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Comparison of different methods of electrical conductivity determination for assessment of salinity in soils of coastal region, West Bengal

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Abstract
Electrical conductivity of soil saturation paste extract (ECe) was determined in soil samples (Inceptisols) collected from different locations of Canning II block, South 24 Parganas, West Bengal under coastal agro-ecosystem for assessment of soil salinity. Electrical conductivity (EC) was also determined in extracts of 1:5, 1:2.5 and 1:1 soil: water ratio and compared with ECe. Results showed high significant correlation between electrical conductivity values measured in saturated paste extracts and in extracts of different soil to water ratios. Strength of correlation for linear regression model suggested greater reliability on $EC_{(1:5)}$ for predicting ECe ($R^2 = 0.985$) than $EC_{(1:2.5)}$ ($R^2 = 0.857$) and $EC_{(1:1)}$ ($R^2 = 0.847$). A linear regression equation *viz*. ECe = 4.834 $EC_{(1:5)}$ + 0.437 is proposed for routine conversion in soils of the study region.

Keywords: Electrical conductivity, soil salinity, coastal agro-ecosystem, saturation paste, regression equation

Introduction

Soil salinity is a severe problem worldwide limiting plant growth (Al Busaidi *et al*., 2006) [3], (He *et al*., 2012, 2013) [9, 10] and is a basic factor that, to a large extent, determines soil suitability for agricultural productivity (Kargas *et al*., 2018) [14]. Globally, more than 800 Mha of land is estimated to be salt affected (FAO, 2008) [7]. An area of 6.74 Mha in India suffers from salt accumulation, out of which 3.78 Mha are sodic, whereas, 2.96 Mha are saline soils (Mandal *et al*., 2010) [17]. Moreover, by 2025 area projected under salt affected soils in India is about 13 Mha (Sharma and Chaudhari, 2012) [23]. An excess of inorganic salts in soil inhibits water uptake in plants leading to cell plasmolysis, chlorosis and leaf burning (Biswas and Biswas, 2014) [4]. Adequate knowledge of the amount and distribution of salt is therefore required for the management of saline soils (Kargas *et al*., 2018) [14]. Measuring electrical conductivity (EC) is an essential procedure in routine soil analysis being an accepted indicator of soil salinity as well as soil quality for use in crop productivity and management (U.S. Salinity Laboratory Staff, 1954; Steppuhn *et al*., 2005a, 2005b; Cooper *et al*., 2006) [30, 28, 29, 5]. Customarily, soil salinity has been defined and assessed in term of laboratory measurement of electrical conductivity of the extract of soil saturation paste (ECe) that provide a direct relationship with the field moisture range for most soils (Semiz and Atmaca, 2013; Visconti *et al*., 2010) [22, 32] and hence is the benchmark to assess soil salinity (Sonmez, *et al*., 2008) [27]. Nevertheless, preparation of saturated paste is tedious and time consuming and therefore cannot be used as a routine exercise, more so, when number of soil samples to be analyzed are large, amount of soil sample is limited and repeated samplings are to be made in the same soil (Rhoades, 1982; Hussain and Aggarwal, 1985) [20, 12]. Further, in sodic soils problem of extraction is more due to dispersion action of sodium, especially in heavy textured soils (Hussain and Aggarwal, 1985) [12]. Reliable monitoring of soil salinity based on a less laborious method than the soil saturated paste (SP) extract methodology is therefore required (Kargas *et al*., 2018) [14]. In such context soil water suspensions of different ratios (1:1, 1:2.5, 1:5 etc.) can be more easily made than obtaining saturation extracts (Sonmez *et al*., 2008) [27]. When the objectives are relative changes rather than absolute solute content, as in the case of soil salinity monitoring programmes, the wider extraction ratios have advantage of speed and greater volumes (Rhoades 1989) [21]. Therefore, for the purpose of ease and rapidity, different soil water ratios have been developed for predicting ECe and tested globally (U.S. Salinity Laboratory Staff,1954; Hogg and Henry, 1984; Hussain and Aggarwal, 1985; Rhoades, 1982; Rhoades *et al*., 1989; Slavich and Petterson, 1993, Shirokova *et al*., 2000; Franzen, 2003; Ozcan *et al*. 2006; Al Busaidi *et al*., 2006; Sonmez *et al*., 2008; Visconti *et al*., 2010; Khorsandi and Yazdi, 2011; He *et al*., 2013;Semiz and Atmaca, 2013; Klaustermeier *et al*.2016; Aboukila and Norton 2017, Aboukila and Abdelaty, 2017; Kargas *et al*., 2018) [30, 11, 12, 20, 21, 25, 24, 8, 19, 3, 27, 32, 15, 10, 22, 16, 2, 1, 14]. The benefits of converting results of 1:1, 1:2.5 and 1:5 soil: water ratio ($EC_{1:1}$, $EC_{1:2.5}$ and $EC_{1:5}$) to soil saturated paste (SP) extract (ECe) are potentially large. 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. Additional 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 (Aboukila and Abdelaty, 2017) [1].

