliably assess soil salinity instead of the more time-consuming and expensive saturated paste extraction.

Key Words: Soil salinity, Electrical conductivity, Saturated soil paste, Soil-water extract.

INTRODUCTION

It is crucial to determine the suitability of soils in terms of soil salinity in order to produce crop (Kruse *et al.,* 1990) and plan to make disrupted soils fit for cultivation (Day *et al*., 2015). Electrical conductivity (EC) of a soil extract is commonly utilized as a parameter for identifying soil salinity and estimating the concentration of ions within the soil (Aboukila and Norton, 2017). Nowadays, saturated paste (SP) extract and soil-water extracts are the extraction methods that are applied for soil salinity. Not only the EC of SP extract (EC_e) is recommended as a standard laboratory method for estimating the EC of soil but also it is taken into consideration to be the best indicator of plant response to salinity compared with more dilute soil-water extractions (Herrero and Pérez-Coveta, 2005). Soil management elucidations are based on values obtained from EC_e.

Saturated paste extracts are demanding, time consuming and more skills are needed for determining the correct saturation point (Al-Busaidi *et al*., 2006); therefore, in view of these reasons, it is an uneasy and costly method to determine soil salinity for high sampling frequency (Aboukila and Norton, 2017). Considering all the situations, a much easier, quick, and efficient method is demanded in order to estimate soil salinity with less equipment.

In contrast to SP extracts, soil-water extracts can be composed and derived in a much easy way. To determine the EC values of soils, soil-water extracts of 1:1, 1:2, 1:2.5, 1:5, and 1:10 have been commonly utilized in soil laboratories (Hogg and Henry, 1984; Zhang et al., 2005; Sonmez *et al*., 2008; Chi and Wang, 2010; Khorsandi and Yazdi, 2011; He *et al*., 2013; Klaustermeier *et al*., 2016; Monteleone *et al*., 2016; Aboukila and Norton, 2017). The 1:5 ratio is preferably used as a method for calculating soil salinity in Australia, China, and Central Asia (Shirokova *et al*., 2000; Wang *et al*., 2011) as well as 1:1 ratio in the United States and Canada (Hogg and Henry, 1984; He *et al*., 2013). Albeit, in contrast to the SP extract method, soil-water extracts are considered to be less connected to natural soil conditions (Rhoades, 1996). Ion concentrations and electrical conductivities of SP extracts are typically higher than those of the different soil-water extracts in consequence of the enhanced dilution effect (Sonmez *et al*., 2008). The biggest drawback of utilizing soil-water extract is the influence of water on dissolution of less soluble salts, such as gypsum and calcite (Rhoades *et al.*, 1999). Higher variation of ionic ratios is caused because of increasing the dilution of the soil-water extract compared to the natural soil solution as varying amounts of less soluble

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salts are dissolved (Monteleone *et al*., 2016). Corwin et al. (2012) reported that the causes for these diversions are ion hydrolysis, mineral dissolution, and alterations in exchangeable cation ratios. Gypsum leads to enhancing deviations in soils, since the concentrations of ions abate with enhancing dilution while the concentrations of calcium and sulfate stay nearly constant with dilution (Corwin *et al*., 2012).

The advantages of soil-water extracts are that they require less labor, quicker and can be useful when the objectives are to evaluate the relative changes rather than the absolute solute content (McKenzie *et al.*, 1983; Rhoades, 1996). Since soil-water extract methods can be conducted with relative ease, there have been theoretical relationships developed to convert soil-water extraction results to a SP extraction equivalents (USDA, 1954; Hogg and Henry, 1984; Zhang *et al.*, 2005; Sonmez *et al.*, 2008; Chi and Wang, 2010; Khorsandi and Yazdi, 2011; He *et al.*, 2013; Klaustermeier *et al.*, 2016; Monteleone *et al.*, 2016; Aboukila and Norton, 2017). Despite the reports of highly correlated relationships between the two methods for particular soils, converted values are often imprecise and inaccurate (Wagenet and Jurinak, 1978; Franzen, 2003) especially, if conversion equations are applied to larger regions or different soils (He *et al.*, 2013). Therefore, further studies based on adjusted soil-water extract analysis of soil salinity is necessary to improve soil remediation strategies.

Good relationships have been reported between EC_e and 1:1 extracts and suspensions (Wagenet and Jurinak, 1978; Fowler and Hamm, 1980; Hogg and Henry, 1984; Pitman *et al*., 2002; Zhang *et al.*, 2005; Klaustermeier *et al.*, 2016; Monteleone *et al.*, 2016), 1:2 extracts and suspensions (McKenzie *et al*, 1983; Hogg and Henry, 1984; Khorsandi and Yazdi 2007; Monteleone *et al.*, 2016), 1:2.5 extracts (Ozcan *et al.*, 2006; Sonmez *et al.*, 2008; Aboukila and Norton, 2017) and 1:5 extracts and suspension (Alavi Panah and De Dapper, 2001; Khorsandi and Yazdi, 2011; He *et al.*, 2013; Klaustermeier *et al.*, 2016; Monteleone *et al.*, 2016; Aboukila and Norton, 2017).

There is a considerable difference when comparing the EC_e to EC relationships of different soil-water extract from previous studies, thus uncertainties exist and when applying models from one study to soils from another region. There is limited knowledge and understanding of the transferability of the conversion models because of the uncertainty. Thus, a better understanding of the transferability of these models would provide managers more information about the accuracy of the EC_e values derived from non-local EC conversion models (Khorsandi and Yazdi, 2011; Aboukila and Norton, 2017). Further examination and comparison of these two methods are needed, especially for different soil texture groups (Sonmez *et al.*, 2008; Monteleone *et al*., 2016).

