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Comparative Evaluation of Methods for Estimation of Soil Salinity

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ABSTRACT

Different methods to estimate electrical conductivity (EC) of saturated soil paste extract (EC_e) of 1:2 and 1:5 soil: water suspensions were evaluated. Soil samples were taken from different depths (*viz.* 0-15, 15-30, 30-45, 45-60, and 60-90 cm) of the wheat field under irrigated saline regimes ranging from 1.5 to 12 dSm^{-1}. The relationship between the electrical conductivity of saturated paste extract (EC_e) and soil-water suspension extracts (*i.e.*, $EC_{1:2}$ and $EC_{1:5}$) was established beside the development of regression models and conversion factors. Regression models relating EC_e with $EC_{1:2}$, $EC_{1:5}$ were developed with coefficients of determination (R^2) 0.98 and 0.99 respectively. The average conversion factor between EC_e~ $EC_{1:2}$ and EC_e~ $EC_{1:5}$ were 2.7 and 7.7, respectively. Methods standardized in the study can be used to estimate the EC of different saturated soil paste extract ratios, which will be less cumbersome and significantly reduce the estimation time.

Keywords: soil salinity, soil water extract, saturation extract, electrical conductivity.

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INTRODUCTION

Soil salinity resulting from parent rocks or the use of saline groundwater creates an unfavorable condition for plant growth and affects the soil structure. Soil and fertility management and selection of appropriate crop species and varieties largely depend upon the accurate estimation of soil salinity for enhancing productivity from saline lands. The salinity of soil differs along the field at various soil depths, the salt content depending upon the soil texture and crops grown in the field. In order to differentiate between the saline and non-saline soils, soil salinity limits have been developed to assess the effect of salinity on plants growth (Rhoades 1982; Price 2006; Zhang *et al.* 2019). Soils that contain excessive levels of soluble salts or exchangeable sodium percentages are not suitable for agricultural uses. Maintaining an optimum level of soil salinity is necessary for successful agriculture in salt-affected soils. Soluble salts affect plant growth by increasing the salt content and the degree of saturation of the exchangeable sodium in the soil (Charman and Murphy 2007). Various methods of soil salinity estimation depend on the soil water suspension extract and EC measurement of the saturated soil paste extract (Rhoades *et al.* 1989; Slavich and Petterson 1990; Franzen 2007; Zhang *et al.* 2005; Ozcan *et al.* 2006). The measure of the total quantity of soluble salts per unit weight of soil is the electrical conductivity of the extracts with the ratio 1(soil) and 5 (water) i.e., $EC_{1:5}$ (Rayment and Higginson 1992; Chi and wang 2010; Allison *et al.* 1954; Khorsandi and Yazdi 2007).

The soil suspension method is easy and takes less time as compared to calculating the EC of saturation paste extract (EC_e), which is time-consuming and tedious process. However, the EC_e estimation is more meaningful and accurate as compared to the soil water suspension method. The basis for the management of saline land and subsequent crop planning is carried out either based on EC measured from the soil water suspension method or the equivalent ECe (saturated paste extract) that has been converted from the EC estimated from the soil water suspension extract.

Efforts have been made to develop conversion factors based on broad soil texture grades to calculate ECe from EC1:5 (Slavich and Petterson 1993). Based on soil texture, the association between the electrical conductivity of saturated paste extract of different soil ~water ratios (i.e.,1:1, 1:2.5, 1:5) was determined (Sonmez *et al.* 2008; Amakor 2014). A relationship was established between various soil ~water ratios and the important cations and anions of saturated paste extract. The electrical conductivity from soil water extracts with a ratio of 1:5 was assessed (Visconti *et al.*, 2010). Soil water suspension extract ratios (1:5) can be prepared more rapidly than the saturation paste extracts. Moreover, a relationship between the electrical conductivity of saturation paste extracts (EC_e) and electrical conductivity of suspension extract of 1:5 ratio for the arid region of Central Iran were established (Khorsandi and Yazdi 2011). The electrical conductivity of saturation paste extracts (EC_e) was taken as a standard to assess soil salinity. The measurement of electrical conductivity of soil: water suspension extract of 1:5 is commonly used in Australia (He *et al.* 2012). Salt concentration in the soil above which the plant growth is affected depends on soil texture, salt distribution in soil, the composition of salt, and the crop type and its varieties. Limits for salinity have been developed (Rhoades *et al.* 1992) for distinguishing saline soils from non-saline and for assessing the salinity effects on plants. Review of literature revealed the availability of established methods for the estimation of EC_e from $EC_{1:5}$ by field observations. However, a few attempts (Hog and Henry 1984) to relate EC_e with both $EC_{1:2}$ and $EC_{1:5}$ have been made so far. Using the

