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Calibration of Inductive Electromagnetic Meter for Determining Electrical Conductivity of UAS, Raichur Soil

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Authors' contributions

This work was carried out in collaboration between all authors. Author NS took readings from the field, performed the statistical analysis in Matlab and wrote the first draft of the manuscript. Authors PBD and KS performed the analysis of soil samples in the laboratory and managed the analyses of the study. Author LKD managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

EM-38 electromagnetic induction sensor is a most useful instrument to determine the soil salinity. Significant positive correlation found between inductive electromagnetic meter (IEM) readings and saturated paste extract electrical conductivity (EC) revealed that this technique could be used for determination of soil salinity. However, calibration of the instrument is necessary for interpretation of instrument readings in terms of meaningful parameters of soil salinity. The calibration equations developed elsewhere may not predict electrical conductivity of UAS, Raichur soil accurately. So, in this study, calibration of EM-38 was carried out to find the soil salinity of experimental site soil. A

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multiple linear regression equation was developed which valid up to 20 cm depth after calibration of the instrument for experimental site soil and this equation considered reliable as it showed a significant positive correlation between predicted and measured soil salinity values. Co-efficient of determination (R^2) value was 0.817 between predicted and measured EC values. While salinity measurements made with the EM-38 are not highly accurate, but measurements within reasonable accuracy can be made very rapidly. Hence, this equation enables the user of the EM-38 to derive a realistic index of salinity of soil under consideration in terms of EC.

Keywords: Soil salinity; soil electrical conductivity; EM-38; electromagnetic induction.

1. INTRODUCTION

Irrigation is essential in arid and semi-arid regions for agricultural production. However, it should be noted that soil salinity may be a risk for sustainable agricultural production owing to mismanagement of irrigation schemes and other inherent problems of irrigation methods. Salt accumulation which may occur in plant root zone may closely be associated with the irrigation methods used. Irrigation with inferior quality of water may also increase soil salinity, and it is one of the major pollutants which affect the crop yield and consequently the economic condition of farmers.

Soil salinity assessment concerning area, severity and spatial variability is inevitable for the management and reclamation especially in canal commands, where salinity is one of the significant constraints for crop production. Hence, the assessment of the extent of soil salinity in irrigation command areas is necessary.

The traditional method of electrical conductivity measurement in saturation paste is laborious and time-consuming as it requires extensive soil sampling and laboratory analysis. Therefore, there is a need to standardize the methods which should be rapid, non-destructive and measure the soil salinity directly in the field, without the involvement of any laboratory procedure. During the last two decades many new techniques like Wenner Array [1], Rhoades's electrical conductivity probe [2], Time Domain Reflectrometry (TDR) and Electromagnetic Induction [3,4] have been developed to measure the in-situ soil salinity. In India, EM-38 meter was calibrated for black soils of Upper Krishna Project command in which coefficient of determination (R^2) between predicted and measured EC values were ranged between 0.79 to 0.89 [5].

Electromagnetic induction (EMI) meters have been shown to be useful for accurately and rapidly diagnosing and mapping the spatial distribution of subsurface soil salinity [6]. Serrano et al. [7] tested a non-contact EMI probe with an aim to evaluate the soil and posture variability and find out that apparent electrical conductivity positively and significantly correlated to pH and yield. Martini et al. [8] conducted repeated EMI surveys for mapping of soil moisture and observed that soil moisture has little influence on the measured apparent electrical conductivity of the soils with low clay content. The meters detect the apparent electrical conductivity of soil by measuring the response of the soil to an induced electromagnetic (EM) field. EMI technique is more convenient and faster because its measurements do not require soil sampling and their preparations. In recent years, EMI sensors have experienced a rapid succession of design improvements and have been successfully integrated with new technologies like GPS receivers, Bluetooth, etc. to become even more versatile and useful tool in soils research [9]. An instrument named EM-38, which worked on the principle of EMI (Electromagnetic Induction) is commercially available which can be used to measure soil salinity. EMI surveys using EM-38 were performed across salt affected farmland for digital mapping of soil salinity and crop yield and concluded that EMI surveys could be successfully used to characterize the spatial variability of soil salinity [10]. Utilization of an EM-38 meter seems to be a cost-effective method for assessing field salinity and for experiments on salt tolerance of crops.