The variations in conversion factors make it necessary to examine and compare the different soil-water extraction methods with SP. Furthermore, in soil laboratories, pH is measured in 1:2.5 soil-water extracts. If suitable conversion coefficients were determined, EC may also be measured in the same extract, therefore saving analysis time (Sonmez *et al*., 2008).

The relationships between EC_e and EC of different soil-water extracts are affected by soil texture, salts present in the soil and presence of gypsum (USDA, 1954; Richard and Gouny, 1965; Le Brusq and Loyer, 1982; Alavi Panah and De Dapper, 2001). Another factor that has likely influenced differences among models is equilibration times and equilibration methods (He *et al.*, 2013). Khorsandi and Yazdi (2007, 2011) reported considerable improvement in the prediction of EC_e from EC of 1:2 and 1:5 extracts and 1:5 suspension by categorizing the soils into groups with or without gypsum.

Within many regions around the world, Egypt not being an exception, hundreds of soil samples are routinely analyzed by either government or commercial soil-testing laboratories. Because of the lack of facilities within these labs, $EC_{1:2.5}$ and $EC_{1:5}$ are commonly used to determine the EC value of the samples. To classify soil salinity for management decisions the soil-water extract EC values are then used instead of EC_e values. Until now there has not been any EC_e to EC of soil-water extract studies conducted on the coarse textured soils of the El Beheira Governorate, which is the biggest and most agriculturally important region in Egypt. The objective of this study was to determine the relationships between the EC_e and the EC of 1:2.5, 1:5 soil-water extraction ratios for coarse textured soil collected from El Beheira Governorate, Egypt, and to compare those values with EC_e derived from models developed for other, or more broad, regions.

MATERIALS AND METHODS

Soil Samples

Soil samples (n=136) were collected from south of El Beheira Governorate in the northern part of Egypt (approximate latitude between 30° 05′ 55″ and 30° 46′ 44″ N, and between 29° 57′ 51″ and 30° 51′ 27″ E). The general topography is level. The mean annual temperature is 20.6° C, average high temperature is 27.5° C and mean low temperature is 13.7° C. Annual precipitation is 53 mm, mainly falling in the months of November through February (Climate-Data.org, 2016).

Table 1. Correlation equations established by different studies to convert soil-water extracts at different ratios ($EC_{1:x}$) to saturated paste (EC_e) equivalents

Study	Regression equation				EC_e Range [a]
	With intercept	R^2	Without intercept	R^2	
USDA (1954)			$EC_e = 3.00\ EC_{1:1}$ [b]	0.96	N/A[g]
Hogg and Henry (1984)	$EC_e = 2.06\ EC_{1:1} + 0.05$ [c]	0.97			0.10-22.4
	$EC_e = 2.79\ EC_{1:2} + 0.17$ [c]	0.91			0.10-22.4
Zhang et al. (2005)	$EC_e = 1.79\ EC_{1:1} + 1.46$ [b]	0.85	$EC_e = 1.85\ EC_{1:1}$ [b]	0.85	0.16-108
Ozcan et al. (2006)	$EC_e = 1.93\ EC_{1:1} - 0.57$	0.96			N/A
	$EC_e = 3.30\ EC_{1:2.5} - 0.20$	0.95			N/A
	$EC_e = 5.97\ EC_{1:5} - 1.17$	0.94			N/A
Sonmez et al. (2008)	$EC_e = 2.72\ EC_{1:1} - 1.27$ [c]	0.99	$EC_e = 2.42\ EC_{1:1}$ [c]	0.98	0.22-17.7
	$EC_e = 4.34\ EC_{1:2.5} + 0.17$ [c]	0.99	$EC_e = 4.41\ EC_{1:2.5}$ [c]	0.99	0.22-17.7
	$EC_e = 8.22\ EC_{1:5} - 0.33$ [c]	0.98	$EC_e = 7.98\ EC_{1:5}$ [c]	0.98	0.22-17.7
Chi and Wang (2010)	$EC_e = 11.68\ EC_{1:5} - 5.77$ [b]	0.94			1.00-227
Khorsandi and Yazdi (2011)	$EC_e = 5.43\ EC_{1:5} + 0.43$ [d]	0.96	$EC_e = 5.48\ EC_{1:5}$ [d]	0.96	0.63-91.7
	$EC_e = 5.75\ EC_{1:5} - 4.45$ [e]	0.97	$EC_e = 5.37\ EC_{1:5}$ [e]	0.96	0.54-126
Monteleone et al. (2016)			$EC_e = 9.63 EC_{1:2.5}$ [b]	0.99	0.15-62.9
Klaustermeier et al. (2016)	$EC_e = 10^{[1.256\ (\log EC_{1:5}) + 0.766]}$ [b]	0.97			0.41-126
Aboukila and Norton (2017)	$EC_e = 3.05\ EC_{1:2.5} + 0.41$ [f]	0.93	$EC_e = 3.34\ EC_{1:2.5}$ [f]	0.92	0.62-10.3
	$EC_e = 5.04\ EC_{1:5} + 0.37$ [f]	0.93	$EC_e = 5.49\ EC_{1:5}$ [f]	0.92	0.62-10.3
This study	$EC_e = 3.73\ EC_{1:2.5} + 0.79$ [c]	0.96	$EC_e = 4.13\ EC_{1:2.5}$ [c]	0.94	0.29-18.3
	$EC_e = 7.46\ EC_{1:5} + 0.43$ [c]	0.97	$EC_e = 7.89\ EC_{1:5}$ [c]	0.96	0.29-18.3

[a] Units of EC are in dS m^{-1}
[b] Combined soil textures.
[c] Coarse textured soils.
[d] Coarse textured soils without gypsum.
[e] Coarse textured soils with gypsum.
[f] Fine textured soils.
[g] Data not available.

