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Estimating the electrical conductivity of a saturated soil paste extract (EC_e) from 1:1($EC_{1:1}$), 1:2($EC_{1:2}$) and 1:5($EC_{1:5}$) soil:water suspension ratios, in calcareous soils from the Mediterranean Islands of Malta

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ABSTRACT

The standard method to determine soil salinity is by measuring the electrical conductivity (EC) of a saturated soil paste extract (EC_e). Models that convert EC of soil:water suspensions ($EC_{(soil:water)}$) to EC_e are soil specific and are not universal models. This study aimed to develop models to convert $EC_{(1:1;\ 1:2;\ 1:5)}$ to EC_e for the calcareous soil of Malta. Moreover, the effect that soil texture, carbonate and organic matter content might have on these models was investigated. Using 114 soil samples with contrasting textural, carbonate and organic matter characteristics, the general models followed the equation $EC_e = 10^{(a(\log EC(soil:water))+b)}$ with good correlation coefficients ($r^2 = 0.91–0.93$, $p < .001$). Models specific to fine and medium textured soil, soils with carbonate content between 35% and 50%, and soils with organic matter content between 2.5% and 4.2% showed a higher correlation coefficient (mean $r^2 = 0.96$). Validation of the models using 22 independent soil samples showed that the general models are reliable (RMSE = 0.93, 0.87, 0.97 dS m^{-1}; NSE = 0.96, 0.97 and 0.95 for 1:1, 1:2 and 1:5, respectively). Except for the models developed from coarse textured soil, all the parameter-specific models were reliable. This study suggests that the general models could be used for soils of Malta having contrasting characteristics except for those with high sand content.

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Dilution factor; regression equation; salinity; salt affected soil; soil carbonates; soil organic matter

Introduction

Soil salinity is caused by high levels of dissolved ions such as sodium (Na^+), potassium (K^+), calcium (Ca^{++}), magnesium (Mg^{++}), chloride (Cl^-), sulfate (SO_4^-), and bicarbonate (HCO_3^-), and is one of the major threats to soil. Salinity not only increases osmotic suction and toxicities (Castillo et al. 2007; Läuchli and Epstein 1990), which will affect crop yield, but also, in the long run, damages soil structure (Rengasamy and Olsson 1991), causing adverse effects on its stability, water infiltration and drainage. Soil microbial community structure and activity are also affected by high salinity (Rath et al. 2019; Wichern, Wichern, and Joergensen 2006). Saline soils make up more than 3% of the topsoil and 6% of the subsoil of the planet (FAO 2021), and those that are mostly affected occur in arid or semi-arid regions like the Mediterranean, where salinity is caused by low rainfall coupled with a high rate of evaporation. In agricultural soil, this is often aggravated by irrigation, generally with water that is high in dissolved solids, and excessive use of fertilizers. In small islands like Malta, sea spray may also contribute to the problem.

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Table 1. Linear regression equations from various studies to convert $EC_{1:5}$ to EC_e.

Study	Regression Equation	r^2
Aboukila and Norton (2017)	$EC_e = 5.04*EC_{1:5} + 0.37$	0.93
Aboukila and Abdelaty (2017)	$EC_e = 7.46*EC_{1:5} + 0.43$	0.97
Chi and Wang (2010)	$EC_e = 11.74*EC_{1:5} - 6.15$	0.94
	$EC_e = 11.04*EC_{1:5} - 2.41$	
	$EC_e = 11.68*EC_{1:5} - 5.77$	
Kargas et al. (2018)	$EC_e = 6.53*EC_{1:5} - 0.108$	0.931
Khorsandi and Yazdi (2011)	$EC_e = 5.37*EC_{1:5} + 0.57$	
	$EC_e = 5.60*EC_{1:5} - 4.37$	
Ozcan et al. (2006)	$EC_e = 5.97*EC_{1:5} - 1.17$	0.94
Park et al. (2019)	$EC_e = 8.70*EC_{1:5}$	0.90
Sonmez et al. (2008)	$EC_e = 8.22*EC_{1:5} - 0.33$	0.98
	$EC_e = 7.58*EC_{1:5} + 0.06$	0.99
	$EC_e = 7.36*EC_{1:5} - 0.24$	0.99
Visconti Reluy and De Paz (2012)	$EC_e = 5.70*EC_{1:5} - 0.2$	