In saline soils, salt dominates the response of the EM meter, and generally good correlations have been found between apparent soil electrical conductivity (ECa) and salinity [11-13]. So, EM-38 records readings proportionate to the extent of salt in the soil. Also, EM-38 does not require direct soil penetration; therefore a large number of readings can be taken at much lower cost than conventional soil sampling. It can be used to measure soil salinity to approximately 0.6 to 1.2 m depth depending on the orientation of meter.

By keeping all above points in mind, the present study was carried out to calibrate the EM-38 meter and develop a multiple linear regression equation to determine the soil salinity of experimental area accurately and at a faster rate.

2. MATERIALS AND METHODS

2.1 Working Principle and Setting Procedure of EM-38

Robinson et al. [14] showed the schematic diagram for working principle of EM-38. EM-38 consists of two electrical coils named transmitter coil and the receiver coil, placed one meter apart. Transmitting coil creates a primary magnetic field, and this magnetic field generates an eddy current in the ground. Generated eddy current loop induces its magnetic field in the soil. The ratio of the primary magnetic field and magnetic field induce by eddy current are measured by a receiver coil, and this ratio is proportional to the electrical conductivity of the soil.

Before using EM-38 for taking readings, initial phase nulling of EM-38 is required to facilitate the receiver coils to measure the minimal signal from eddy currents in the presence of the much larger signal arising from the primary magnetic field. Setting procedure of EM-38 is readily available in the user manual of EM-38.

2.2 Experimental Site

The experimental site is located in the UAS, Raichur campus comprises block No. 87 to 107 of agricultural land in Raichur district of Karnataka, India. This study area is situated in the northeastern dry zone of Karnataka located at 16.198° N latitude, 77.33° E longitude and 389.5 mm above mean sea level. The daily climatological data during the period of study were recorded from the metrological station at the regional research station, Raichur. It is seen that the maximum temperature of 43.3°C was recorded in May and the minimum temperature of 20°C was recorded in January. The maximum average relative humidity of 78.5% was recorded in January and minimum of 23.5% was recorded in March. The maximum wind velocity of 21.2 km per hour was in February. The maximum evaporation of 16.5 mm/day was in May and the minimum evaporation of 2.0 mm/day was in January.

2.3 Soil Salinity Data Collection

The data was collected from block No. 87 to 107 of experimental site. The soil type of experimental site is mainly black cotton soil with clay, silt, and sand percentage as 24.3%, 8.8%, and 66.9% respectively and soil bulk density is around 1.94 g/cm^3. Fig. 1 shows the map of the study area and red dots in map denotes the plots from which samples were taken.

For taking readings using EM-38, place the EM-38 horizontally and record the reading, H. Then, place it vertically and record the reading, V. Collect the soil sample from the same place to determine the electrical conductivity of soil of that point in the laboratory.

2.4 Data Analysis

After collection of data, i.e., H and V values and finding out electrical conductivity (EC) of collected soil samples in the laboratory, it was necessary to analyses data whether dependent variable, i.e., electrical conductivity depends on independent variables, i.e., H and V values. Fig. 2 shows the graph of electrical conductivity and horizontal values. The coefficient of determination (r^2) is 0.7182 which is on the higher side. So, we can say that electrical conductivity depends on horizontal values which we obtained using EM-38. Similarly, Fig. 3 shows the graph of electrical conductivity and vertical values. The coefficient of determination (r^2) is 0.726 which suggest that electrical conductivity does depend on vertical values too.

Multicollinearity is a condition in which independent variables in a regression model are correlated. Multicollinearity condition between independent variables also checked in this study because the presence of multicollinearity reduces the precision of estimate coefficients, which weakens the statistical power of regression model. Fig. 4 shows the graph between horizontal and vertical values and their coefficient of determination (r^2) is 0.425. From this, we can say that vertical and horizontal values are not highly correlated and hence multicollinearity is not present in this case.