The soil samples were collected from 136 different agricultural sites, at the depths of 0-30 cm. Of the 136 samples, 115 were used to develop the relationships, and 21 were used for validation the relationships. The soils are classified as *Typic Torripsamments* (Soil Survey Staff, 2014). The soil texture ranged from sand to sandy loam. Each sample was air-dried, ground, sieved through a 2-mm sieve, and stored in plastic bags for analysis.

Soil pH was measured in a 1:2.5 soil-water suspension. Soil texture was determined by the hydrometer method (Gee and Bauder, 1986). Calcium carbonate equivalent (CCE) was estimated by pressure-calcimeter methods (Nelson, 1982). Organic matter content (OM) was determined by the dichromate oxidation method (Nelson & Sommers, 1982) (Table 2).

Saturated Paste (SP) Extraction

The EC of SP of each soil sample was determined using the methods outlined by USDA (1954). Saturated paste extracts were prepared by adding distilled water to approximately 500 g soil and stirring until complete saturation occurred. The SP was allowed to equilibrate for 18 h. Vacuum extracts were obtained and filtered using Whatman No. 42 filter paper into 50-ml polyethylene bottles, and the EC_e were measured at 25°C using a Jenway 4510 Conductivity Meter.

Soil-Water Solution Extractions

Prior to extraction, 25 g of each soil sample was oven dried overnight at 105°C to determine gravimetric water content. An appropriate amount of distilled water was added to 50 g of air-dried soil to create a 1:2.5 soil-water suspension. A 1:5 soil-water suspension was prepared by adding the appropriate amount of distilled water to 25 g of air-dried soil. The 1:2.5 and 1:5 the soil-water suspensions were allowed to equilibrate for 23 h prior to agitation with a mechanical shaker (132 rev min^{-1}) for 1 h (Soil Survey Staff, 2011). After agitation, the soil solutions were filtered through a Whatman No. 42 filter paper into 50-mL polyethylene bottles, and the

EC readings were measured at 25°C using a Jenway 4510 Conductivity Meter.

Validation of Relationships between EC_e and EC of Soil-Water Extracts

The EC_e, $EC_{1:2.5}$ and $EC_{1:5}$ values of the 21 soil samples were measured using the standard method and estimated using each one of the models. Regression equations were used to predict EC_e equivalents from $EC_{1:2.5}$ and $EC_{1:5}$ measurements; the results were then compared with actual EC_e measurements. To evaluate the best model to determine salinity of the tested coarse textured soils, we used the same samples to test models established by other researchers (Table 1). Values of EC_e predicted by this study and other researchers' models were also compared with actual measurements via regression analysis (Table 4).

Statistical Analysis

Potential differences among methods were examined using a one-way analysis of variance set in a randomized complete block design. Post hoc mean separation was conducted using Fisher's protected least significant difference. Statistical computations were facilitated using GLM procedure and MEAN option of SAS 13.1 (SAS Institute, 2013). To assess the possible linear relationship of EC_e to EC (1:2.5 or 1:5), simple linear regression models were run with either $EC_{1:2.5}$ or $EC_{1:5}$ as the dependent variable (x) and the response of EC_e as the independent (y) variable. A validation study for these linear relationships using a paired t test was conducted to test the null hypothesis that the relationship between the measured values of EC_e were the same as model-predicted values (i.e., the Y intercept = 0 and the slope = 1). This validation study was conducted on an independent data set (21 samples total), and statistical computations were facilitated using the MEANS procedure of SAS 13.1 (SAS Institute, 2013).

The performance of the models was compared as well. Root mean square error (RMSE) was used as measure of model performance:

$$RMSE = \sqrt{\tfrac{1}{N}\sum_{i=1}^{N}(EC_1 - EC_p)^2}$$

Where N is the number of observations, EC_i is the measured value, and EC_p is the predicted value based on the derived regression equations by this study and different studies (Table 4). The RMSE values were calculated for each model. The model with the least RMSE was assumed to predict EC_e better than the other models.

RERSULTS AND DISCUSSION

Electrical Conductivity of SP and Different Soil-Water Ratio Extracts

The summary statistics for electrical conductivity of the soil samples are shown in Table 2. Electrical conductivity for the soil samples ranged from 0.29 to 18.35 dS m^{-1} for the SP extracts, from 0.08 to 4.53 dS m^{-1} for the 1:2.5 extracts, and from 0.06 to 2.40 dS m^{-1} for 1:5 soil-water extracts, indicating that a wide range in salinity levels were obtained for comparing the SP with either 1:2.5 or 1:5 extraction methods.

Mean EC for saturated paste extracts was almost 4.5 fold greater than that of the 1:2.5 soil-water extracts, and approximately 8.3 fold greater than that of the 1:5 soil-water extracts. Our results are similar to those of other researchers who reported that the EC_e extracts are greater than the EC of more diluted extracts (USDA, 1954; Hogg and Henry, 1984; Zhang et al., 2005; Ozcan *et al.*, 2006; Sonmez et al., 2008; Aboukila and Norton, 2017).

These results are comparable to that from Sonmez *et al.* (2008) who reported that mean EC_e was about four and eight fold greater than that of the $EC_{1:2.5}$ and $EC_{1:5}$, respectively. They concluded that about twofold diluted values are measured when soil-water ratios are increased about twofold. Zhang *et al.* (2005) and Sonmez *et al.* (2008) reported about twofold dilution when they compared the saturated paste result with 1:1 soil-water extract.

The considerable difference between the EC of soil-water extracts and EC_e extracts is most likely due to a dilution effect that has been suggested by USDA (1954) and Rhoades (1982). Approximately 24 % of the soils samples had an $EC_e < 2$ dS m^{-1} while approximately 85 % of the soils had an $EC_{1:2.5} < 2$ dS m^{-1} and 99 % of the soils had an $EC_{1:5} < 2$ dS m^{-1} (Table 3).