The standard method to determine soil salinity is by measuring the electrical conductivity (EC) of the water extracted from a saturated soil-water paste (SP). This is referred to as the EC of the saturated extract (EC_e), and soils are generally considered saline if the EC_e is equal to and greater than 4.0 dS m^{-1}. This method is tedious and very time consuming, and therefore simpler methods that involve the preparation of soil-water suspensions in mass ratios generally of 1:5 ($EC_{1:5}$), 1:2 ($EC_{1:2}$), and 1:1 ($EC_{1:1}$) are used, especially in the routine analysis of soil used in agricultural operations. As the water quantity in the suspension increases, the EC decreases mainly due to the dilution effect. Converting $EC_{(soil:water)}$ to the EC_e equivalent is not achieved by simply multiplying by the dilution factor, as factors such as soil texture, organic matter (OM) content, levels of gypsum, and the methodology itself, such as the amount of water used in the suspension and the time of equilibrium, play an important role in how much ions are extracted from the soil matrix into the soil solution. Larger dilutions, such as the 1:5 ratio, and longer and more vigorous shaking of the suspensions, will increase the solubility of certain ions present in the soil (He et al. 2013; Sonmez et al. 2008), while on the other hand, high soil clay content might retain more ions from dissolving. Moreover, the soil:water suspension methods do not simulate soil water conditions in the field (Rhoades et al. 1996) and therefore are also inaccurate in this respect. A number of models (Table 1) have been developed to convert $EC_{(soil:water)}$ to EC_e for various soils, where different extents of salinity, soil texture and methodologies were considered. Although many researchers have reported high correlation between EC_e and the various soil:water suspension methods, differences between the models are evident, as each one is specific to the soil type it was developed from. Therefore, there is no universal conversion model that could be used for all soil types from different regions. The soils of Malta are calcareous with moderate to high clay content and are low in OM. The Mediterranean climate together with extensive cultivation and irrigation, generally with water containing a moderately high level of dissolved solids, lead to an increase in soil salinity.

The objective of this research was to investigate the relationship between EC_e and $EC_{1:5}$, $EC_{1:2}$ and $EC_{1:1}$ and develop a conversion model for these calcareous soils. Moreover, the effect that varying levels of carbonate and OM, and different textural characteristics might have on these models was investigated. Several conversion models have been developed considering texture as a factor, however very few have considered carbonate and OM content.

Materials and methods

Soil sampling

Soil samples were collected from 136 randomly selected sites from the islands of Malta and Gozo (Figure 1). The islands are located in the center of the Mediterranean Sea and have an area of approximately 316 km^2. The climate is typically Mediterranean with wet mild winters and dry hot summer and with an annual average rainfall of around 600 mm. The geology is sedimentary limestone

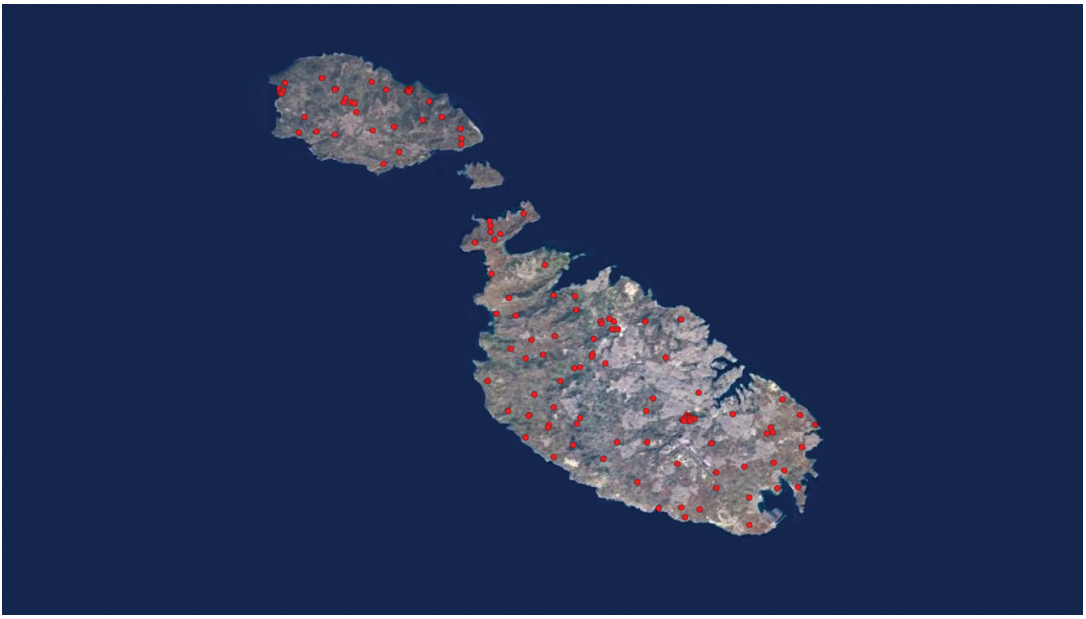


Figure 1. Sampling locations from the islands of Malta and Gozo. Source: Google Maps 2023.

deposited during late Oligocene to late Miocene, which together with low rainfall, results in the formation of shallow soils that are calcareous.

The soil sampling sites varied from cultivated, irrigated, unirrigated and abandoned fields together with soil from the natural environment, mainly the garrigue. The samples were obtained from five separate points across each site, from depths down to 30 cm. From the garrigue, the sample depth was less than 10 cm, as the soil here is shallow. The samples from each five points were mixed to produce one bulk sample, which was then air dried for a few days and crushed lightly to pass through a 2 mm sieve. Soil texture was determined by the hydrometer method (Van Reeuwijk 2002), the OM content was determined according to the Walkley and Black method (Walkley and Black 1934) and the carbonate content by the CO_2-loss method. The textural class of the soil was determined using a USDA soil textural triangle.

Preparation of the soil saturated paste and soil:water suspensions

The SP was prepared by adding small increments of deionized water to 200 g of soil in a glass container and mixing with a glass rod until a consistency as described by Rhoades et al. (1996) was produced. The paste was covered with cling film and allowed to equilibrate for 18 h at 25°C following which the water was extracted by suction through a filter paper (Whatmann no. 42) in a Buchner funnel. The electrical conductivity of the soil paste extract (EC_e) was measured with a Thermo Scientific Orion 3-Star benchtop conductivity meter taking all the necessary precautions.