Fig. 1. Map showing sampling locations with red dots

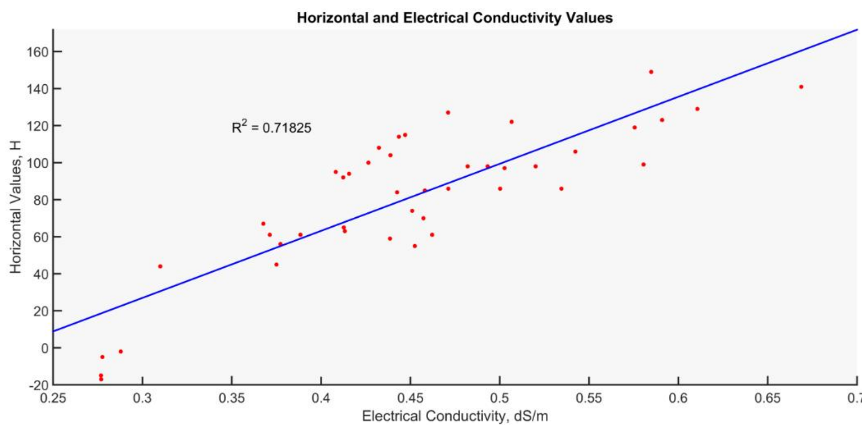

Fig. 2. The correlation coefficient between electrical conductivity and horizontal values

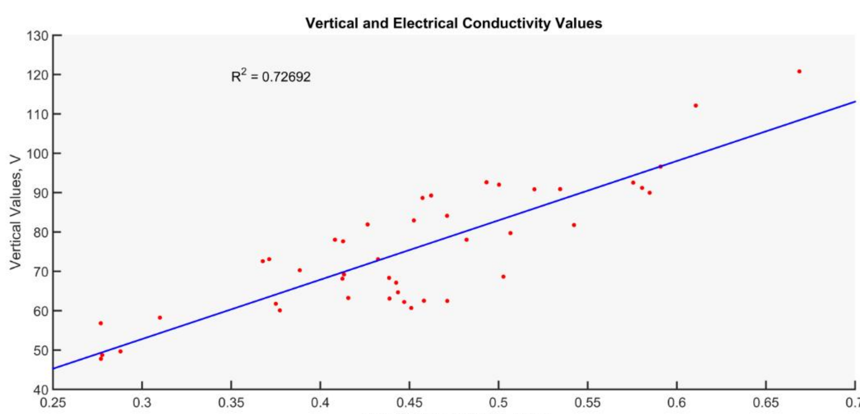

Fig. 3. The correlation coefficient between electrical conductivity and vertical values

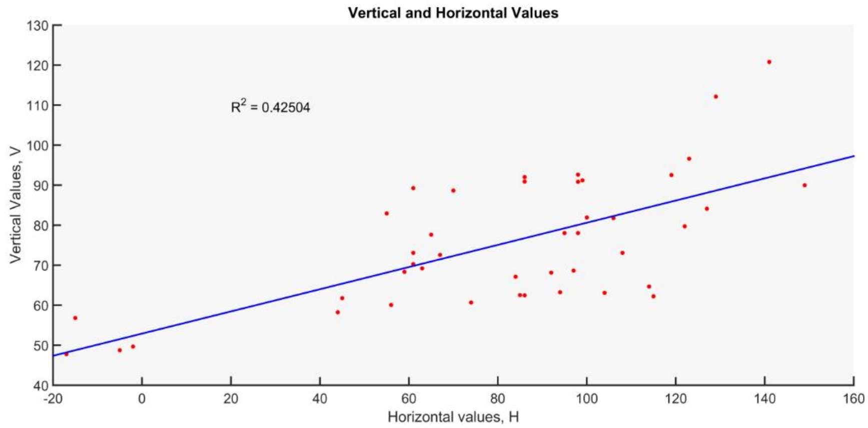

Fig. 4. Graph showing multicollinearity between horizontal and vertical values

3. RESULTS AND DISCUSSION

3.1 Development of Predictive Equation

Field data (H and V readings along with respective EC) valued were subjected to multiple linear regression analysis. The new predictive equation was developed for depth of 0-20 cm using EM-38 data. Up to 20 cm depth is considered for this study because tillage operations usually performed up to 20 cm only. Table 1 shows the output estimated coefficients obtained from multiple regression analysis. In Table 1, it observed that after conducting the t-test, a p-value of each predictor is less than 0.0001 at a significance level of 5%.