Relationship between EC_e and $EC_{1:2.5}$, $EC_{1:5}$

Electrical conductivity of SP versus that of different soil-water extracts is shown in Fig. 1. Different dilution ratios affected both the slope and the intercept of the regression line, although the slope was much more influential than the intercept (Table 1). A higher slope for the regression equations of EC was observed when soil-water ratio increased from 1:2.5 to 1:5, indicating that additional water causes dilution. Sonmez et al. (2008) considered the slopes of the regression equations as a dilution ratio. Electrical conductivity of SP was highly correlated with $EC_{1:2.5}$ and $EC_{1:5}$ for all soils (R^2 = 0.96-97, $P < 0.001$) (Fig. 1).

The results of our study are similar to reportedthose reported by other researchers who found that highly

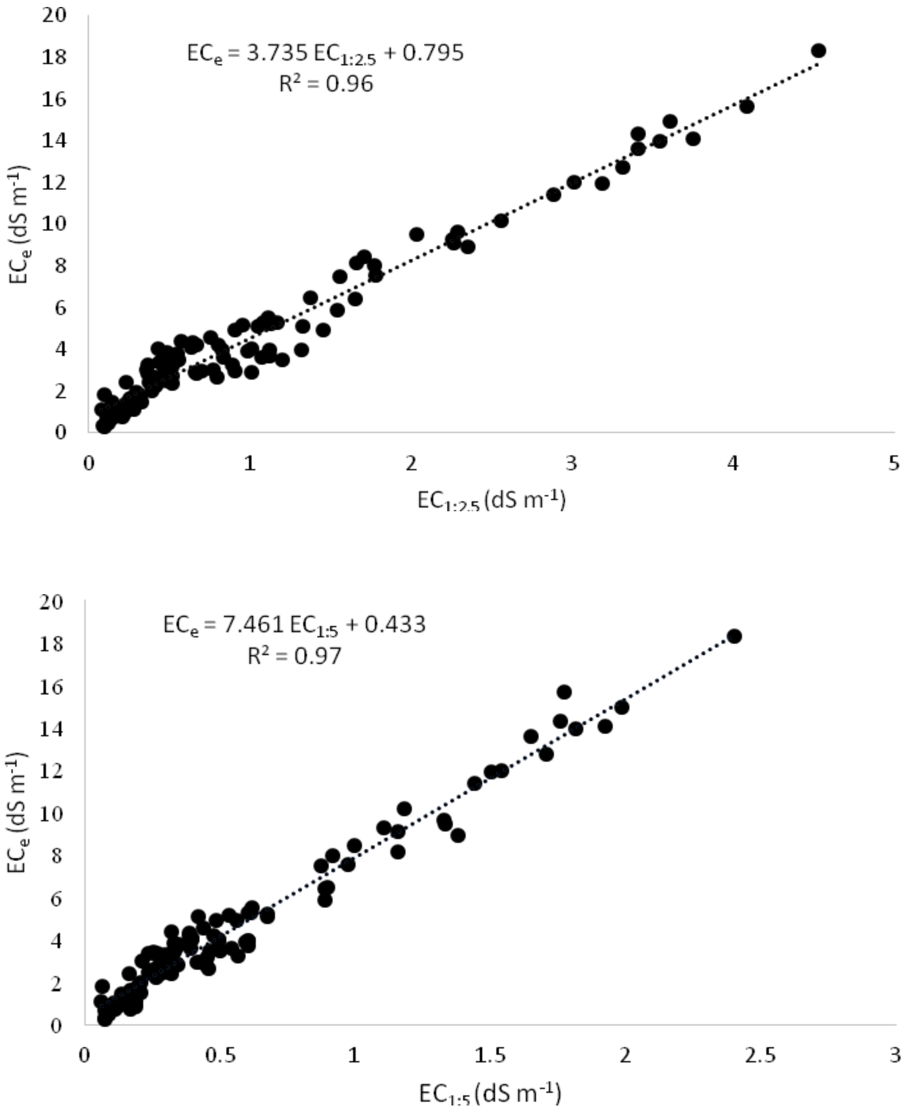

Fig. 1. Relationship between EC of SP extracts (EC_e) and soil-water extracts ($EC_{1:2.5}$, $EC_{1:5}$) for 115 study soil samples

Table 2. Summary statistics for selected physical and chemical properties of 115 soil samples used to establish relationships between saturated paste extracts (ec_e) and two soil-water ratio extracts ($EC_{1:2.5}$ and $EC_{1:5}$)

	EC_e	$EC_{1:2.5}$	$EC_{1:5}$	pH	% CCE	% OM	Sand	Clay	Silt
Mean	4.52	1.01	0.55	7.36	1.17	0.40	73	9.6	17.4
Median	3.38	0.56	0.35	7.35	0.75	0.18	74	9.8	17.2
Minimum	0.29	0.08	0.06	6.85	0.01	0.02	56	4	5
Maximum	18.35	4.53	2.40	8.18	4.25	1.44	89	18	35
St. Dev.	3.82	1.01	0.50	0.28	0.99	0.44	11.7	4.8	10.7

CCE, Calcium carbonate equivalent; St. Dev., Standard deviation.

Table 3. Electrical conductivity of saturated paste extracts (EC_e) and two soil-water ratio extracts ($EC_{1:2.5}$ and $EC_{1:5}$) for the study soils

Range of EC ($dS\ m^{-1}$)	EC_e		$EC_{1:2.5}$		$EC_{1:5}$	
	No. of samples	% of samples	No. of samples	% of samples	No. of samples	% of samples
0-2	28	24.3	98	85.2	114	99.1
2-4	45	39.1	15	13.0	1	0.9
> 4	42	36.5	2	1.7	0	0

significant relationships existed between the EC_e and EC of either 1:2.5 extracts (Ozcan *et al.*, 2006; Sonmez *et al.*, 2008; Aboukila and Norton, 2017) or 1:5 extracts (Ozcan *et al*., 2006; Sonmez et al., 2008; Chi and Wang, 2010; Khorsandi and Yazdi, 2011; He *et al*., 2013; Klaustermeier *et al*., 2016; Monteleone *et al*., 2016; Aboukila and Norton, 2017).