For the soil:water suspension methods (1:1, 1:2 and 1:5), deionized water was added to 10 g of soil according to the required ratio in polypropylene tubes which were then shaken at 180 rpm for 60 min at 25°C. The tubes were then centrifuged at 3500 rpm for 5 min and the EC of the supernatant was determined as described for the EC_e. For each soil sample, the SP extraction and all the other soil:water suspensions were carried out in triplicate.

Data analysis

Spearman rank correlation was carried out to test for correlations between EC_e, $EC_{(1:1;\ 1:2;\ 1:5)}$, sand, silt, clay, OM and carbonate content in the soils. The relationship EC_e vs $EC_{(1:1,\ 1:2,\ 1:5)}$ was tested by linear regression using 114 soil samples that were selected at random from the 136 soil samples. As the data were not normally distributed, to satisfy the conditions for linear regression, these were $\log_{10}$-transformed prior to the regression analysis. To investigate whether different textural characteristics, carbonate and OM content have an effect on the EC_e vs $EC_{(1:1,\ 1:2,\ 1:5)}$ relationship, linear regression was repeated after the data were grouped. For this comparison, the data from the soil samples were grouped under fine, medium and coarse texture; under (0–35%), (35–50%) and (50–80%) carbonate content; and under (0–2.5%) and (2.5–4.2%) OM content.

Verification and validation of the regression model equations was carried out using the remaining 22 soil samples that were not used to generate the regression models. The performance of the models was tested using the root mean square error (RMSE) and the Nash-Sutcliffe prediction efficiency (NSE) according to the following equations:

$$RMSE = \sqrt{\frac{1}{N}\sum_{m=1}^{N}(mEC_e - pEC_e)^2}$$

$$NSE = 1 - \frac{\sum_{m=1}^{N}(mEC_e - pEC_e)^2}{\sum_{m=1}^{N}(mEC_e - m`EC_e)^2}$$

where N is the number of samples, pEC_e is the predicted EC by the models, mEC_e is the measured EC, and $m`EC_e$ is the arithmetic mean of the measured EC over N observations. The model equations were also compared with models developed for different soils by other researchers. Statistical analyses were carried out using Sigma Plot statistical software (Systat Software, Inc, San Jose, CA).

Results and discussion

Electrical conductivity and other characteristics of the soils

The salinity, OM and carbonate content, and textural characteristics of the soils are shown in Table 2. Most of the soil sampled were highly calcareous and with low OM content. In terms of classification, the sampled soils were mainly Calscisols; however, examples of Regosols, Leptosols, Luvisols, Vertisols and Cambisols were also represented. More than 57% of the soils had a clay content greater than 25% and in more than 71% this was greater than 20%. The textural classes (USDA) were clay loam (33%), loam (16%), clay (14%), silt loam (14%), sandy loam (10%), silty clay loam (5%), sand (4%), sandy clay loam (2%), loamy sand (1%), and silty clay (1%). Therefore, most of the sampled soil corresponded to medium and to fine soil textures. These characteristics are typical of the soils of the islands (Lang 1960). Salinity was represented over a wide range, with approximately 45% of the soil having an EC_e of less than 2.0 dS m^{-1}. In 33% it ranged from 2.0 dS m^{-1} to 4.0 dS m^{-1}, and in 22% salinity was greater than 4.0 dS m^{-1}. Moreover, about 8% had an EC_e greater than 10 dS m^{-1}. The mean EC_e of the samples

Table 2. Descriptive statistics of the salinity, texture, OM, and carbonate content of the soils used in this study.

	EC_e (dS *m*-^{1})	$EC_{1:1}$ (dS m^{-1})	$EC_{1:2}$ (dS m^{-1})	$EC_{1:5}$ (dS m^{-1})	OM %	Carbonate %	Sand %	Silt %	Clay %
Mean	3.75	1.96	1.12	0.53	2.3	38.8	37.6	35.5	26.9
Median	2.13	1.13	0.66	0.31	2.2	36.1	33.0	34.5	27.5
Max	26.73	16.03	8.78	4.09	4.2	80.6	100.0	74.4	61.
Min	0.73	0.35	0.20	0.12	0.0	1.1	5.0	0.0	0.0
n	114	114	114	114	114	114	114	114	114

Table 3. Spearman rank order correlation between EC_e and sand, silt, clay, OM and carbonate content.

	Sand	Silt	Clay	OM	Carbonate	EC_e
Sand	1.00	***−0.705	***−0.610	*−0.235	*** 0.516	0.134
Silt		1.00	0.0419	***0.306	*−0.225	−0.0202
Clay			1.00	*0.218	***−0.419	−0.152
OM				1.00	*−0.194	**0.269
Carbonate					1.00	*0.216
EC_e						1.00

*** denotes ($p < .001$), ** denotes ($p < .01$), * denotes ($p < .05$).

was 1.9 times higher than the mean $EC_{1:1}$, 3.4 times higher than the mean $EC_{1:2}$, and 7.1 times higher than the mean $EC_{1:5}$; all the means were significantly different ($p < .001$). These values show that as the amount of water in relation to the soil increased, the EC of the solution decreased, mainly due to the dilution effect. This has also been reported by others (Hogg and Henry 1984; Kargas et al. 2018; Ozcan et al. 2006); however, the reported relationship between the mean EC_e and the mean $EC_{soil:water}$ at various dilutions are different from these values. For example, Sonmez et al. (2008) reported a mean EC_e 3.5 times greater than $EC_{1:2.5}$ and 5.7 times greater than $EC_{1:5}$. Aboukila and Abdelaty (2017) reported an EC_e 4.5 times greater than $EC_{1:2.5}$, and 8.3 times greater than $EC_{1:5}$.