The multiple linear regression equation to predict EC with a coefficient of determination (R^2) is shown in Table 2. As the coefficient of determination is more than 0.80, so we can say that this equation is able to predict EC accurately at a faster rate as compared to conventional laboratory method.

To examine the quality of the fitted model, ANOVA is conducted on collected data as shown in Table 3. From Table 3, it observed that the effects of H and V in the model are significant as p-value is less than 0.05 for both variables.

3.2 Regression Model Evaluation

Adequacy of a regression model was determined using residual analysis (residuals uncorrelated and normally distributed with zero mean and constant variance [15]. All statistical analyses required for model evaluation were performed using MATLAB 2014b. Significance was reported at a probability level of 0.05. The histogram of residual can be used to check whether the variance is normally distributed or not. Figure 5 shows the histogram of residuals. The symmetric bell-shaped histogram which is evenly distributed around zero indicates that the normality assumption is likely to be true.

A normal probability plot of residuals also is used in this study to check whether the variance is normally distributed or not. If the resulting plot is approximately linear, we can proceed to assume that the error terms are normally distributed. As shown in Fig. 6 residuals are lying on a line so we can say that variance is normally distributed.

The residual error log plot, constructed by plotting residual (i) against residual (i-1) is useful for examining the dependency of error terms on each other. Any non-random pattern in a plot

Table 1. Estimated coefficients obtained from multiple linear regression analysis

	Coefficients	Standard error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	0.134103	0.026239	5.110819	8.31E-06	0.081072	0.187134
H	0.001176	0.000182	6.473375	1.02E-07	0.000809	0.001543
V	0.002919	0.000438	6.657588	5.64E-08	0.002033	0.003805

Table 2. Developed equation and coefficient of determination

Depth, cm	Equation used	No. of samples	R^2
0-20	0.00117(H) + 0.00292(V) + 0.134	43	0.824

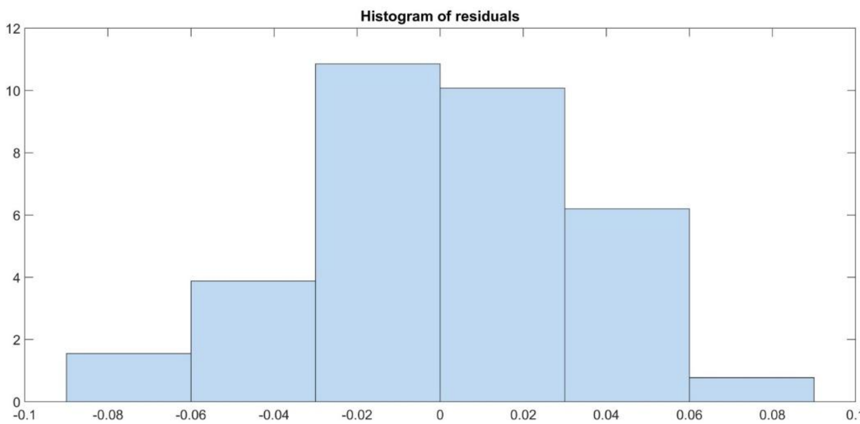

Fig. 5. Histogram of residuals

Table 3. Summary of ANOVA

	SS	DF	MS	F	p Value
H	0.048484	1	0.048484	41.36	1.17E-07
V	0.051511	1	0.051511	43.942	6.19E-08
Error	0.04689	40	0.001172		