In light of above background, the present study attempts to establish a relationship between the electrical conductivity of the soil saturated paste extract (ECe) and the electrical conductivity determined in the 1:1, 1:2.5 and 1:5 soil: water ratio *viz*. $EC_{(1:1)}$, $EC_{(1:2.5)}$ and $EC_{(1:5)}$ with a view to comparing the same and suggesting the most reliable soil: water ratio for quick appraisal of soil salinity for appropriate management in soils of Canning II block, South 24 Parganas, West Bengal under coastal agro-ecosystem.

Materials and Methods

Soil samples (Inceptisols) from different depths of soil profiles collected from seven villages *viz. viz*. Chengdona (266.25 ha), Gabbuni (599.41 ha), Bamunia (173.29 ha), Deuli (101.51 ha), Mallik Kati (758 ha), Maukhali Kumarkhali (1080.79 ha), and Patikhali (681.70 ha) of Canning II block, South 24 Parganas, West Bengal were used for electrical conductivity determination by different methods. The maximum depth of sampling was 1.5m. The study region falls under agroecological subregion (AESR) 18.5 (hot subhumid bioclimate) characterized by hot summer and mild winter. The area represents "ustic" and "aquic" soil moisture regime and "hyperthermic" soil temperature regime (Velayutham *et al*., 1999; Nayak *et al*., 2001) [31, 18].

Selected physical and chemical properties of the soils were analyzed using standard procedure (Jackson 1973) [13] and are presented in table 1. Saturation paste extract and extract for different soil water ratios *viz*.1:1, 1:2.5 and 1:5 was prepared following standard methods (U.S. Salinity Laboratory Staff, 1954; Rhoades, 1982) [30, 20]. Saturated paste extracts were prepared by adding distilled water to approximately 250g soil sample with stirring until it reached a condition of complete saturation (Rhoades, 1982) [20] and left for 24 h to reach equilibrium. Subsequently the paste was extracted using a vaccum pump at 5 millibar suction. The electrical conductivity in all the extracts was measured by a conductivity meter (Elico CM 180).

Table 1: Selected physical and chemical properties of soils (Inceptisols) of Canning II block, South 24 Parganas, West Bengal

Soil sample number	$pH_{aq.}$ (1:2.5)	$EC_{(1:2.5)}$ (dsm^{-1})	Organic carbon (gkg^{-1})	Textural class	CEC* (cmol kg^{-1})	ESP**	BS*** (%)
S1	5.4	1.98	16.8	sic	14.9	1.34	66
S2	5.4	1.84	8.4	sic	17.1	2.34	67
S3	4.7	1.78	15.6	sic	16.0	1.25	65
S4	4.5	1.92	17.9	sic	15.8	3.16	64
S5	4.3	1.88	8.4	sic	14.6	6.16	62
S6	4.3	1.55	7.0	sic	15.8	12.02	57
S7	4.1	1.68	9.2	sicl	14.9	12.08	56
S8	4.0	1.48	9.4	sic	16.3	10.43	52
S9	4.1	2.12	10.5	sic	17.3	10.40	53
S10	4.3	2.32	5.2	sicl	17.5	4.00	64
S11	6.9	2.16	4.2	sicl	15.0	4.44	75
S12	8.2	1.32	3.9	sicl	11.6	2.59	92
S13	8.2	2.28	3.0	sil	15.8	2.53	89
S14	8.2	3.11	8.0	sil	11.5	4.65	83
S15	8.1	3.55	6.2	sil	7.2	5.56	80
S16	7.0	4.22	5.0	sil	9.8	11.22	82
S17	7.9	3.9	3.3	sil	8.2	15.85	86
S18	6.9	5.54	3.2	sil	10.6	6.60	76
S19	6.9	1.72	8.6	sicl	16.9	13.02	87
S20	7.7	3.11	3.9	sic	16.8	14.28	92
S21	8.1	4.52	6.7	sil	16.6	16.76	91
S22	6.9	5.12	8.6	sicl	16.9	11.24	81
S23	7.7	3.55	3.1	sic	16.8	16.67	88
S24	7.7	2.83	2.8	sicl	16.7	17.36	88
S25	7.8	2.95	2.0	sicl	15.2	19.70	91