Carbonate content was moderately positively correlated with sand content ($r_s = 0.516$; $p < .001$) and weakly negatively correlated with clay and silt ($r_s = −0.419$; $p < .001$ and −0.225; $p < .05$ respectively) (Table 3). Organic matter was weakly negatively correlated with sand and weakly positively correlated with silt and clay content ($r_s = 0.306$; $p < .001$ and −0.235; $p < .05$ respectively). The correlation between the sand, silt and clay fractions was as expected, since as the level of one increases, the level of the other two generally decrease. No significant correlation was shown between the soil EC_e and the level of sand, silt, and clay in the soil. This was also confirmed by an analysis of variance on the EC of the soil samples when grouped into contrasting textural classes ($p = .465$). A very weak positive correlation between EC and carbonate and OM content ($r_s = 0.216$ and 0.269, respectively; $p < .05$) was observed. These results suggest that the level of salinity in these soils is not mainly dependent on the soils' physical properties. Other factors such as agricultural management, irrigation, low precipitation, high evapotranspiration and in some places, the closeness to the coast, could be the main factors in determining salinity in these soils.

Linear regression relationships of EC_e with $EC_{(soil:water)}$ suspensions; general models

The model equations generated from the linear regressions of the $\log_{10}$-transformed EC data ($n = 114$) are presented in Figure 2 and Table 4. EC_e was highly correlated with $EC_{1:1}$ ($r^2 = 0.93$, $p < .001$), $EC_{1:2}$ ($r^2 = 0.93$, $p < .001$) and $EC_{1:5}$ ($r^2 = 0.91$, $p < .001$). Different soil:water ratios affected both the slope and the intercept of the regression model in a way that as the dilution increased, both the slope and the intercept of the regression line increased, indicating that a higher water ratio increases dilution. This trend is similar to what was observed by other researchers (Table 4), who all reported an increase in slope and intercept as the dilution increases.

As soil texture can affect the EC of a soil:water suspension (Hogg and Henry 1984), the soils were divided into three groups according to texture. These included a coarse textured soil group comprising sand and loamy sand ($n = 7$) with EC_e ranging from 1.136 to 8.77 dS m^{-1}, a medium textured soil group comprising sandy loam, loam, silt loam, sandy clay loam and clay loam ($n = 85$) with EC_e ranging from 0.727 to 24.98 dS m^{-1}, and a fine soil group comprising silty clay loam, silty clay and the clay ($n = 22$) with EC_e ranging from 0.987 to 26.73 dS m^{-1}. The mean EC_e of the three groups were not significantly different ($p = .565$). Linear regression was performed for each group and the models (referred to here as parameter-specific) generated from each soil:water ratio (Table 4) were compared with the general models obtained from the 114 soil samples using analysis of covariance. For all soil:water ratios, the regression model obtained from the coarse textured soil group was significantly different from the