Neither the slopes nor the R^2 are changed much when intercepts are not included in the regression equations (Table 1). Forcing the regression line through zero slightly increased the slope from 3.73 to 4.13 and from 7.46 to 7.89 for the 1:2.5 and 1:5 relationships, respectively (Table 1).

The slopes obtained in this study are 3.73 and 7.46 for 1:2.5 and 1:5 extracts, respectively. The slope of 3.73 is close to the slope of 3.30 reported by Ozcan et al. (2006) and to the slope of 4.34 reported by Sonmez et al. (2008) for the same EC_e and $EC_{1:2.5}$ relationships. The slope of 7.46 derived from the EC_e and $EC_{1:5}$ relationship is similar to that of 8.22 reported by Sonmez et al. (2008). However, our results differed drastically from those of Ozcan et al. (2006), Khorsandi and Yazdi (2011), and Monteleone et al. (2016) who slope values of 5.97, 5.43 and 9.63, respectively, for the same EC_e and $EC_{1:5}$ relationships.

The differences in regression equations reported by various researchers may be due to the clay content of the soil samples, as well as the type of clay (Sonmez et al., 2008), type of salts present (Richard and Gouny, 1965; Le Brusq and Loyer, 1982), gypsum content (Khorsandi and Yazdi, 2007, 2011) equilibration times and equilibration methods (He *et al*., 2013) and the EC_e range of soil samples used to develop the conversion equations (Aboukila and Norton, 2017).

Validation of Models

Twenty-one soil samples independent of those used to generate the regressions for this study were used to validate the relationships between EC_e and the two $EC_{1:2.5}$ and $EC_{1:5}$. We used the same samples to test the models established by other researchers (Table 4).

The EC_e means predicted by the regression equations of this study were 4.83 and 4.75 $dS\ m^{-1}$ for 1:2.5 and 1:5 models, respectively. The predicted EC_e were not significantly different ($P > 0.05$) than the mean actual measured EC_e of 4.84 $dS\ m^{-1}$ in the validation soils (Table 4). The discrepancies between the average measured and predicted values are -0.27 %, and -1.99 % for 1:2.5 and 1:5 models, respectively.

The regression equations of Ozcan et al. (2006) resulted in EC_e means of 3.37 and 2.28 $dS\ m^{-1}$ for 1:2.5 and 1:5 models, respectively, which were significantly different ($P < 0.01$) than the mean actual measured EC_e (Table 4). The difference between the average measured and estimated values are -30.5 %, and -52.9 % for 1:2.5 and 1:5 models, respectively.

The EC_e means determined using the regression equations of Sonmez *et al*. (2008) were 4.86 and 4.42 $dS\ m^{-1}$ for 1:2.5 and 1:5 models, respectively. For 1:2.5 model, the predicted EC_e mean was not significantly different ($P > 0.05$) than the mean of the actual measured EC_e, while, the predicted EC_e mean from 1:5 model was significantly different ($P < 0.05$) than the mean of the actual measured EC_e (Table 4). The difference between the average measured and predicted values are 0.34 %, and -8.69 % for 1:2.5 and 1:5 models, respectively.

The computed EC_e for 1:5 soil to water ratios using the regression equations of Chi and Wang (2010), Khorsandi and Yazdi (2011), Monteleone et al. (2016), and Klaustermeier et al. (2016) were 0.98, 3.57, 5.57, and 3.31 $dS\ m^{-1}$, respectively. The calculated EC_e means were significantly different than mean of the actual measured EC_e (Table 4). The discrepancies between the average measured and calculated values are -79.7, -26.3, 14.9, and -31.7 % for Chi and Wang (2010), Khorsandi and Yazdi (2011), Monteleone *et al*. (2016), and Klaustermeier et al. (2016), respectively.

Ideally, if the predicted values of EC_e were exactly the same as the measured EC values, the slope would equal 1.0, R^2 would equal 1.0, and the *y* intercept would equal zero (Zhang *et al*., 2005). The regression line between measured and predicted values was not statistically different from the 1:1 bisecting line of the quadrant. The slope for the relationship between predicted and measured EC_e was almost 1.0 for our models (Fig. 2), indicating that both models were more accurate than other models to determine salinity of the coarse textured soil, with EC_e range between 0.29-18.35 dS m^{-1}.

Validation RMSE values were 0.61 and 0.70 dS m^{-1} for $EC_{1:2.5}$ and $EC_{1:5}$ values, respectively. Estimates for converting to saturated paste (EC_e) values using a 1:2.5 soil-to-water ratio had the lowest RMSE values (Table 4). This indicates that $EC_{1:2.5}$ estimates were closer to the measured data than the $EC_{1:5}$ estimates.

Our newly developed equations were compared with 8 equations derived from six other EC conversion studies (Fig. 3; Table 4). The same validation data set, as mentioned previously, was used for the comparisons. Among the models developed here and the other 8 models reported in the literature, our 1:2.5 and 1:5 models were the most accurate followed by the models developed by Sonmez et al. (2008) at predicting EC_e on studied soils based on RMSE, slop, R^2, and predicted EC_e values. This was expected since Sonmez et al. (2008) used soils with similar EC_e range and soil texture as the present study to develop their model.

