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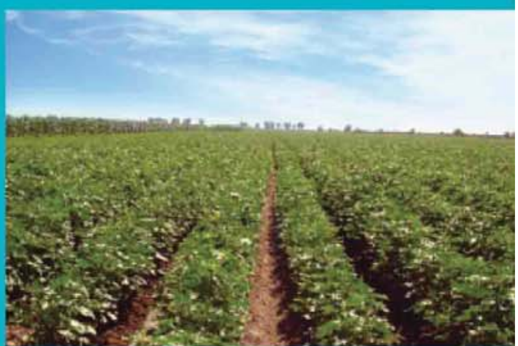

Conversion Factors to Estimate Soil Salinity Based on Electrical Conductivity for Soils in Khorezm Region, Uzbekistan

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Abstract

This paper compares different procedures for soil salinity analyses to determine electrical conductivity: saturated paste extract (EC_e), fixed soil:water ratio extracts $EC_{1:1}$ and $EC_{1:5}$, and soil solution paste prepared with 1:1 soil: water ratio and measured directly in the solution above the paste (EC_p), apparent electrical conductivity (EC_a) of a soil down to a depth of 0.75 and 1.5 m measured by electromagnetic device, and laboratory analyses for total dissolved solids (TDS) and ion composition. Conversion factors between these different methods to estimate salt content of soils are presented and can be applied for the predominant textures in the Khorezm region in Uzbekistan. The procedures described allow easy follow-up and replication of the approach.

Key words: saturation extract, electromagnetic induction, salinity, classification.

Introduction

Traditional soil salinity analysis in Uzbekistan involves determining the amount of total dissolved solids (TDS) in a given soil sample. Conductivity of the saturation extract (EC_e) is recommended as a general method for appraising soil salinity in relation to plant growth (USSL 1954). This is explained by the fact that plants are generally responsive of the salt concentration of the soil solution that highly correlates with the electrical conductivity (EC) of this solution (USSL 1954). Although TDS and ECe are realistic estimates of soil salinity, their estimation require considerable time and resources. Simplified measurements and proxy instruments for estimating TDS and EC_e values are commonly used to overcome such requirements.

This paper describes procedures and conversion factors to estimate soluble salts from electrical conductivity of the saturation extract, soil solutions (and paste), and electromagnetic (EM) conductivity. There is a range of conversion factors in the literature to estimate soluble salts for diverse soils. This paper presents similar factors for the conditions of the Khorezm region in Uzbekistan. This exercise was part of the development of a soil salinity monitoring system for large areas. Results from this exercise are applicable to all locations with similar soil textures and can thus be generally employed throughout the Khorezm region as well as, possibly, adjacent regions such as Karakalpakstan in Uzbekistan, and Dashoguz in Turkmenistan.

Materials and methods

Soil sampling and analysis

The study was conducted at the Cotton Research Station, east of Urgench city, Khorezm region, Uzbekistan. The area is fed by the Shavat canal, which runs along the northern side of the station. Topsoil of the station is of loamy texture, with textures ranging from loamy sands to clays in the middle of the soil profile, and deeper layers consisting of sands. Soils were sampled and measured in March and April 2008. These observation periods coincided with pre- and post-leaching events in the region. Random samples were collected from four fields, with an average field size of around 7 ha each. Soil samples were collected from 5 layers at 30-cm intervals (0-30, 30-60, 60-90, 90-120, 120-150 cm). The locations of the sampling points before leaching were recorded by GPS, which allowed revisiting the same points after leaching. In total, 15 locations were sampled before leaching and 21 locations after leaching.

Samples were analysed for TDS and ionic composition by the Soil Research Institute laboratory using methods described by Vorobyova (1998). Additional analyses were conducted in the ZEF/UNESCO project laboratory including electrical conductivity of saturation extract (EC_e), fixed soil:water ratio soil solution extracts ($EC_{1:1}$ and $EC_{1:5}$) following the procedures in USSL (1954).

The EC of the water (EC_p) was measured by inserting the electrical conductivity cell directly in the solution above a 1:1 soil:water paste. This is different from measuring the apparent EC of the soil paste where the electrodes are embedded in the wall of the container (Rhoades et al. 1999). Soil texture analyses were conducted by the feel method.
For our purpose two electrical conductivity meters (Eijkelkamp 18.21 and Hanna Instruments HI 98312) were selected to cross-check the measurements for quality control.