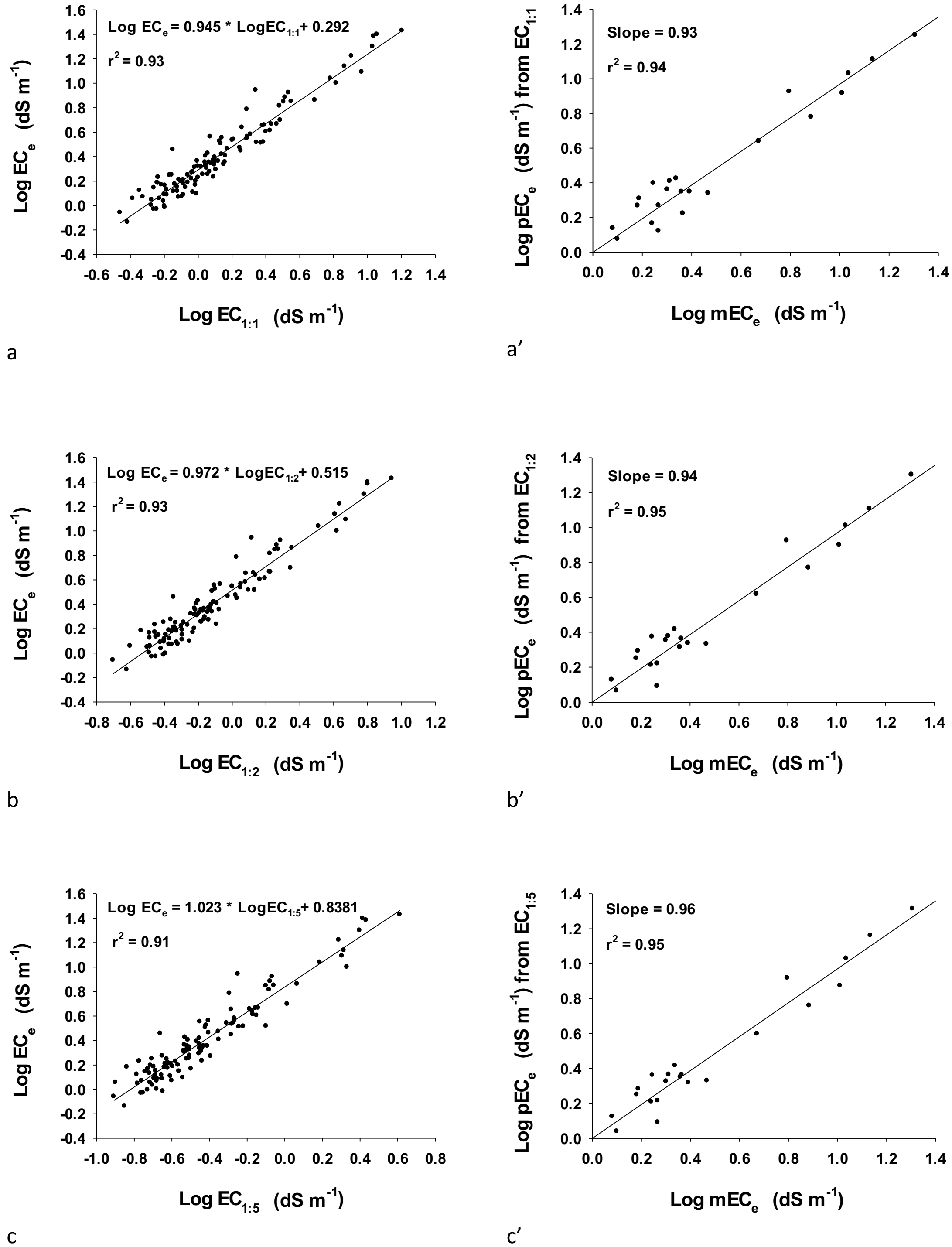


Figure 2. Relationships of EC_e with the $EC_{1:1}$(a), $EC_{1:2}$ (b) and $EC_{1:5}$ (c), and validation of the linear regression equations for EC_e vs $EC_{1:1}$ (a′), EC_e vs $EC_{1:2}$ (b′) and EC_e vs $EC_{1:5}$ (c′).

general models and the other parameter-specific models obtained from the medium and fine textured soil groups. This can also be seen from the slope and the intercept of the equations (Table 4). For every soil:water suspension ratio, the slope and the intercept of the equations developed from the coarse textured soil group are much higher than those of the equations developed from the medium and fine textured soil groups, and from the general equations generated from the 114 samples. This indicates that the general models generated from the 114 sampled soils can be used for soils of fine and medium texture but might not work well for soils with high sand content as they might underestimate the result when used to convert $EC_{soil:water}$ to EC_e. That said, it should be noted that the number of samples comprising coarse textured soils was small ($n = 7$) and a higher number of samples might have produced a more reliable result. The fact that the differences between the general model and those generated from the fine and medium textured soil groups were not significant for all the soil:water ratios was somehow expected when considering that the majority of the soils used to generate the general models were of the medium and fine textural category. However, although the difference between these models was not significant, compared with the general model, the parameter-specific models for the individual textural classes might improve prediction for their respective textural class as their r^2 is slightly higher. The differences in the models between the coarse and medium/fine textured soil groups may be attributed to a number of soil properties, however the main factor could be the clay content, although ionic composition, and the level of salinity itself might contribute as well. Increasing clay levels in soil, increases ion retention and the saturation percentage. Therefore, less ions are released in solution as the clay content increases, and increasing saturation percentage decreases the dilution factor for the conversion of $EC_{soil:water}$ to EC_e. This highly contrasts with soils that are rich in sand, where ion retention will be poor and most of the salts will readily dissolve in solution. Other researches also reported increasing slopes and intercepts as the sand content of the soil increased (Chi and Wang 2010; Franzen 2007; Hossain et al. 2020; Sonmez et al. 2008).

The soils were also divided into three groups according to their carbonate content. A "low" carbonate content soil group (<35% carbonate; $n = 51$) with EC_e ranging from 0.929 to 12.32 dS m^{-1}, a "medium" carbonate content soil group (35–50% carbonate; $n = 40$) with EC_e ranging from 0.872 to 26.73 dS m^{-1}, and a "high" carbonate content soil group (>50% carbonate; $n = 23$) with EC_e ranging from 0.727 to 24.07 dS m^{-1}. In this instance, the mean EC_e of the high carbonate group was significantly greater that the low carbonate group ($p = .023$). The model equations from the linear regression (Table 4) and analysis of covariance indicated that the models for the soils with low and medium carbonate content were similar to the general model generated from the 114 soil samples for all the soil:water suspensions. The model generated for the soils with high carbonate content was significantly different from the general model at the 1:5 and the 1:1 soil:water ratios, but not at the 1:2 ratio, although at this ratio the regression line for this model still indicated a drift from the other models. The slope and the intercept of the equations did not indicate large differences from the general equations especially in those models generated by the soil with medium carbonate content, where both the slope and the intercept are very similar to those of the general model. The models from the soil with low carbonate content have slightly lower slopes, but the intercepts are very similar to those of the general equation. The models from the soils with high carbonate content also have similar slopes, but the intercepts are slightly higher. This indicates that for soils with high carbonate content, the general model might underestimate the result of an $EC_{soil:water}$ to EC_e conversion. Although not as much as pronounced, the difference in the model from high carbonate soil could be compared to that of the model from the sandy soil. This similarity could be explained by the fact that there is a positive correlation between sand content and carbonate content, which might indicate that the increase in carbonate in the samples is due to an increase in sand content.