*CEC: cation exchange capacity; **ESP: exchangeable sodium percent; ***BS: base saturation sic: silty clay; sicl: silty clay loam; sil: silty loam

Results and Discussion

The electrical conductivity of the saturation paste extract (ECe) *vis-a-vis* electrical conductivity in different soil: water ratio *viz*. $EC_{(1:1)}$, $EC_{(1:2.5)}$ and $EC_{(1:5)}$ is presented in table 2. Inspection of data reveals that electrical conductivity of the saturation paste extract (ECe) for all the soils were greater than 4 dsm^{-1}, [except soil sample no. S-12 (ECe = 2.92 dsm^{-1})] and the spread of ECe ranged from 2.92 dsm^{-1} to 15.68 dsm^{-1}. The electrical conductivity (EC) of extracts obtained from 1:1, 1:2.5 and 1:5 soil: water ratios varied from1.34 dsm^{-1} to 5.97 dsm^{-1}, 1.32 dsm^{-1} to 5.54 dsm^{-1} and 0.51 dsm^{-1} to 4.27 dsm^{-1} respectively. The electrical conductivity exhibited a decreasing trend with increasing dilution. Similar trend was reported by Hussain and Aggarwal (1985) [12]. Considering the criteria for categorization of salt affected soils in terms of pH, EC and ESP (U.S. Salinity Laboratory Staff, 1954; Eynard *et al*., 2006) [30, 6], majority of the soils (72%) were saline (pH < 8.5, ECe > 4 dsm^{-1} and ESP < 15%) in the study area.

Table 2: Electrical conductivity of saturation paste extract (ECe) *vis-a vis* Electrical conductivity at different soil: water ratios

Soil sample number	ECe* (dsm^{-1})	$EC_{(1:1)}$ (dsm^{-1})	$EC_{(1:2.5)}$ (dsm^{-1})	$EC_{(1:5)}$ (dsm^{-1})
S1	5.42	2.13	1.98	1.06
S2	4.96	2.1	1.84	0.96
S3	5.27	2.95	1.78	1.04
S4	5.54	2.12	1.92	1.11
S5	5.2	2.67	1.88	0.92
S6	5.6	2.08	1.55	1
S7	5.2	2.01	1.68	1.02
S8	5.57	2.56	1.48	1.1
S9	6.1	2.76	2.12	1.28
S10	6.52	2.27	2.32	1.43
S11	5.64	2.25	2.16	1.23
S12	2.92	1.34	1.32	0.51
S13	6.88	3.05	2.28	1.35
S14	8.2	3.19	3.11	1.49
S15	10.26	3.61	3.55	1.93
S16	11.54	4.48	4.22	2.21
S17	10.42	4.12	3.9	1.93
S18	15.2	5.72	5.54	3.04
S19	6.24	2.3	1.72	1.11
S20	6.8	3.78	3.11	1.32
S21	15.68	6.8	4.52	3.12
S22	20.8	5.97	5.12	4.27
S23	11.34	4.42	3.55	2.28
S24	11.22	3.31	2.83	2.48
S25	10.32	3.14	2.95	1.83

*ECe: Electrical conductivity of saturation paste extract

Relationship between electrical conductivity measured by saturation paste extract (ECe) and EC $_{(1:5)}$, EC $_{(1:2.5)}$ and EC $_{(1:1)}$ soil: water ratio with intercept and without intercept is shown in Figs. 1 a, b; 2a, b, c and 3 a, b respectively and the relationship between different methods of electrical conductivity determination is presented in table 3.