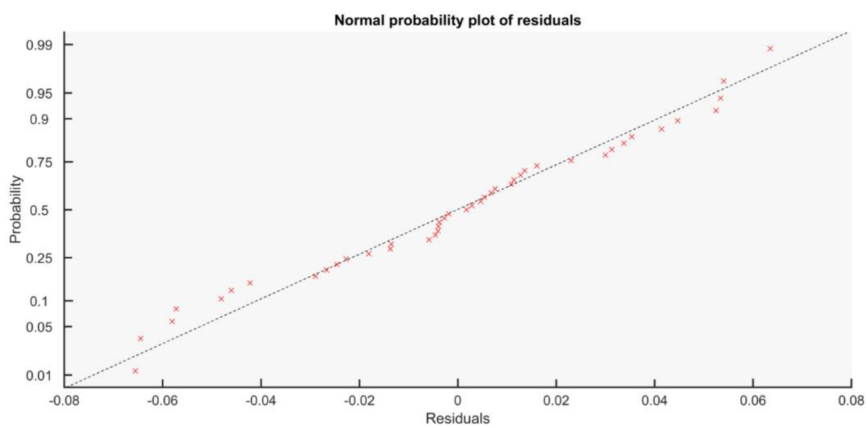

Fig. 6. Normal probability plot of residuals

suggests that variance is non-random. As shown in Fig. 7, the pattern is random which suggest that the variance is random and error terms are not related to each other.

Residual case order plot was used to find out outlier points. As shown in Fig. 8, the interval around all the residual does contain zero which indicates that the residual is smaller than expected in 95% of observations and it suggests that there were no outlier data points.

Fig. 9 shows the 3D plot between collected data and EC. Variation in EC is shown using a 3D surface with color map bar.

To evaluate the accuracy and precision of suggested multiple linear regression model, 20 readings were taken using EM-38 and electrical conductivity of soil was found out in the laboratory for the same places. Using model, the electrical conductivity of soil at these points were predicted, and the graph was plotted between