Like clay, OM adsorbs ions and thus might influence their release into solution. To test whether levels of OM in soil have an effect on the model, the soil samples were divided into two groups based on their OM content. A "low" OM content group that included soils with an OM content of less than 2.5% ($n = 70$) with EC_e ranging from 0.727 to 24.98 dS m^{-1}, and a "high" OM content group with an OM content ranging from 2.5% to 4.2% ($n = 44$) and EC_e ranging from 0.928 to 26.73 dS m^{-1}.

Table 4. Relationship between EC_e and $EC_{1.5}$, $EC_{1:2}$, $EC_{1:1}$ for all the sampled soil (general model) and for soil grouped according to contrasting characteristics (parameter specific model), and comparison of validation results for this study and studies reported by other researchers.

Study	N	Equation	r^2	RMSE dS m^{-1}	NSE
This study (All soil 1:5)	114	$EC_e = 10^{1.023*Log\ (EC1:5)\ +\ 0.838}$	0.91	0.93	0.96
	114	$EC_e = 10^{0.972*Log\ (EC1:2)\ +\ 0.515}$	0.93	0.87	0.97
This study (All soil 1:1)	114	$EC_e = 10^{0.945*Log\ (EC1:1)\ +\ 0.292}$	0.93	0.97	0.96
This study (Fine Textured Soil 1:5)	22	$EC_e = 10^{1.101*Log\ (EC1:5)\ +\ 0.801}$	0.96	1.07	0.95
This study (Fine Textured Soil 1:2)	22	$EC_e = 10^{1.048*Log\ (EC1:2)\ +\ 0.456}$	0.96	1.03	0.96
This study (Fine Textured Soil 1:1)	22	$EC_e = 10^{0.992*Log\ (EC1:1)\ +\ 0.231}$	0.96	1.16	0.94
This study (Medium Textured Soil 1:5)	85	$EC_e = 10^{1.043*Log\ (EC1:5)\ +\ 0.849}$	0.93	0.98	0.96
This study (Medium Textured Soil 1:2)	85	$EC_e = 10^{0.985*Log\ (EC1:2)\ +\ 0.521}$	0.94	0.85	0.97
This study (Medium Textured Soil 1:1)	85	$EC_e = 10^{0.960*Log\ (EC1:1)\ +\ 0.292}$	0.94	0.90	0.97
This study (Coarse Textured Soil 1:5)	7	$EC_e = 10^{1.261*Log\ (EC1:5)\ +\ 1.162}$	0.91	15.29	−3.23
This study (Coarse Textured Soil 1:2)	7	$EC_e = 10^{1.160*Log\ (EC1:2)\ +\ 0.729}$	0.93	7.19	−1.18
This study (Coarse Textured Soil 1:1)	7	$EC_e = 10^{1.131*Log\ (EC1:1)\ +\ 0.460}$	0.92	6.40	−0.73
This study (Carbonate 0–35% 1:5)	51	$EC_e = 10^{0.985*Log\ (EC1:5)\ +0.796}$	0.88	1.18	0.94
This study (Carbonate 0–35% 1:2)	51	$EC_e = 10^{0.941*Log\ (EC1:2)\ +0.488}$	0.90	1.22	0.94
This study (Carbonate 0–35% 1:1)	51	$EC_e = 10^{0.908*Log\ (EC1:1)\ +0.274}$	0.90	1.44	0.91
This study (Carbonate 35–50% 1:5)	40	$EC_e = 10^{1.026*Log\ (EC1:5)\ +0.834}$	0.95	0.93	0.96
This study (Carbonate 35–50% 1:2)	40	$ECe = 10^{0.977*Log\ (EC1:2)\ +0.514}$	0.96	0.88	0.97
This study (Carbonate 35–50% 1:1)	40	$EC_e = 10^{0.968*Log\ (EC1:1)\ +0.278}$	0.97	0.94	0.96