Electromagnetic conductivity measurement

The apparent electrical conductivity (EC_a) of the sampling locations was measured with the electromagnetic induction device (EM38) before and after leaching. Electromagnetic induction devices can be used in two modes, vertical and horizontal, in regard to the orientation of the meter to the soil surface to measure EC_a (mS/m). In the vertical mode (EMv), 70% of the conductivity contribution to the meter reading comes from the 0–1.5-m depth interval as compared to 0–0.75-m in the horizontal mode (McNeill 1980).

Temperature standardization

It is important to emphasize that all readings by electrical (i.e. Eijkelkamp, Hanna Instruments) and electromagnetic (EM38) conductivity devices need to be expressed at the standardized reference temperature of 25°C. Soil temperature to reference EM38 readings were measured at several locations down to the depth of 50-70 cm by inserting a temperature sensor. The formula provided in Sheets and Hendrickx (1995), is used:

$$EC_{25} = EC_a \times 0.4470 + 1.4034\Sigma^{(T/26815)}$$

where EC_{25} is the standardized EC_a and T is the soil temperature in degrees Celsius.

Results and Discussion

Saturation percentage (SP)

SP for the 75 soil samples taken before leaching in our test ranged from 27% to 55%, with an average of 41% (±6%). These values are similar to the values reported by USSL (1954) for a selection of medium soil textures that included very fine sandy loams, loams, silt loams and silts.

Estimation of EC_e from EC_p, $EC_{1:1}$ and $EC_{1:5}$

Electrical conductivity (EC_e) readings were graphed using scatter plots and the data was fit a linear regression forced through zero. In general, the fit of the regression line was accurate as demonstrated by the high R^2 of 0.84-0.94 (Table 1). The only notable difference in the regression coefficient for pre- as compared to post-leaching was for EC_p. Since EC_p was determined in the water above a 1:1 paste, EC_p should be about equal to $EC_{1:1}$ as should the regression coefficient relating EC_p and $EC_{1:1}$ to EC_e. This was the case for post-leaching, where the respective regression coefficients were 2.08 and 2.16, a difference that likely is not statistically significant. For pre-leaching, the regression coefficient for EC_p was greater than that for EC_e. This could be attributed to measurement technique: before leaching EC_p was measured in the water above the paste before letting the suspended soil particles settle; whereas after leaching the EC was measured in the water above the paste after the water was let to settle and clear.

The regression coefficients were similar for pre- and post-leaching for $EC_{1:1}$ and $EC_{1:5}$ as would be expected if leaching did not result in a major change

Table 1. Relationships for predicting electrical conductivity of the saturation extract from fixed soil:water ratio soil solutions

Pre-leaching	R^2	N	Post-leaching	R^2	N	Combined	R^2	N
$EC_e = 2.97 \times EC_p$	0.92	75	$EC_e = 2.08 \times EC_p$	0.92	105	$EC_e = 2.42 \times EC_p$	0.86	180
$EC_e = 1.98 \times EC_{1.1}$	0.88	75	$EC_e = 2.16 \times EC_{1.1}$	0.93	105	$EC_e = 2.06 \times EC_{1.1}$	0.90	180
$EC_e = 6.53 \times EC_{1.5}$	0.89	75	$EC_e = 2.08 \times EC_{1.5}$	0.92	105	$EC_e = 2.42 \times EC_{1.5}$	0.86	180

in the amount of gypsum and calcite present as a solid phase in the soil. Therefore, it was thought reasonable to use regression for combined pre- and post-leaching datasets.

Among the few studies reported for Uzbekistan, Shirokova et al. (2000) estimated conversion factor of 3.64 for the soil types dominant in the Syrdarya region whilst the EC_p was measured in a soil-water suspension as defined in our report. For soils in the Khiva region, Akramkhanov et al. (2008) estimated a conversion factor of 2.47.

A factor of 2.06 was required to estimate EC_e from $EC_{1:1}$ from the datasets in this study. This is close to the conversion factor of 2.2 reported by Landon (1984). To convert $EC_{1:1}$ to EC_e for soils in Oklahoma (USA), Zhang et al. (2005) reported coefficients of 1.79 (with an intercept 1.46) and of 1.85 if plotted without intercept. Hogg and Henry (1984) reported a conversion factor of 1.56 (with an intercept -0.06) based on their findings from Saskatchewan (Canada). For soils in Saudia Arabia, Al-Mustafa and Al-Omran (1990) reported a coefficient of 3.03 (with intercept –0.638). The theoretical value suggested by USSL (1954) for chloride salts was 2.7.