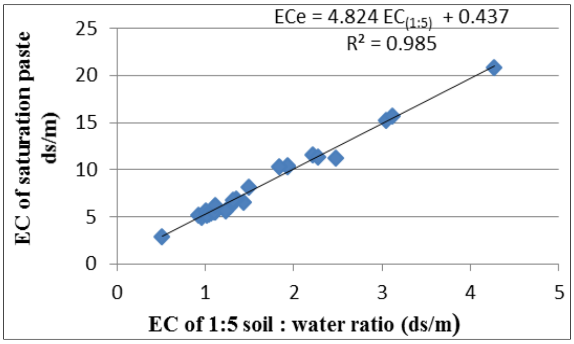

Fig 1a: Relationship between electrical conductivity measured by saturation paste extract (ECe) and EC (1:5) soil: water ratio (with intercept).

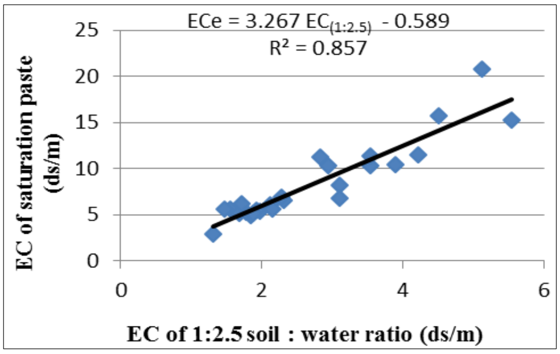

Fig 2a: Relationship between electrical conductivity measured by saturation paste extract (ECe) and EC (1:2.5) soil: water ratio (with intercept).

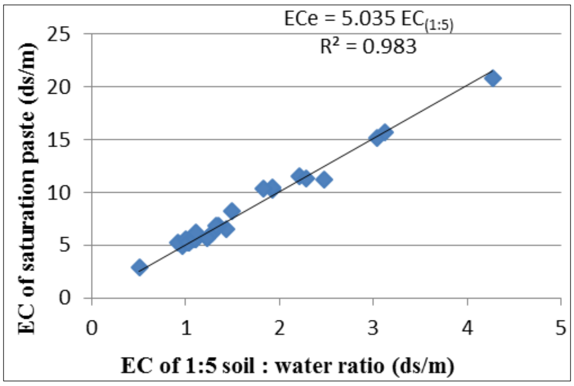

Fig 1b: Relationship between electrical conductivity measured by saturation paste extract (ECe) and EC (1:5) soil: water ratio (without intercept).

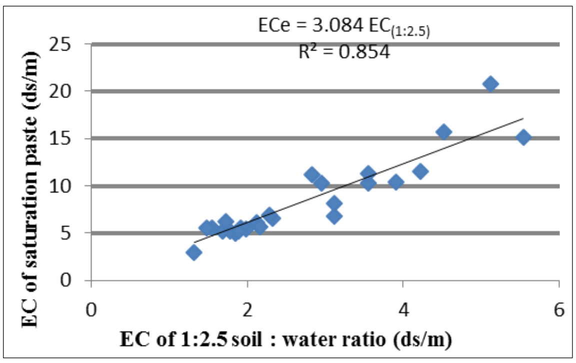

Fig 2b: Relationship between electrical conductivity measured by saturation paste extract (ECe) and EC (1:2.5) soil: water ratio (without intercept)

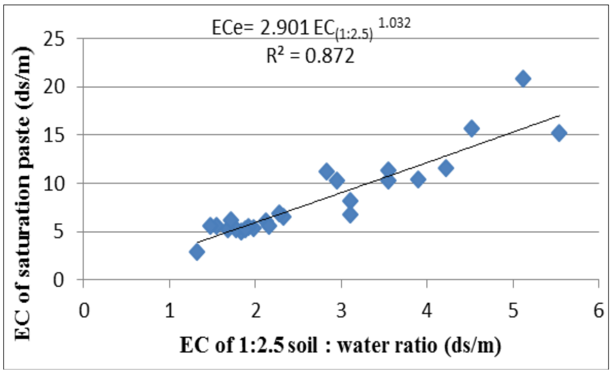

Fig 2c: Relationship between electrical conductivity measured by saturation paste extract (ECe) and EC (1:2.5) soil: water ratio (power form)