This study (Carbonate 50–80% 1:5)	23	$EC_e = 10^{1.009*Log\ (EC1:5)\ +0.891}$	0.90	1.20	0.90
This study (Carbonate 50–80% 1:2)	23	$EC_e = 10^{0.95*Log\ (EC1:2)\ +0.564}$	0.91	0.90	0.91
This study (Carbonate 50–80% 1:1)	23	$EC_e = 10^{0.914*Log\ (EC1:1)\ +0.360}$	0.91	0.93	0.91
This study (OM 0–2.5% 1:5)	70	$EC_e = 10^{1.078*Log\ (EC1:5)\ +0.884}$	0.90	1.42	0.92
This study (OM 0–2.5% 1:2)	70	$EC_e = 10^{1.005*Log\ (EC1:2)\ +0.539}$	0.91	0.97	0.96
This study (OM 0–2.5% 1:1)	70	$EC_e = 10^{0.970*Log\ (EC1:1)\ +0.314}$	0.91	0.86	0.97
This study (OM 2.5–4.2% 1:5)	44	$EC_e = 10^{0.995*Log\ (EC1:5)\ +0.796}$	0.95	1.17	0.94
This study (OM 2.5–4.2% 1:2)	44	$EC_e = 10^{0.936*Log\ (EC1:2)\ +0.486}$	0.96	1.26	0.93
This study (OM 2.5–4.2% 1:1)	44	$EC_e = 10^{0.963*Log\ (EC1:1)\ +0.251}$	0.97	1.19	0.94
Aboukila and Abdelaty (2017)	-	$EC_e = 7.46*EC_{1:5} +0.43$	0.97	1.19	0.94
Aboukila and Abdelaty (2017)	-	$EC_e = 5.04*EC_{1:5} +0.37$	0.93	1.86	0.85
Chi and Wang (2010)	-	$EC_e = 11.68*\ EC_{1:5} - 5.77$	0.94	4.36	0.20
Franzen (2007)	-	$EC_e = 3.01*EC_{1:1} - 0.77$	-	3.5	0.48
Gharaibeh, Albalasmeh, and El Hanandeh (2021)	-	$EC_e = 8.467*EC_{1:5}$	0.83	1.67	0.88
Hogg and Henry (1984)	-	$EC_e = 2.75*EC_{1:1} - 0.69$	0.98	2.68	0.70
Kargas et al. (2018)	-	$EC_e = 6.53*EC_{1:5} - 0.11$	0.93	1.06	0.95
Kargas et al. (2018)	-	$EC_e = 1.83*EC_{1:1} +0.117$	0.97	0.86	0.97
Khorsandi and Yazdi (2011)	-	$EC_e = 5.43*EC_{1:5} +0.43$	0.95	1.52	0.90
Klaustermeier et al. (2016)	-	$EC_e = 10^{1.256*\ Log\ (EC1:5)\ +\ 0.766}$	0.91	1.4	0.92
Klaustermeier et al. (2016)	-	$EC_e = 10^{1.2533*Log\ (EC1:1)\ +\ 0.3533}$	0.97	6.40	−0.73
Ozcan et al. (2006)	-	$EC_e = 5.97*EC_{1:5} - 1.17$	0.94	2.21	0.79
Ozcan et al. (2006)	-	$EC_e = 1.93*EC_{1:1} - 0.57$	-	1.00	0.96
Park et al. (2019)	-	$EC_e = 8.70*EC_{1:5}$	0.90	1.86	0.85
Sonmez et al. (2008) (Sandy soil)	-	$EC_e = 8.22*EC_{1:5} - 0.33$	0.98	1.34	0.92
Sonmez et al. (2008) (Sandy soil)	-	$EC_e = 2.72*EC_{1:1} - 1.27$	0.99	2.36	0.77
Sonmez et al. (2008) (Loam)	-	$EC_e = 7.58*EC_{1:5} - 0.06$	0.99	1.09	0.95
Sonmez et al. (2008) (Loam)	-	$EC_e = 2.15*EC_{1:1} - 0.44$	0.99	1.07	0.95
Sonmez et al. (2008) (Clay soil)	-	$EC_e = 7.36*EC_{1:5} - 0.24$	0.99	0.96	096
Sonmez et al. (2008) (Clay soil)	-	$EC_e = 2.03*EC_{1:1} - 0.41$	0.99	0.92	0.96
USDA (1954)	-	$EC_e = 3.00*\ EC_{1:1}$	-	3.94	0.35
Visconti Reluy and De Paz (2012)	-	$EC_e = 5.70*EC_{1:5} - 0.20$	0.89	1.67	0.88
Zhang et al. (2005)	-	$EC_e = 1.79*EC_{1:1} +1.46$	0.85	1.44	0.91

