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Determination of global and dynamic salinity of soils using electromagnetic conductivity.
Détermination de la salinité globale et de la dynamique de la salinité des sols par conductivité électromagnétique

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The use of electromagnetic conductivity as a means to estimate soil salinity is now widespread. Reconnaissance surveys of soil salinity used this technique first. Using this technique, it is now possible to determine with accuracy the global salinity of the upper 200 cm of the soil. It is also possible to estimate the salinity of the layer of soil upper than l60 cm and between 60 and 120 cm depth, and to deduce if the dynamics of the salt within the profile are dominated either by capilarity or by lixiviation.

The instrument used in our study (EM38) has an intercoil spacing of 100 cm. It is convenient for measuring soil salinity of soil to a depth of 200 cm.

Previously, the calibration of instrument readings versus soil salinity was done either by comparison with the four electrode probe response, or directly from the measurement of the electric conductivity of the saturation extract : ECe.

However, these calibrations are convenient for large surveys as long as the soil porosity and the soil water content are reasonably constant, so that the calibration holds. This is not the case in irrigated lands, where the profile salinity may be inverted or normal, without a sharp boundary between soil horizons. Furthermore, the soil moisture content is highly variable from plot to plot, so that the effect of the soil moisture content of soil cannot be neglected in surveys.

The aim of our paper is to propose a precise method of calibration of the electromagnetic response of the soil, versus the electrical conductivity of the saturation extract of the soil, taking into account the water content and the level of soil salinity. The study was done on 117 soil profiles representing a wide variety of irrigated soils of Sénegal, Syria, Tunisia and Mexico. The electrical conductivity and the water content of each soil profile was determined on extracts of soils sampled with a depth increment of 20 cm until 200 cm. Three levels of salinity were considered fot the calibration : 0-5 dSm^{-1}, 5-15 dSm^{-1}, and 15-50 dSm^{-1}.

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Introduction

In arid zones, the soil salinity of irrigated areas is highly variable from plot to plot due to the combined effect of soil properties and quantityof water applied. Therefore, the evaluation of of soil salinity in laboratory requires a great quantity of samples (Job et al., 1987).

A way of limiting the number of soil samples is to measure in situ the electromagnetic conductivivty of the soil (ECm) and to calibrate the measurement versus the salinity of the soil. Using an electromagnetic conductivimeter Geonics EM-38, it is possible to calibrate ECM versus the salinity of the soil from the surface down to 200 cm measured in the laboratory as the average of the electrical conductivity of the saturation extracts of 10 soil layers taken with a 20 cm depth increment down to 200 cm : $ECsat_{(0\text{-}200)}$, or down to any smaller depth.

Evaluation of soil salinity using this technique relies on the application of the equations developped by McNeal (1980):

$$Rv(z)=1/(4z^2+1)^{1/2} \quad (1) \qquad \text{and : } Rh(z)=(4z^2+1)^{1/2} - 2z \quad (2)$$

Where Rv(z) and Rh(z)represent the contribution to the EM reading of the soil layer between the surface and the normalized depth z. (z is the depth d divided by the intercoil spacing of the equipement used : e. (as far as the EM-38 is concerned, e=1).

According to the theory, these equations are valid for an homogeneous medium with respect to the nature of the material, its porosity and its salt and water content : $\theta_{(0\text{-}200)}$. These conditions seldom exist in cultivated soils, and approximations must be adopted.

A number of calibration techniques have been proposed (De Jonc et al, 1979; Corwin and Rhoades, 1981, Job et al., 1987, Diaz and Herrero, 1992). To our knowledge, none of them takes into account the soil water content at the time of the measurement.

In the following work, $ECsat_{(0\text{-}h)}$ represents the electical conductivity (dSm^{-1}) of the saturation extract of the soil between the surface and the depth h, $ECmv_{(\theta)}$ and $ECmv_{(\theta)}$ the electromagnetical conductivity (mSm^{-1}) as mesured by EM-38 in vertical and horizontal positions of the coils respectively, and $\theta_{(0,h)}$ the water content of the soil as the percentage of the weight of soil on oven dry (60°C) soil basis measured down to the depth h.

In addition, we assumed that in a given irrigated area, the soils pertaining to a same family, have a reasonably homogeneous porosity. That is to say that by measuring ECmv or ECmh it is possible to estimate $ECsat_{(0\text{-}h)}$ with the condition of estimating $\theta_{(0\text{-}h)}$., without caring for the porosity of the soil volume investigated.

Material and methods :

Using the above mentioned equipement, known as Slingram configuration (Tabbagh, xx, Job and al, xx), it is possible to measure the ECM of a soil either with the coils in vertical (ECMv), or in horizontal position (ECMh). In each case, the geometry of the electromagnetic field produced in the soil is different (MNeill, 1980).

Two experiments experiments have been realized.