To convert $EC_{1:5}$ to EC_e for Iran soils, Alavi Panah and Zehtabian (2002) reported conversion factors of 6.92 and 8.79 for topsoil and the whole soil profile samples, respectively. In Saudi Arabia, the conversion factor from $EC_{1:5}$ to EC_e suggested was as high as 9.57 (Al-Mustafa and Al-Omran, 1990). Landon (1984) reported a factor of 6.4. For soils under irrigated cotton in Australia Triantafilis et al. (2000) reported value of 6.3. Shirokova et al. (2000) established a conversion factor of 5.6 for soils from Syrdarya region, Uzbekistan.

Estimation of salt content from electrical conductivity

Many recommendations are based on the salt content in a soil sample. Different types of salts present in the soil and the various analyses of the samples complicate the direct conversion of EC into (TDS), and vice versa. Some salts have a higher EC compared to other salts. In this study, there was a good correlation between EC of various soil solutions and TDS, and individual ions (Table 2).

Table 2. Correlation coefficients between EC of various solutions and TDS and individual ions

	TDS %	HCO_3 %	Cl %	SO_4 %	Ca %	Mg %	Na %	sum %
EC_e	0.78	-0.59	0.96	0.62	0.53	0.79	0.93	0.78
$EC_{1:1}$	0.81	-0.63	0.90	0.68	0.58	0.80	0.91	0.81
$EC_{1:5}$	0.87	-0.65	0.88	0.76	0.66	0.81	0.91	0.87
EC_p	0.81	-0.60	0.91	0.68	0.57	0.77	0.90	0.80

USSL (1954) provided a general formula to estimate TDS from EC, where TDS (%, or g/100g dry soil) was equal to EC_e (dS/m) via a coefficient of 0.064. However, other conversion coefficients reported in the literature ranged from 0.05 to 0.1. The coefficients estimated in this study were 0.0574 (with intercept of 0.0787) and 0.0655 (when forced through zero). It is essential to mention which salinity classification system is used because it is complicated to compare between classifications based on TDS and salinity type and those based on EC_e.

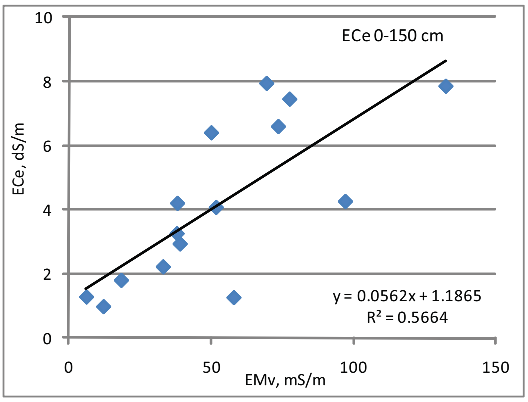
Alternatively, some recommendations are made based on the chloride ion content, which often constitutes the major anion in the extract and is used as an indicator of total salt content. There was a high correlation coefficient between EC_e and chloride anion (Cl), hence the regression equation [$Cl=EC_e \times 0.0093 - 0.0073$; $R^2 = 0.92$] could be used to estimate Cl with a high accuracy. Safe Cl ion content for normal plant growth in the Khorezm region reported in Nerozin (1980) is around 0.03-0.04%. Compared to salinity classification based on TDS, the use of salinity classification based on Cl offers more uniform ranges between various levels of salinity and is comparable to EC_e salinity classification.

Relationship between ECe and EM38 readings

Linear regression was used to calibrate the EM38 readings with EC_e. Average values of ECe for the depth of 1.5 and 0.90 m were plotted against EMv and EMh, respectively, since most of the conductivity contribution to EMv and EMh comes from their respective sensing depths. Figure 1 shows that about 57% and 60% of the variation in soil salinity at the 1.5 and 0.9 m soil layer can be explained by EMv and EMh readings respectively.

Although an effort was made to obtain a wide range of salinity values, the highest readings rarely exceeded 150 mS/m (unit EM device expresses EC). Given the fact that most soil types in the Khorezm region are similar, differences between soil textures were not considered during the study.

Our study gave somewhat lower R^2 values compared to other reported studies in the literature. This could be due to the narrow salinity range (0-180 mS/m) for calibration. However, there is clear trend suggesting that values of EC_a measured by EMv and EMh above 150 mS/m indicate very saline soils.