Although the mean EC_e in the high OM content group was larger, the difference between the two groups was not statistically significant ($p = .51$). The model equations for the linear regressions for each group (Table 4) and an analysis of covariance indicated that the models generated from the soils with different OM content were similar to the general model generated from the 114 soil samples for all soil:water suspensions. It can therefore be assumed that the level of OM in this range of salinity and in these soils has very little effect on the model.

Validation of the models

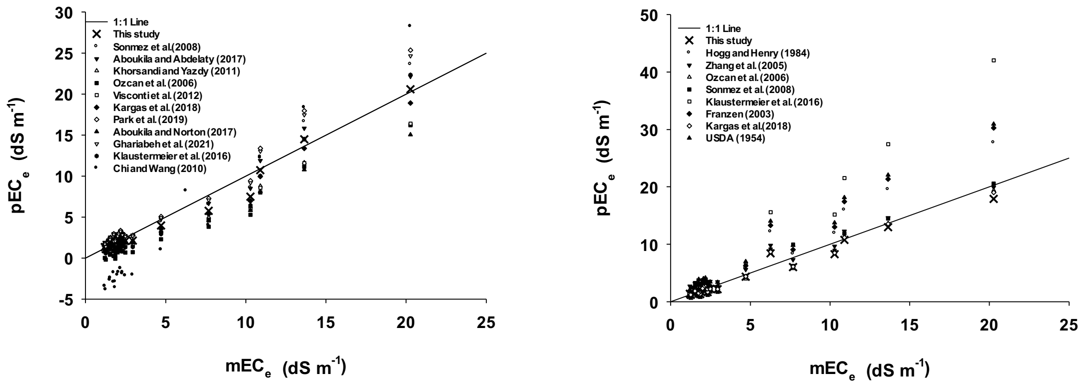
The general models were verified and validated using the measured EC_e (mEC_e) of the 22 independent soil samples that were not included in producing these general models. The characteristics of these 22 soil samples are shown in Table 5. Verification was carried out by comparing the EC_e of the 22 soils that was predicted by the general models (pEC_e), with the actual measured EC_e (mEC_e) using paired t-test and linear regression. The mEC_e data were not statistically different from the pEC_e data (p = .302; 0.317 and 0.524 for $CE_{1:1}$, $CE_{1:2}$ and $CE_{1:5}$ respectively). The linear regression between mEC_e and the pEC_e predicted by the models for $CE_{1:1}$, $CE_{1:2}$ and $CE_{1:5}$ showed that the slopes of the regression were close to 1 with r^2 being greater than 0.96 (Figure 2). Validation was tested by determining the RMSE and NSE. An NSE value close to unity indicates a perfect model, which indicates a perfect match of the model to the observed data, while small RMSE values indicate better model performance. The RMSE and NSE values are shown in Table 4. These data indicate that the general models from the three different soil:water suspension ratios perform very well, with NSE levels being above 0.98 and RMSE below 0.97 dS m^{-1}. The 1:2 soil:water suspension possibly gives better conversions than the other two suspension ratios, as the NSE and RMSE for this ratio are 0.97 and 0.87 dS m^{-1}, respectively.

The models generated from the parameter-specific soils groups (texture, carbonate and OM content) were also validated using these methods. Except for the model generated from the coarse textured soils, both NSE and RMSE indicated that the parameter-specific models performed well. The NSE and RMSE values for the general models indicate that these models perform better than most of the parameter-specific models, except for those generated from medium textured soil for the 1:2 and 1:1 suspension, although the differences in both NSE and RMSE are not large. The high RMSE and NSE values of the models from the coarse texture soil, supports what was stated previously regarding the possibility that the low number of samples (n = 7) might have affected the outcome of the models for soils rich in sand.

The general models generated from the 1:5 and the 1:1 soil:water suspensions were also compared with models developed by other researchers (Figure 3) (Table 4). Due to the shortage of available data, the 1:2 model was not included in this comparison. Compared with the reported models, the RMSE of the models from this study is low, and the NSE is close to unity. For the 1:5 suspension ratio, both RMSE and NSE are similar to those reported by Kargas et al. (2018), and for the 1:1 suspension, these are similar to those by Sonmez et al. (2008) and Ozcan et al. (2006). The models reported by Chi and Wang (2010) for the 1:5, and by Klaustermeier et al. (2016), USDA (1954) and Franzen (2007) for the 1:1, are the least accurate in predicting EC_e from 1:5 and 1:1 soil:water suspensions in these type of soils. As pointed out earlier, these differences among the various models are most likely due to differences in soil properties, such as texture, levels of salinity, mineral composition and to differences in the methodology of the analysis. The similarity of the models from this study with those reported by Kargas et al. (2018) might be due to the fact that the soils studied come from the same Mediterranean region and might have similar properties.

Table 5. Descriptive statistics of the salinity, texture, OM and carbonate content of the soils used for validation of the models.

	EC_e (dS m^{-1})	$EC_{1:1}$ (dS m^{-1})	$EC_{1:2}$ (dS m^{-1})	$EC_{1:5}$ (dS m^{-1})	OM %	Carbonate %	Sand %	Silt %	Clay %
Mean	4.669	2.434	1.396	0.660	2.7	35.9	35.9	38.7	25.5
Median	2.234	1.163	0.690	0.339	2.6	36.9	34.0	33.5	26.0
Max	20.270	10.317	6.440	2.913	7.2	62.8	93.0	74.0	46.0
Min	1.206	0.589	0.344	0.166	1.2	12.2	11.0	2.0	2.00
n	22	22	22	22	22	22	22	22	22



a b

Figure 3. Comparison of models developed by other researchers with those developed from this study. The measured values are from 22 soil samples selected at random from the 136 sampled soils. Fig a refers to $EC_{1:5}$, and figure B refers to $EC_{1:1}$.

Conclusion

The results of this study indicate that the developed general models can be used to estimate EC_e from $EC_{(1:1,\ 1:2,\ 1:5)}$ for the calcareous soils of Malta. All soil:water suspension ratios can produce a certain degree of accuracy, however, based on the regression coefficient, RMSE and NSE, using a soil:water ratio of 1:2 gives a better estimation of EC_e. The general models also work for soils of medium and fine texture as the differences between the regression equations were not significant; however, if applied for soils high in sand content, the EC_e will be underestimated. Soils with very high sand content are rare in these islands and are restricted to a small area of cultivated land on the island of Gozo. The majority of the soils on the main islands fall under the loam, clay loam and clay textural classes. This study has also shown that carbonate and OM content have very little effect on the models, as the parameter-specific model equations are similar to the general equations. This suggests that the general models can be applied to soils with a wide range of carbonate and OM content.

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