Models developed by Chi and Wang (2010), Ozcan et al. (2006) (1:5 model), and Khorsandi and Yazdi (2011) were the least accurate at predicting EC_e from $EC_{1:2.5}$ and $EC_{1:5}$ values, with RMSE of 4.56, 2.79, and 1.87 dS m^{-1}, respectively. In contrast, Sonmez et al. (2008) and our new models were the most accurate, with RMSE of 0.90-0.98 and 0.61 to 0.70 dS m^{-1}, respectively (Table 4). With the exception of the Sonmez et al. (2008) models, all other models produced RMSE of 2.4-7 times greater than those observed for the models presented in this study.

These differences in RMSE among models are likely due to the differences in soil texture, type of clay, salts present in the soil, presence of gypsum, equilibration times and equilibration methods and EC_e range of soil samples used to establish the models.

Soil textural differences affect soil EC values in soil-to-water extracts (Hogg and Henry, 1984; Sonmez et al., 2008). The equations developed by Aboukila and Norton (2017) (Table 1) for fine textured soil of El Beheira governorate, Egypt produced RMSE of 2.40-3.14 times greater than those observed for the equations presented in this study (data not shown). Therefore, improvements in conversion equation accuracy might be gained by differentiating soils by texture.

Table 4. Comparison of 8 developed EC conversion equations with $EC_{1:2.5}$ and $EC_{1:5}$ equations developed in this study

Reference	Equation	Measured EC_e	Predicted EC_e	% difference	Slope	R^2	RMSE (dS m^{-1})
Ozcan et al. 2006 (1:2.5)	$EC_e = 3.30\ EC_{1:2.5} - 0.20$	4.84	3.37^{**}	-30.51	0.78	0.95	1.65
Ozcan et al. 2006 (1:5)	$EC_e = 5.97\ EC_{1:5} - 1.17$	4.84	2.28^{**}	-52.90	0.60	0.89	2.79
Sonmez et al. 2008 (1:2.5)	$EC_e = 4.34\ EC_{1:2.5} + 0.17$	4.84	4.86^{NS}	0.34	1.07	0.97	0.98
Sonmez et al. 2008 (1:5)	$EC_e = 8.22\ EC_{1:5} - 0.33$	4.84	4.42^{*}	-8.69	0.97	0.96	0.90
Chi and Wang 2010 (1:5)	$EC_e = 11.68\ EC_{1:5} - 5.77$	4.84	0.98^{**}	-79.73	0.77	0.56	4.56
Khorsandi and Yazdi 2011(1:5)	$EC_e = 5.43\ EC_{1:5} + 0.43$	4.84	3.57^{**}	-26.30	0.72	0.97	1.87
Monteleone et al. 2016 (1:5)	$EC_e = 9.63\ EC_{1:2.5}$	4.84	5.57^{*}	14.95	1.19	0.97	1.54
Klaustermeier et al. 2016 (1:5)	$EC_e = 10^{[1.256\ (\log EC_{1:5}) + 0.766]}$	4.84	3.31^{**}	-31.74	0.79	0.93	1.73
This study (1:2.5 Model)	$EC_e = 3.73\ EC_{1:2.5} + 0.79$	4.84	4.83^{NS}	-0.27	1.00	0.98	0.61
This study (1:5 Model)	$EC_e = 7.46\ EC_{1:5} + 0.43$	4.84	4.75^{NS}	-1.99	0.97	0.97	0.70

^{NS} Not significantly different from EC_e measurement at $\alpha = 0.1$.

*Significantly different from EC_e measurement at $\alpha = 0.05$.

**Significantly different from EC_e measurement at $\alpha = 0.01$.

RMSE, root mean square error.