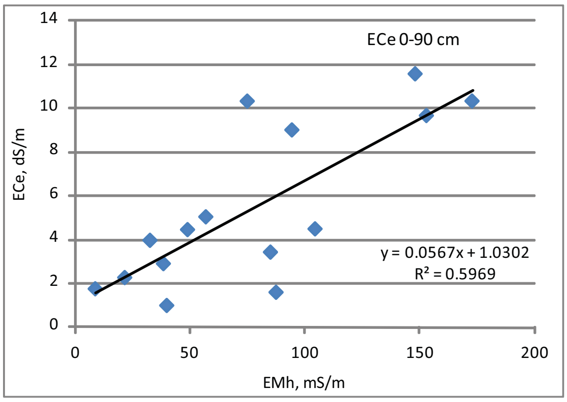


Figure 1. Relationships between EM38 readings in the vertical and horizontal modes of operation and EC_e of 150 and 90 cm soil layers

Conclusions

Irregular analysis of soil salinity and the lack of facilities and time often deter the routine estimation of EC_e in the laboratory. It has become common practice to estimate EC_e by EC_p, $EC_{1:1}$, $EC_{1:5}$. The EM38 readings can also be regressed against EC_e, EC_p, $EC_{1:1}$, $EC_{1:5}$ to classify EM38 readings into salinity classes. Results obtained in this study are applicable to loamy soils predominant in the region and hence can be applied to areas with similar soil textures. Therefore, the user can select which method to pursue, how much time will be required, and what accuracy to expect when relating EM38 readings to salinity levels.

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References

Akramkhanov A., R. Sommer, C. Martius, J. M. H. Hendrickx, P.L.G. Vlek. 2008. Comparison and sensitivity of measurement techniques for spatial distribution of soil salinity. Irrigation and Drainage Systems 22: 115-126.

Alavi Panah S. K., G. R. Zehtabian. 2002. A database approach for soil salinity mapping and generalization from remote sensing data and geographic information system. FIG XXII International Congress, Washington, D. C. USA, April 19-26, 2002.

Al-Mustafa W.A., A.M. Al-Omran. 1990. Reliability of 1:1, 1:2, and 1:5 weight extracts for expressing salinity in light-textured soils of Saudi Arabia. J. King Saud Univ. Vol. 2, Agric. Sci (2) 321-329.

Hogg T.J., J.L. Henry. 1984. Comparison of 1:1 and 1:2 suspensions and extracts ensions and extracts with the saturation extract in estimating salinity in Saskatchewan soils. Can. J. Soil Sci. 64: 699-704.

Landon J.R. (ed) 1984. Booker tropical soil manual. Booker Agriculture International Limited, Bath, 441 pp.
McNeill J.D. 1980. Electromagnetic terrain conductivity measurement at low induction numbers. Techincal Note TN-6. Geonics Limited, Mississauga, ON, Canada.
Nerozin A.E. 1980. Selskohoziaystvennie melioracii, Uqituvchi, Ташкент (Russian).
Rhoades J.D., F. Chanduvi, and S.M. Lesch. 1999. Soil salinity assessment: methods and interpretation of electrical conductivity measurements. Irrigation and Drainage Paper, Vol. 57. FAO, Rome.
Sheets K.R., J.M.H. Hendrickx. 1995. Noninvasive soil water content measurement using electromagnetic induction. Water Resources Research 31: 2401-2409.
Shirokova Yu. I., I. Forkutsa, and N. Sharafutdinova. 2000. Use of electrical conductivity instead of soluble salts for soil salinity monitoring in Central Asia. Irrig. Drain. Syst. 14: 199-205.
Triantafilis J., G.M. Laslett, A.B. McBratney. 2000. Calibrating an electromagnetic induction instrument to measure salinity in soil under irrigated cotton. Soil Sciecne Society of America Journal 64: 1009-1017.
United States Salinity Laboratory Staff. 1954. Diagnosis and improvement of saline and alkali soils. Handbook 60. United States Department of Agriculture. 160 pp.
Vorobyova L. A. 1998. Khimicheskiy analiz pochv. Moscow State University Press, Moscow, 272 pp, (Russian).
Zhang H., J.L. Schroder, J.J. Pittman, J.J. Wang, and M.E. Payton. 2005. Soil salinity using saturated paste and 1:1 soil to water extracts. Soil Sci. Soc. Am. J. 69: 1146-1151.