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salinity of collected soil samples of wheat under irrigated saline environment from field experiments, an attempt has been made in this study to estimate EC_e from $EC_{1:2}$ and $EC_{1:5}$ through regression models and conversion factors. The salinity of soil samples collected from field experiments of wheat under irrigated saline environment were used to estimate EC_e, $EC_{1:2,}$ and $EC_{1:5}$. Depending upon the dilution factor the regression models, as well as the conversion factors, were used. Due to the easy accessibility and minimum time required for the measurement of $EC_{1:2}$ and $EC_{1:5,}$ the EC_e can be determined from conversion factors and regression equations developed in the study.

MATERIALS AND METHODS

Study Area

The experiment for conducting the research was carried at the Water Technology Centre (WTC), the research farm of the Indian Agricultural Research Institute (IARI), New Delhi during the *Rabi* seasons (October to March) of 2009-10 and 2010-11. The artificially prepared saline water with differing salinity levels *i.e.*, 4, 8, and 12 dS m-1 were used to irrigate the plots of 5m × 8m (Fig. 1). At ratios of 2.5:1.5:1 of NaCl, $MgSO_4$, and $CaCl_2$respectively, saline water was prepared to obtain the desired salinity level (Kumar *et al.*, 2013). The soil samples were collected from five depths (*i.e.* 0-15, 15-30, 30-45, 45-60, and 60-90 cm) and twelve different locations as three replicates (n=60) from groundwater irrigated plots (1.75 dSm^{-1}), 4, 8 and 12 dS m^{-1} saline water irrigated plots of experimental area for estimation of soil salinity. The physic-chemical properties of the experimental site are illustrated in Table 1.

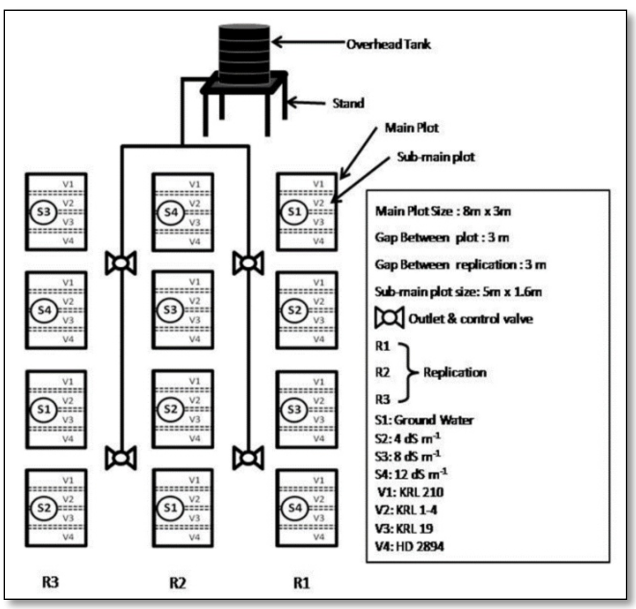

Fig.: 1. Layout of the experiment showing different salinity levels for soil sampling

Methods for Measurement of Soil Salinity

The actual salinity of the soil in the field may not be indicated when the measurements are taken on stagnant water. Soil salinity is normally measured in terms of EC with unit dSm^{-1} or m.mhos.cm^{-1}. The ratio 1:2 or 1:5 in terms of mixing one part of soil with that of two and five parts of water respectively is the ratio used for the preparation of normal soil solution. The quantity of salts in kg of salts per kg of soil is a measure of $EC_{1:2}$ while ECe is the measure in kg of salts per litre of soil water.

Table 1: Physical and chemical properties of the soil of the experimental field

Determination	Soil depth				
	0-15	15-30	30-45	45-60	60-90
Sand (%)	62.4	63.7	44	39	38
Silt (%)	21	19	23	25	27
Clay (%)	16.6	17.3	33	36	34
Soil texture FC (%	Sandy loam	Sandy loam	Loam	Loam	Clay loam
w/w,0.03 Mpa) PWP	20.45	22.02	30.59	32.8	33
(%,w/w,105 Mpa)	9.5	10.2	13.7	14.7	15
Ks (cm d^{-1})	27.4	26.2	18.6	19.1	19.5
Bd (g cm^{-3})	1.66	1.7	1.88	1.67	1.83
EC (dS m^{-1})	0.2	0.12	0.11	0.13	0.12
pH	7.7	8.1	8.01	8.05	8.5
Organic matter (%)	0.53	0.48	0.40	0.37	0.38
N (ppm)	179	159	130	123	126
P (ppm)	3.3	3.7	129.6	4.3	4.1
K (ppm)	172.4	177.7	182.5	188.1	191.2