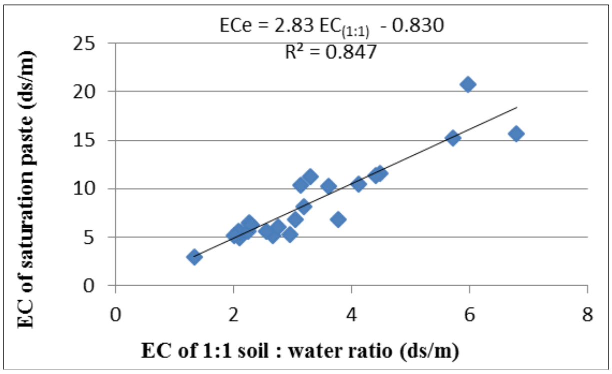

Fig 3a: Relationship between electrical conductivity measured by saturation paste extract (ECe) and EC (1:1) soil: water ratio (with intercept)

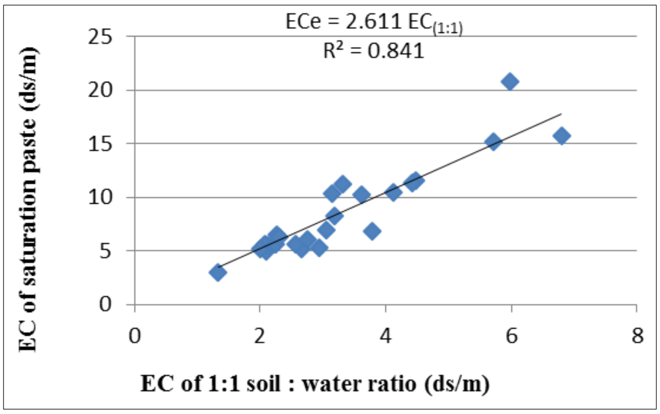

Fig 3b: Relationship between electrical conductivity measured by saturation paste extract (ECe) and EC (1:1) soil: water ratio (without intercept).

Strong association between EC $_{(1:5)}$ and ECe was observed at EC less than 2 dsm^{-1} and ECe less than 12 dsm^{-1}, when maximum number of experimental points touched the regression line and thereafter the relationship was affected by high soil salinity (Fig1a,b). Similar strong association between EC $_{(1:2.5)}$, EC $_{(1:1)}$ and ECe was observed at EC less than 4 dsm^{-1} and ECe less than 12 dsm^{-1} respectively (Figs.2a, b, c; 3a, b).

Table 3: Relationship between different methods of electrical conductivity determination

Method of comparison	Relationship (Regression equations)	R^2
ECe# *vs.* EC$_{(1:5)}$	ECe = 4.824 EC$_{(1:5)}$ + 0.437 (linear; with intercept)	0.985
	ECe = 5.035 EC$_{(1:5)}$ (linear; intercept = 0)	0.983
ECe *vs.* EC$_{(1:2.5)}$	ECe = 3.267 EC$_{(1:2.5)}$ – 0.589 (linear; with intercept)	0.857
	ECe = 3.084 EC$_{(1:2.5)}$ (linear; intercept = 0)	0.854
	ECe = 2.901 EC$_{(1:2.5)}$ $^{1.032}$ (power form)	0.872
ECe *vs.* EC$_{(1:1)}$	ECe = 2.83 EC$_{(1:1)}$ - 0.830 (linear; with intercept)	0.847
	ECe = 2.611 EC$_{(1:1)}$ (linear; intercept = 0)	0.841

ECe#: electrical conductivity of saturation paste extract.

The regression equations clearly indicate that all the methods for electrical conductivity determination were highly correlated. Neither the slopes nor the coefficient of determination changed drastically when intercepts are not included in the regression equations (Table 3). An increasing slope for the regression equations of electrical conductivity was observed when soil to water ratio is increased from (1:1) to (1:5), indicating that additional water causes dilution. In a sense, the slopes of the regression equations can be considered as dilution ratio (Sonmez *et al.*, 2008) [27]. A slightly greater scatter of the data points and resultant lower determination coefficients for EC $_{1:2.5}$ and the EC$_{1:1}$ extracts was probably due to an increase in the solubility of sparingly soluble salts such as gypsum and carbonate (Sonneweld and van 1971; Wadleigh *et al*., 1951) [26, 33].