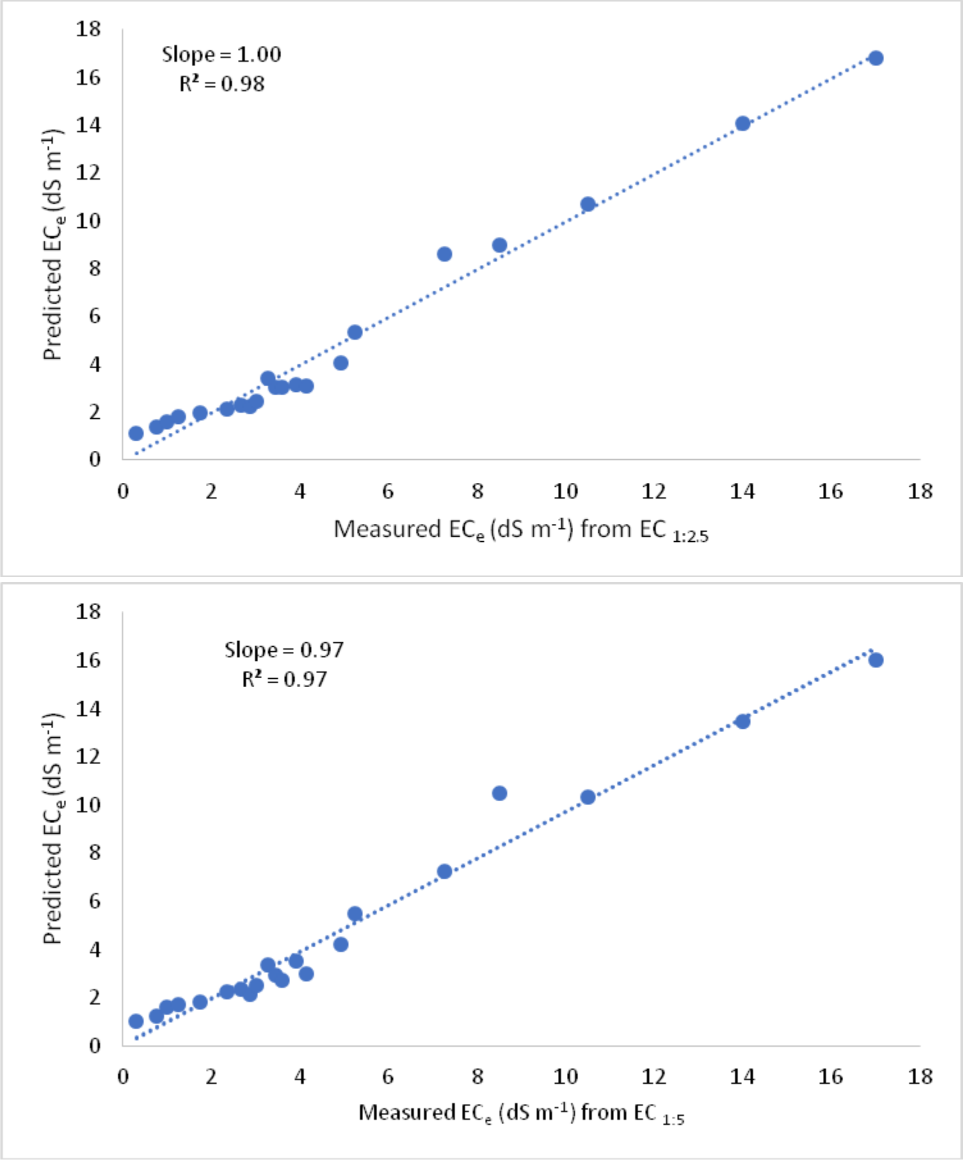

Fig. 2. Relationship between measured EC of SP extract (EC_e) and predicted EC_e from the regression equations obtained from 1:2.5 and 1:5 soil-water extracts for 21 samples used to validate the models shown in Fig1.

The new models presented here reduced errors by 2.4 to 7 times as compared with other equations reported in the literature. Therefore, our models are considering significant improvement for predicting EC_e of coarse textured soils in El Beheira governorate than previous models reported in the literature. These models will be applicable to course textured soils. As these equations are valid for soil EC_e from 0.3 to 18.3 dS m^{-1}, they can be used for soils classified as both nonsaline and saline. We highly recommend that both 1:2.5 and 1:5 models be used in soil laboratories to determine soil salinity of coarse textured soil with EC_e less than 18.35 dS m^{-1}. 1:5 soil-water extract is easier to filter. However, 1:2.5 model would be the first choice to measure EC and pH in the same extract. The soil-water suspension of (1:2.5) prepared for pH measurements can be extracted and used for further EC measurements, minimizing time and cost associated with soil salinity studies.

The maximum EC_e of soils used to develop the models was 18.35 dS m^{-1}. However, we tested both models using four other samples with very high mean EC_e of 43.2 dS m^{-1}. The means predicted EC_e were 40.9 and 41.6 dS m^{-1} for 1:2.5 and 1:5 models, respectively. The difference between the average measured and predicted values were -5.3 %, and -3.5 % for 1:2.5 and 1:5 models, respectively. We determined that both