† Bd: Bulk Density, Ks: Saturated Hydraulic Conductivity, FC: Field Capacity, PWP: Permanent Wilting Point, EC: Electric Conductivity

Extraction of saturated soil paste

The regulated hand mixing procedure is the method that has been used to measure the electrical conductivity of the solution which is extracted from a water-saturated soil paste (Richard 1954). Stirring the soil till it is fully saturated by the addition of 15-20 ml of demineralized water to 50-gram air-dry soil was carried out to prepare the saturation soil paste. Further, the EC meter was used to estimate the electrical conductivity of the extracted saline water $EC_{e.}$ The water was extracted (5-7ml) by using the suction filter from the saturated paste. Moreover, the accurate and meaningful method for estimating soil salinity is the saturated paste extract method which is independent of soil texture. However, this process is tedious and time-consuming.

Extraction of soil water suspension (1:2)

Laboratory facilities are required for both the soil water extract method and saturation extract method for measuring soil salinity. But the soil-water extract method is easier as compared to that of the saturation extract method. The addition of 100ml of distilled water (2 parts) to that of the air-dried soil sample *i.e.*, 50g was used to prepare the soil-to-water ratio suspensions (1:2). The mixture was shaken for one hour using a mechanical shaker and the stirred solution obtained was allowed to settle down. Further, one drop of 0.1% $(NaPO_3)_6$ solution for 25ml extract was added after filtration.

The EC was measured for the saturated paste extracts using the described method.

Extraction of soil water suspension (1:5)

The soil to water ratio suspensions (1:5) was prepared by adding 100 ml of distilled water (5 parts) to 20 gram of air-dried sample. The mixture was shaken for 1 hour and after settlement of the soil, the EC meter was placed in the soil water suspension and the EC was measured using the same methods as described for saturated extracts (Loveday 1974). The EC measured using different procedures can be converted from one value to the other through the use of conversion factors (f) relating $EC_{1:2}$ to $EC_{1:5}$, $EC_{1:5}$ to EC_e and $EC_{1:2}$ to EC_e

i.e., $EC_{1:2} = f EC_{1:5}$ 1(a)

$EC_{1:5} = f EC_e$ 1(b)

$EC_{1:2} = f EC_e$ 1(c)

Regression Equations

The $EC_{1:2}$, $EC_{1:5}$ and EC_e values measured from various soil samples with varying salinity levels taken from the experimental plot were used to develop the regression equations. These relationships were developed by fitting regression equations between the soil salinity values estimated using different methods.

Conversion Factors

The soil salinity value (average) of samples (n=60) was estimated using the above procedures of soil salinity determination as the ratio of $ECe/EC_{1:2}$ and $EC_e/EC_{1:5}$ was used to develop the conversion factor. The following equation was used to calculate the conversion factor:

i.e., $EC_e = f(EC_{1:2} \text{ or } EC_{1:5})$ (2)

Model Evaluation

The regression equations and the conversion factor '*f*' thus developed were further compared with the observed values of EC_e with EC of different soil suspension ratios (1:2 and 1:5). Predication error statistics were used to analyze the goodness of fit between observed values to that estimated by regression equations and conversion factors. The prediction error statistics used were: the coefficient of determination (R^2), index of agreement (d), index of agreement (d), mean absolute error (MAE), root mean square error (RMSE), and model efficiency (ME). The R^2, d, and ME were used to access the predictive power of the model while the MAE and RMSE indicated the error in model prediction.

The following statistical indicators were used to compare the measured and simulated values. Model efficiency (ME) (Nash and Sutcliffe 1970) was used for model performance evaluation:

$$ME = 1 - \frac{\sum_{i=1}^{N}(O_i - E_i)^2}{\sum_{i=1}^{N}(Oi - \bar{O})^2} \quad (3)$$

Where:

E_i and Oi are estimated and actual (laboratory observed) data, $\bar{O}_i$ is the mean value of O_i whereas, N is the number of observations.

$$RMSE = \sqrt{1/(N)\sum_{i=1}^{N}(Oi - Si)^2} \quad (4)$$

$$MAE = \sqrt{\sum_{i=1}^{n}|Pi - Oi|/n} \quad (5)$$

Model efficiency (ME) and R^2 approaching 1 and the MAE and RMSE close to zero were considered for better model performance.