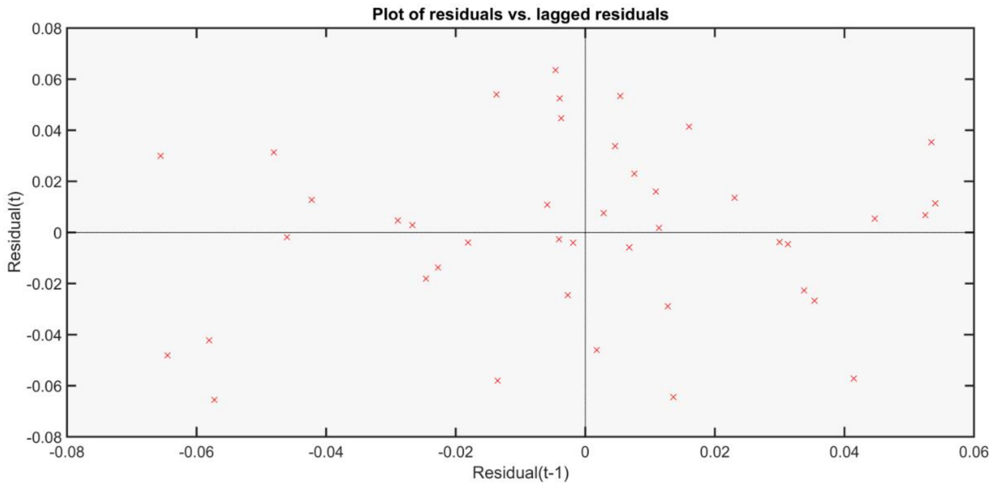

Fig. 7. Residual vs. lagged residual graph

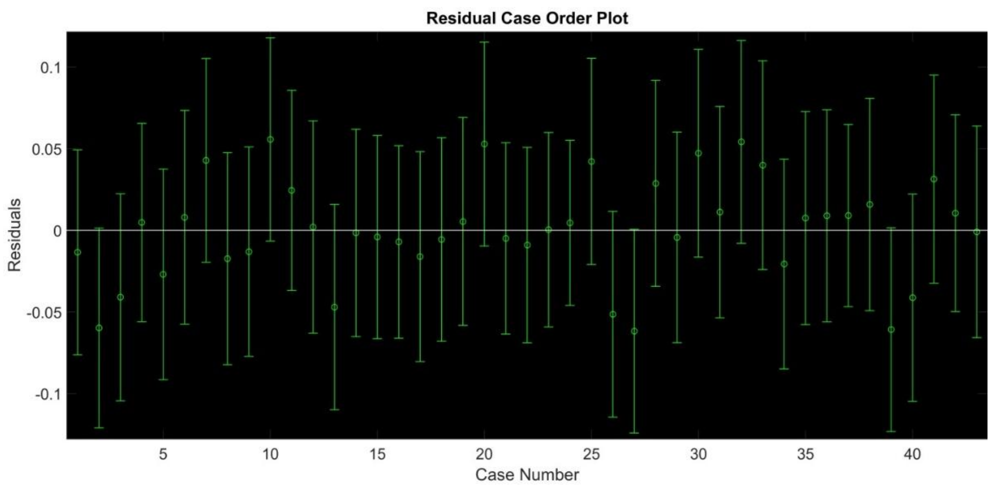

Fig. 8. Residual case order plot to find outlier data points

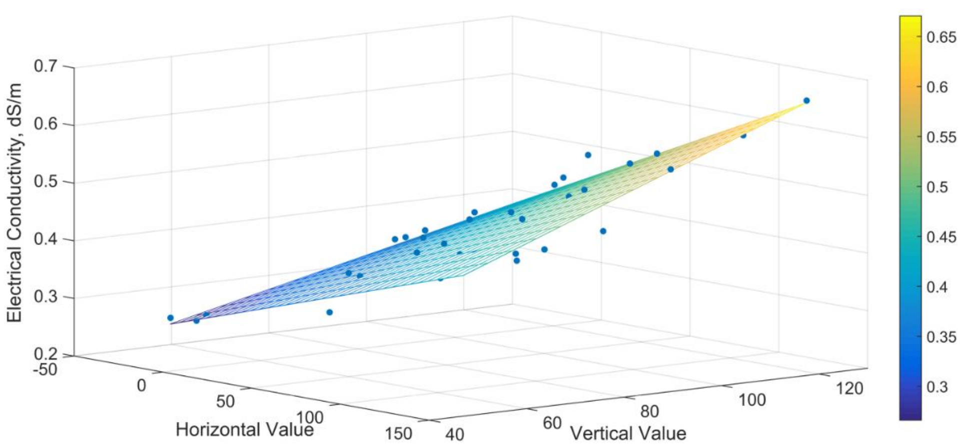

Fig. 9. The plot of collected data and EC

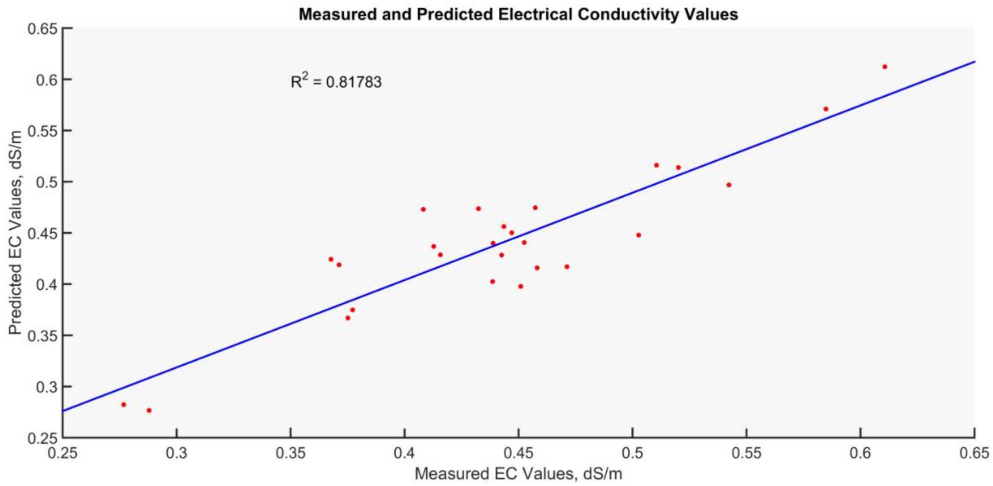

Fig. 10. The plot of measured and predicted EC values

predicted and actual electrical conductivity as shown in Fig. 10. (above) From Fig. 10, it observed that the coefficient of determination (r^2) is 0.817. Therefore, the model proposed in this study can be used to predict electrical conductivity of experimental site soil.