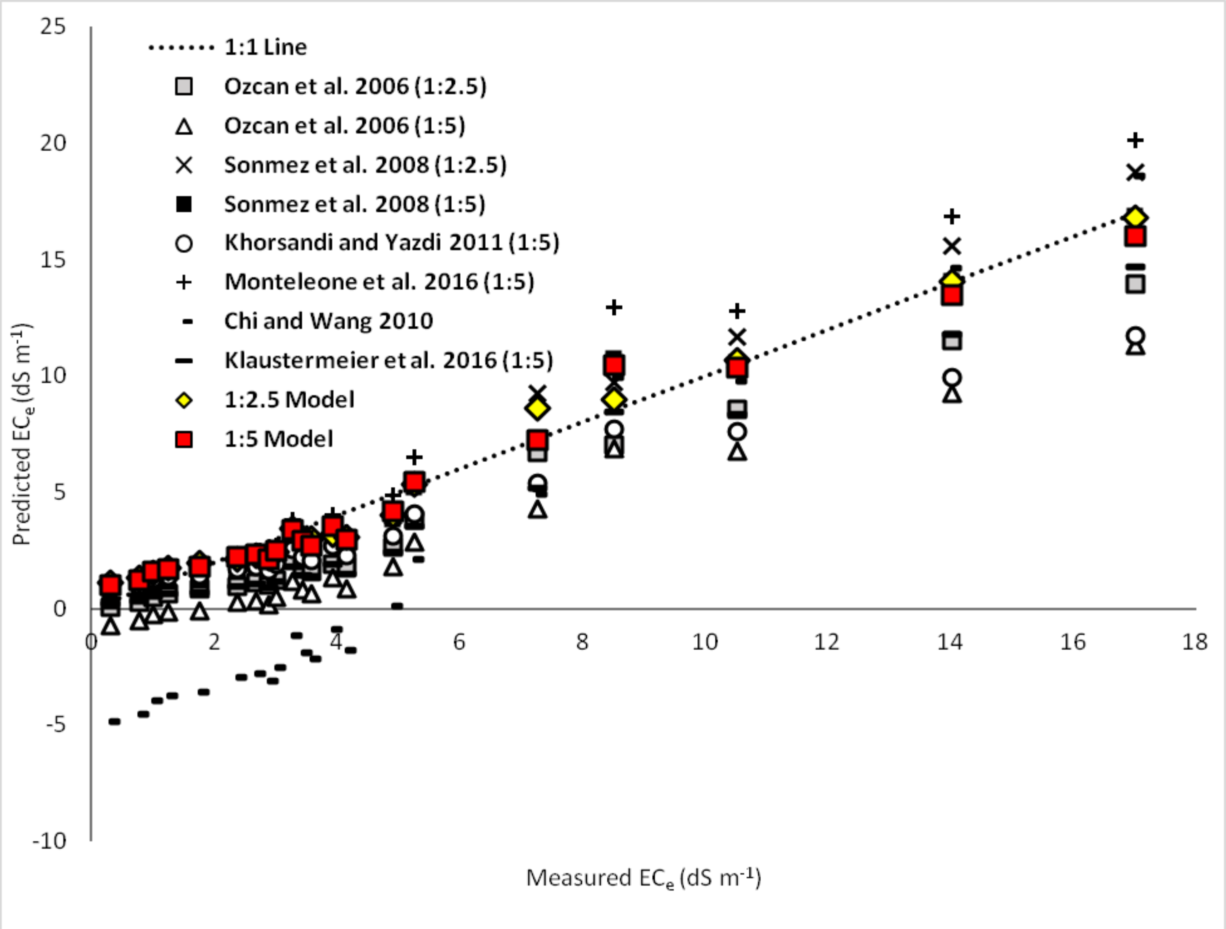

Fig 3. Comparison of 8 developed EC_e conversion equations from six previous soil salinity studies with those developed in this study. Measured values are from a set of 21 validation soil samples

models could be used to test soil salinity for soil samples outside the studied EC_e range. However, more studies are needed before it is recommended that both models be used for soil samples with EC_e greater than 18.35 dS m^{-1}.

CONCLUSION

The relationships between EC_e and both $EC_{1:2.5}$ and $EC_{1:5}$ were highly correlated (R^2 = 0.96-0.97, $P < 0.001$), indicating strong evidence that EC_e of coarse textured soils can be accurately estimated from $EC_{1:2.5}$ and $EC_{1:5}$ values using the newly developed models in this study. Based on model validations, using $EC_{1:2.5}$ to convert to EC_e had the smallest RMSE values. Therefore, if possible, the $EC_{1:2.5}$ method should be used when evaluating soil salinity levels. However, both $EC_{1:2.5}$ and $EC_{1:5}$ models reduced errors by 2.4 - 7 times as compared with other conversion equations listed in the literature. The benefits of converting results of $EC_{1:2.5}$ or $EC_{1:5}$ to EC_e are many. Soil laboratories may reduce the cost and time associated with soil salinity analysis by using these models, while still maintaining a high degree of precision and accuracy. Another benefit of measuring $EC_{1:2.5}$ is that pH measurements can be conducted on the same extract, minimizing time and cost associated with soil salinity analysis. These newly derived models will allow remediation specialist, and research scientists to assess the salinity of coarse textured soils more accurately than previous models reported in the literature. In summary, soil salinity of coarse textured soil can be accurately assessed for EC_e values between 0.3 and 18.3 dS m^{-1} using the models generated by this study.

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الملخص العربي

تقدير ملوحة عجينه التربة المشبعة باستخدام مستخلصات التربة المائية 1:2.5 و 1:5 للأراضي الخشنة القوام

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من الضروري تقدير ملوحة التربة باستخدام طريقة دقيقه وسهله الاستخدام. تعتبر طريقه قياس التوصيل الكهربي لمستخلصات التربة المائية هي الطريقة الشائعة لتقدير ملوحة التربة وذلك لسهولتها بالمقارنة بالطريقة الموصي بها وهي مستخلصات عجينة التربة المشبعة (EC_e). ونظرا لان درجه تحمل المحاصيل للملوحة واستصلاح الأرض الملحية تعتمد على قيم التوصيل الكهربي لمستخلص عجينه التربة المشبعة (EC_e) فانه من الضروري تحويل قيم التوصيل الكهربي لمستخلصات التربة المائية الى ما يقابلها من (EC_e). اهداف هذه الدراسة هو استحداث نماذج رياضيه لاستنتاج قيم (EC_e) وذلك من قيم التوصيل الكهربي لمستخلصات التربة المائية 1:2.5 و 1:5 ($EC_{1:2.5}$, $EC_{1:5}$) للأراضي الخشنة القوام. تم جمع مائه وست وثلاثون عينه تربه خشنة القوام من محافظه البحيرة، مصر. منها 115 عينه استخدمت لاستنتاج النماذج الرياضية، في حين تم استخدام 21 عينه للتحقق من صحة هذه النماذج. قدر التوصيل الكهربي في مستخلصات التربة المائية (1:2.5, 1:5) وكذلك في مستخلص عجينه التربة المشبعة. تم استخدام معادلات الانحدار الخطى للتنبؤ بهذه النماذج. أظهرت النتائج وجود علاقة ارتباط قوية ($R^2 =$ 0.96 to 0.97, $P < 0.001$) بين التوصيل الكهربي لعجينة التربة المشبعة (EC_e) ومستخلصات التربة المائية ($EC_{1:2.5}$, $EC_{1:5}$) وذلك للتربة ذات المدى من (EC_e) يتراوح بين 0.3 الى 18.3 $dS\ m^{-1}$. مجموعه العينات المستقلة والمستخدمة في التحقق من صحة النماذج الرياضية أظهرت ان قيم معامل الارتباط R^2 وميل خط الانحدار بين قيم (EC_e) المحسوبة باستخدام هذه النماذج من قيم ($EC_{1:2.5}$, $EC_{1:5}$) وقيم (EC_e) الفعلية كانت قريبه جدا من الوحدة. ومن ناحية أخرى، فان النماذج المستحدثة في هذه الدراسة قللت من خطأ تقدير (EC_e) بمعدل 2.4 الى 7 مرات وذلك عند مقارنتها بثمانية نماذج أخرى من دراسات اخرى تم الإشارة اليها في البحث. النتائج المتحصل عليها من هذه الدراسة تؤكد على ان النماذج الرياضية المستحدثة يمكن استخدامها لتقدير ملوحة التربة للأراضي خشنة القوام بدلا من طريقه عجينه التربة المشبعة وبذلك نتغلب على نقص الإمكانيات وأيضا نقلل من الوقت والجهد والتكاليف.