The index of agreement (d) was calculated using the equation (Willmott 1982):

$$d = 1 - \frac{\sum_{i=1}^{n}(S_i - O_i)^2}{\sum_{i=1}^{n}(|S_i - \bar{O}| + |O_i - \bar{O}|)^2} \quad (6)$$

The value of R^2, ME and index of agreement is a descriptor of prediction accuracy and its values approaching one indicates better accuracy of the estimation procedures.

RESULTS AND DISCUSSION

Comparative Evaluation of EC Measured by Different Soil: Water Suspension Method

The electrical conductivities of soil samples for (1:2, 1:5) soil to water ratio and saturated paste extracts ranged from 0.22 to 1.62 dS m^{-1}, 0.17 to 0.71 dS $m^{-1}$and 1.77 to 3.98 dS m^{-1} respectively. It was observed that the EC decreased due to

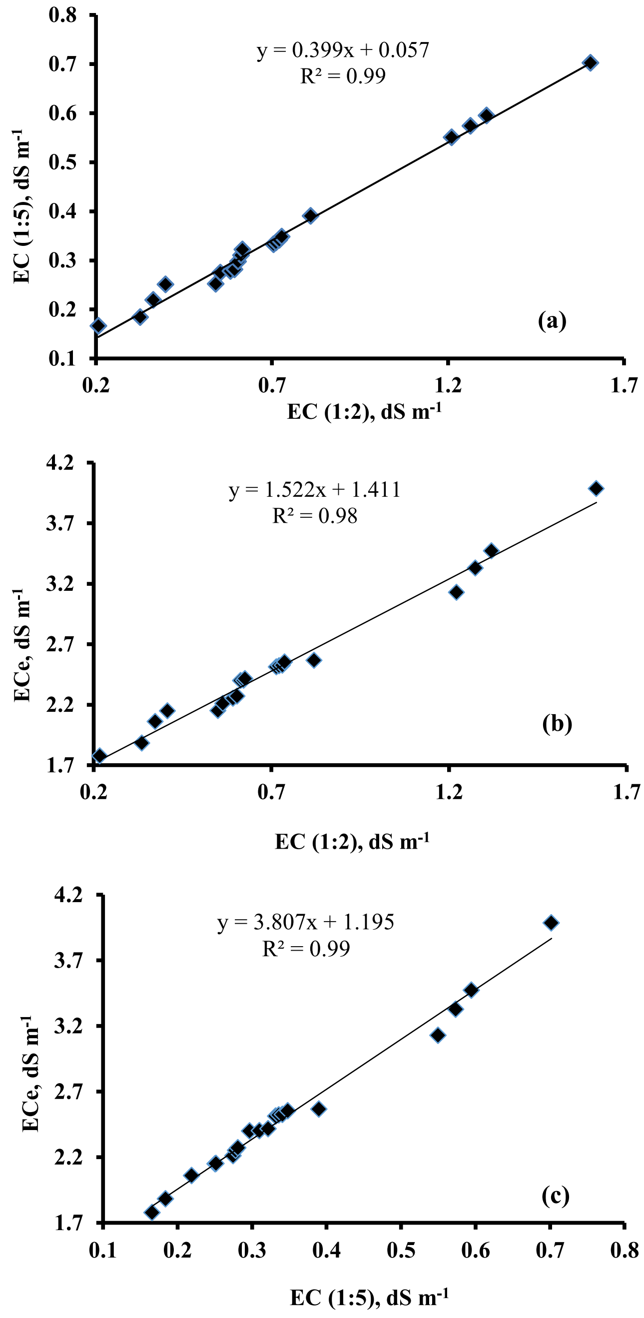

Fig. 2: Relationship between a) $EC_{1:2}$ to $EC_{1:5}$ b) $EC_{1:2}$ to EC_e c) $EC_{1:5}$ to EC_e by using measured soil salinity

dilution effects and an increase in the soil to water ratio. The relationship of electrical conductivity of saturated paste (EC_e) versus different soil to water ratios are presented in Fig. 2(a) to 2(c). A high correlation was observed between the EC of saturated paste extract (EC_e) for both soil to water ratios of 1:2 and 1:5 with R^2values (*i.e.,* 0.98 to 0.99) close to one.