The first one took place in South Tunisia at El Guettar, a 500 ha traditional pre-saharian oasis cultivated since ancient times. Irrigation water of acceptable quality (2.3 g/l, mainly sodium chloride and magnesium sulfate) is distributed from artesian wells trough 200 km of concrete canals to 2453 individual very small plots. Soils are very homogeneous eolian deposits of quaternary lenticular gypsum.

Due the limited quantity of water available, many plots are underirrigated, and the spatial variation of soil water content in very great. Profiles of salinity increasing from 2 to 50 dSm^{-1} were selected. For each profile, the soil water content and the electric conductivity of the saturation extract was measured for 6 samples taken at 20 cm depth increment down to 120 cm. The values $ECsat_{(0\text{-}120)}$ and $\theta_{(0\text{-}120)}$ were then determined int the laboratory. The depth of 120 cm was choosed to avoid the disturbance due to the water table. Out of 120 profiles, the same limited number of 30 were taken into account in each range 0-5, 5-15 and 15-50 in order to comply with the statistical distribution of soil salinity in the area.

Two regression equations $Ecm_{(\theta=cste)} = a_*ECsat_{(0\text{-}120)} + b$ and $Ecm_{(ECsat(0\text{-}120)=cste)} = a'_*\theta + b'$ were established by iteration until the coefficients a,b,a',b' reached a constant value.

A second experiment was conducted in the Northern central plain of Mexico. The Comarca Lagunera is a modern irrigated district of 100 000 ha. Fresh irrigation water is supplied by a dam built in the nearby Sierra Madre Occidental and complemented or mixed with underground local water of poor quality (1 to 5 grl^{-1}, of total salts, mainly sodium chloride and sodium sulfate).

Four 25 m² plots of alluvial soil, having a salt content constant from the surface down to 200 cm, were selected and flooded with just the quantity of water necessary to moist the soil down to 200 cm after four days of application. The soil water content and the electrical conductivity of the saturation extract was then measured for each sample taken at 20 cm depth. increment, down to 200 cm. This depth correspond to the maximum penetration of the electromagnetic field induced by the EM-38, when there is no water table. Every 7 days during six months ECmv and ECmh were measured, in situ, $ECsat_{(0\text{-}200)}$ and $\theta_{(0\text{-}200)}$ determined in the laboratory as done in the first experiment.

Results

The equations derived from El Guettar experiment were :

$$ECmv_{(20)} = ECmv_{(\theta)} + 5.7*(20 - \theta) \qquad (3)$$

Were θ is the actual soil water conent in the field and 20 a reference value choosed as being the average of the soil water content of irrigated soils at El Guettar (medium texture irrigated eolian gypsum).

with :
n= 90, $50 < ECmv_{(20)} < 700$ $17 < \theta_{(0\text{-}200)} < 25$,

The soil salinity was related to the electromagnetic conductivity measured with the coils in horizontal position with the regression equation :

$$ECsat_{(0\text{-}120)} = 0.094_* ECmh_{(20)} - 0.64 \qquad (4)$$

with :

n=90, $3 < ECsat_{(0\text{-}120)} < 50$ $\theta_{(0\text{-}120)}=20$

More accurate equations was obtained in the second experiment :

$$ECmvh_{([(0\text{-}200), 20]} = ECmvh_{(([(0\text{-}200), \theta]} + (4.6\text{-}s)*(20 - \theta_1) \qquad (5)$$

with : $ECmvh_{([(0\text{-}200),\ \theta]} = [ECmv_{([(0\text{-}200),\ \theta]} + ECmh_{([(0\text{-}200),\ \theta]}]/2$ (6)

n=63, 0.3 <s = sand percentage<0.8 15 < $CEm_{(v,\ 20)}$ < 150 10< θ < 28

while the soil salinity was related to $ECmv_{(0\text{-}200)}$ within two narrower range :

1- over in the 0.4 < $ECsat_{(0\text{-}200)}$ < 4 dsm^{-1}range :

The electromagnetic induction tehcnique is a simple way of measuring global soil salinity over the all range encoutered in irrigated soils. Provided a preliminary calibration and an estimation of the soil water content to the nearest 10, 15 or 20% (weigth/versus weight), it is possible to achieve an accuracy of 20% in the evaluation of the salinity of any soil profile perteining to the same soil family (same parent material, same porosity).

In order to comply with the initial hypothesis of soil homogeneity, the experiment was conducted on soil profiles lacking of well differenciated diagnostic horizon. The study was restricted to alluvial soils having the same distribution of horizons within the soil profile.

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Keywords : salinity of soils, electromagnetic conductivity, Senegal, Syria, Tunisia, Mexico
Mots clés : salinité des sols, conductivité électromagnétique, Sénégal, Syrie, Tunisie, Mexique

The effect of soil water content on the electromagnetic conductivity of soil was investigated in the 10%-35% range for soils of different textures.

Keywords : salinity of soils, electromagnetic conductivity, Senegal, Syria, Tunisia, Mexico
Mots clés : salinité des sols, conductivité électromagnétique, Sénégal, Syrie, Tunisie, Mexique