4. CONCLUSIONS

The objective of this paper was to infer the soil salinity value of UAS, Raichur soil using the EM-38 meter as this meter able to infer salinity rapidly without any post-processing of soil sample in the laboratory. Before using EM-38, its calibration is required to decrease errors in predicted soil salinity. Multicollinearity was not found between independent variables as the r^2 value was 0.425. Also, high correlation was obtained when electrical conductivity values were plotted against horizontal values (r^2 = 0.718) and vertical values (r^2 = 0.727). Therefore, both values contributed significantly to the prediction of electrical conductivity of the soil. Normal probability plot of residuals shows that variance is normally distributed and error terms are independent of each other as finding out from the plot of residuals vs. lagged residuals. Co-efficient of determination (R^2) between predicted and measured values of electrical conductivity was 0.817. Hence, proposed equation enables the user of EM-38 to derive a realistic index of soil salinity regarding electrical conductivity.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Rhoades JD, Ingvalson RD. Determining salinity in field soils with soil resistance measurements. Soil Science Society of America Proceedings. 1971;35:54-60.
2. Rhoades JD. Measuring, mapping and monitoring field salinity and water depths with soil resistance measurements. FAO Soils Bulletin. 1976;31:69-109.
3. McNeill JD. Electrical conductivity of soil and rocks. Technical note TN-5 Geonics Ltd. Mississauga, Ontario, Canada. 1980a;21.
4. McNeill JD. Electromagnetic terrain conductivity measurements at low induction numbers. Technical note TN-5 Geonics Ltd. Mississauga, Ontario, Canada. 1980b;15.
5. Kuligod VB, Salimath SB, Vijayashekhar K, Balakrishnan P. Calibration of inductive electromagnetic meter for determining electrical conductivity in vertisols. J. of Indian Society of Soil Science. 2001;49: 479-482.
6. Corwin DL, Lesch SM. Application of soil electrical conductivity to precision agriculture: Theory, principles, and guidelines. Agron. J. 2003;95:455–471.
7. Serrano JM, Peca JO, Silva JRM, Shaidian S. Mapping soil and pasture variability with an electromagnetic induction sensor. Computers and Electronics in Agriculture. 2010;73:7-16.
8. Martini E, Werban U, Zacharias S, Pohle M, Dietrich P, Wollschlager U. Repeated

electromagnetic induction measurements for mapping soil moisture at the field scale: Validation with data from a wireless soil moisture monitoring network. Hydrol. Earth Syst. Sci. 2017;21:495-513.
9. Doolittle JA, Brevik EC. The use of electromagnetic induction techniques in soils studies. Geoderma. 2014;223-225, 33-45.
10. Yao R, Yang J, Wu D, Yie W, Gao P, Jin W. Digital mapping of soil salinity and crop yield across a coastal agricultural landscape using repeated electromagnetic induction (EMI) surveys. Plos One. 2016;11(5):e0153377.
11. De Jong E, Ballantyne AK, Cameron DR, Read DWL. Measurement of apparent electrical conductivity of soils by an electromagnetic induction probe to aid salinity surveys. Soil Sci. Soc. Am. J. 1979;43:810–812.
12. Cameron DR, de Jong E, Read DWL, Oosterveld M. Mapping salinity using resistivity and electromagnetic inductive techniques. Can. J. Soil Sci. 1981;61:67–78.
13. Williams BG, Baker GC. An electromagnetic induction technique for reconnaissance surveys of soil salinity hazards. Aust. J. Soil Res. 1982;20:107–118.
14. Robinson DA, Lebron L, Lesch SM, Shouse P. Minimizing drift in electrical conductivity measurements in high temperature environments using the EM-38. Soil Sci. Soc. Am. J. 2004;68:339-345.
15. Montgomery DC, Peck EA. Introduction to linear regression analysis. New York, N.Y.: John Wiley and Sons; 1982.

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