Regression model and conversion factors

Regression Model

Soil salinity value of 60 soil samples taken from five soil depths, four locations, and three replications were used to develop the regression models. To relate and to establish a relationship, the observed data of soil salinity with different soil to water ratios, (*i.e.,*1:2 and 1:5) were used to developed regression equations to estimate electrical conductivity in terms of saturated extract (EC_e). Developed relationships are presented in Equations 7(a) to 7 (c). It was observed that Eq.7a can be used to convert $EC_{1:2}$to $EC_{1:5}$and equations 7b and 7c can be used for conversion of $EC_{1:2}$ and $EC_{1:5}$ to EC_e, respectively. The coefficients of determination (R^2) range between 0.98 to 0.99, which indicated the best model fit, and standard errors of these equations were found to vary from 1% to 6%.

$EC_{1:5} = 0.399\, EC_{1:2} + 0.057$ $R^2 = 0.99$ $SE = 0.01$ ....7(a)

$EC_e = 1.522\, EC_{1:2} + 1.488$ $R^2 = 0.98$ $SE = 0.07$ ....7(b)

$EC_e = 3.807\, EC_{1:5} + 1.195$ $R^2 = 0.99$ $SE = 0.06$ ....7(c)

Conversion Factors

The conversion factor '*f*' was estimated by estimating the ratio of observed ECe, $EC_{1:2,}$ and $EC_{1:5}$ values. Moreover, the conversion factors were estimated depth-wise which was due to variation of soil texture at different soil depths (Table 2). Thus, the developed conversion factors can be directly used to obtain EC_e from $EC_{1:2}$or $EC_{1:5}$ for different soil depths.

Table 2: Conversion factor of ECe for different depths and soil texture

Depth, cm	Soil texture	Conversion Factor	
		$EC_{1:2}$ to EC_e	$EC_{1:5}$ to EC_e
0-15	Sandy Loam	4.0	9.1
15-30	Sandy Loam	3.0	6.2
30-45	Loam	3.3	7.0
45-60	Loam	2.1	9.4
60-90	Clay Loam	1.4	7.0
Average		2.8	7.7

Validation of Developed Regression Equations and Conversion Factors

Validation results of developed regression equations

(EC_e) were validated using the twenty observed data of the experiment and the regression equations of electrical conductivity obtained for (1:2), (1:5) soil to water ratios. The data were estimated by using equations 7(a) to 7(c) and compared with the observed values of $EC_{1:5}$, EC_e from $EC_{1:2}$and EC_e from $EC_{1:2}$, respectively. The observed and regression equation predicted values are presented in Fig. 3a to 3c. It was observed that the estimated and observed values were in line corroborated by R^2 ranging from 0.98 to 0.99. The prediction error statistics are presented in Table 3.

Table 3: Statistics of the regression model evaluation

Regression model	RMSE	MAE	ME	d	R^2
EC1:5 from EC1:2 (eq. 5.7a)	0.03	0.16	0.94	0.99	0.99
ECe from EC1:2 (eq. 5.7 b)	0.15	0.36	0.92	0.97	0.98
ECe from EC1:5 (eq. 5.7 c)	0.15	0.39	0.93	0.97	0.99