Linear relationship between ECe and EC$_{1:5}$ *viz*. ECe = 4.824 EC $_{(1:5)}$ + 0.437 with the coefficient of determination value close to unity (R^2 = 0.985) indicate strong linearity. Further data processing indicated that neither the slope value (4.824) nor the coefficient of determination (R^2 = 0.985) changed significantly by fitting the data to linear regression with an intercept equal to zero (i.e., the line passes through the origin), suggesting that the regression equation can be reliably applied, even for soils with extremely low salinity levels. These findings are similar to those of other researchers (Ozcan *et al.*, 2006; Sonmez *et al.*, 2008; Visconti *et al.*, 2010; Khorsandi and Yazdi, 2011; Klaustermeier *et al.*, 2016; Aboukila and Norton 2017, Aboukila and Abdelaty, 2017; Kargas *et al.*, 2018) [19, 27, 32, 15, 16, 2, 1, 14] who also reported strong linearity for the ECe and EC$_{1:5}$ relationship. However, our results do not match exactly with the findings of other studies but is most close to the findings of Aboukila and Norton (2017) [2], who reported a slope value of 5.04. Differences in the slope values of similar relationships reported by other researchers could be attributed mainly to the different methodologies used for the $EC_{1:5}$ measurements and to diverse physicochemical soil characteristics (Kargas *et al*. 2018) [14]. Similar linear relationship was observed between ECe and $EC_{1:2.5}$ and $EC_{1:1}$ values *viz*. ECe = 3.267 EC $_{(1:2.5)}$ – 0.589 (R^2 = 0.857) and ECe = 2.83 EC $_{(1:1)}$ - 0.830 (R^2 = 0.847) respectively.

The slope value of 3.267 for ECe and $EC_{1:2.5}$ relationship is close to the slope value of 3.3 and 3.05 as reported by Ozcan *et al*., (2006) [19] and Aboukila and Norton (2017) [2], where as the slope value of 2.83 for ECe and $EC_{1:1}$ relationship is close to the slope value of 2.96 as reported by Franzen (2003) [8]. Furthermore it was observed that the relationship between ECe and $EC_{1:2.5}$ improved in power form of regression model as is evident from higher R^2 value (R^2 = 0.872) thereby suggesting the preference of the equation *viz*. ECe = 2.901EC $_{(1:2.5)}^{1.032}$ for the purpose of routine conversion.

Although regression equations for such type of inter-conversions have been reported worldwide by several researchers (U.S. Salinity Laboratory Staff,1954;Hussain and Aggarwal, 1985; Rhoades *et al*., 1989; Slavich and Petterson, 1993, Shirokova *et al*., 2000; Franzen, 2003; Ozcan *et al*.,2006; Al Busaidi *et al*., 2006; Sonmez *et al*., 2008; Visconti *et al*., 2010; He *et al*., 2013;Semiz and Atmaca, 2013; Aboukila and Norton 2017, Kargas *et al*., 2018) [30, 12, 21, 25, 24, 8, 19, 3, 27, 32, 10, 22, 2, 14], similar to the regression equations generated in the present study, it was observed that no single equation is suitable for all soil types due to variation in soil properties and measuring conditions (Al Busaidi *et al*., 2006; Kargas *et al*. 2018) [3, 14].

Nevertheless considering strength of correlation as reflected by the coefficient of determination (R^2) values for various linear regression models, EC $_{(1:5)}$ is the most suitable model for predicting ECe (R^2 = 0.985) in coastal soils of Canning II block, South 24 Parganas, West Bengal than EC $_{(1:2.5)}$ and EC $_{(1:1)}$ with R^2 = 0.857 and 0.847 respectively.

Conclusion

The study concludes that ECe can be predicted with great reliability by measuring EC $_{(1:5)}$ in coastal soils of Canning II block, South 24 Parganas, West Bengal for quick appraisal of soil salinity for appropriate soil management instead of tedious and time consuming saturation paste extraction. In such context a linear regression equation *viz*. ECe = 4.824 EC ($_{1:5}$) + 0.437 is proposed for routine conversion. Nevertheless the study endorses the superiority of saturation paste extraction method over other methods involving different soil water ratios, since the former is the “direct method” (representing the real field condition) and hence more accurate towards soil salinity assessment. Moreover, using indirect methods for quick evaluation of soil salinity are highly dependent on soil properties and measuring conditions and therefore must be used with due caution. Undoubtedly, additional work is needed to improve the accuracy of ECe prediction by including more data for soil samples from the study region as well as from other coastal regions of the country.

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