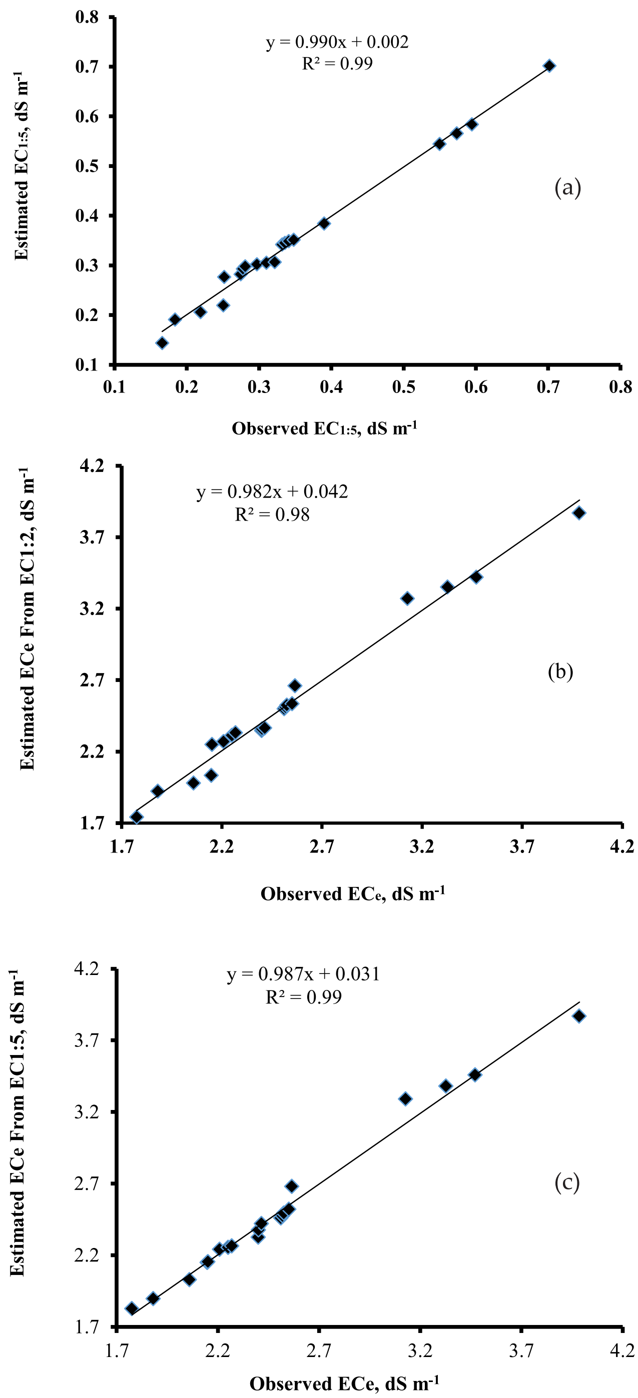

Fig. 3: Relationship between observed and estimated a) $EC_{1:5}$ b) ECe from $EC_{1:2}$ c) ECe from $EC_{1:5}$ by using regression equations

Validation results of developed conversion factors

To establish a relationship between observed and estimated EC_e, the average conversion factor '*f*' (*i.e.*$EC_{1:2}$to EC_e and $EC_{1:5}$ to

EC_e) was used (Fig. 4). The high values of coefficients of determination (R^2) (*i.e.* 0.92 and 0.93) presented in Fig. 4 indicated no significant difference between the observed and estimated values obtained using the conversion factor. Also, the parameters reflecting the prediction error for conversion from ECe to EC 1:2 and EC 1:5 were estimated and presented in Table 4. It was observed from Table 4 that for accurate conversion of soil salinity values from one method to the other, the conversion factors can be a useful alternative (Moriasi *et al*., 2007).

Table 4: Prediction error statistics using the conversion factor for estimation of ECe from EC 1:2 and EC 1:5

Conversion Factor	RMSE	MAE	ME	d	R^2
ECe from EC1:2	0.68	0.68	-0.60	0.85	0.92
ECe from EC1:5	0.60	0.67	-0.26	0.70	0.93

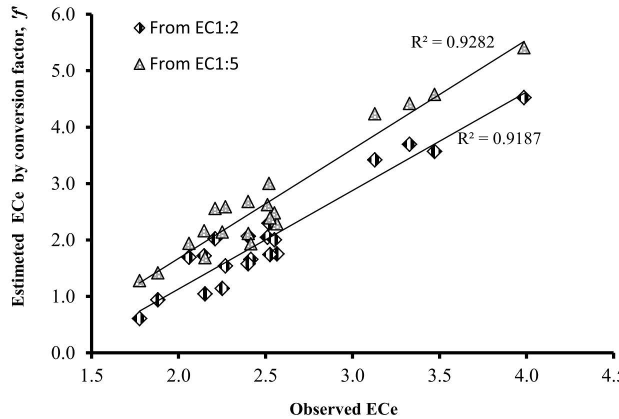

Fig. 4: Relationship between observed and estimated EC_e by using the conversion factor

CONCLUSION

The results indicated a strong correlation between the measured values of the saturated paste extracts and that of the different soil to water extracts for estimation of EC. Therefore, it may be concluded that EC derived from saturated paste extract of soils can be estimated using either 1:2 or 1:5 soil to water ratio depending on the results. Validation was carried out for the developed regression equations and the conversion factors to ascertain that the soil water ration method is at par with the saturated paste extract method. Moreover, regression equations and conversion factors developed in this study would serve as a faster and more reliable alternative to the cumbersome saturated paste extraction method. Nonetheless, the protocol developed in this study can be replicated under different irrigated saline environments with varying soil textures to measure the soil salinity in minimal time besides being a less cumbersome procedure with acceptable accuracy.

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