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# MONITORING SOIL MOISTURE SUCTION VALUES USING NEUTRON MOISTURE METER AND EFFECT OF SOME IONS ON NEUTRON COUNT RATIO

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## ABSTRACT

The aim of this work is to derive an equation to monitor the soil moisture suction (matric potential) using neutron scattering method in situ and effect of sodium and chlorine ions on neutron count ratio. The equation predicts the soil matric suction values to wilting point (15000 mbar). The derivative equation is:

$$h_{,mbar} = h_b\,[\{(a\,C.R + b) - \theta_r\}^{-1/m} (\phi - \theta_r)^{1/m} - 1]^{1/n}$$

Where:

**h,** is the soil matric suction, mbar (taken positive),
**$h_b$,** is the bubbling pressure (air entry suction, mbar),
**a**, is the regression coefficient of neutron calibration curve for the Soil depth under study,
**b**, is the intercept for y axis( soil moisture content),
**C.R**, is the neutron count ratio,
**$\theta_r$,** is the residual soil moisture content, $cm^3\ cm^{-3}$,and
**m,n** , are the constants depend on fitting of soil moisture retention curve.

This study was conducted in desert research center experimental station at Ras Sudr, south of Sinai at different soil depths.

This investigated data show that the relationship between soil suction (h) and neutron count ratio (C.R) is inversely function, it can be predicted with matric suction above tensiometric range(0-850 mbar) up to wilting point (15000 mbar). The derivative equation is considered as a faster method to carryout the irrigation scheduling that detected the soil moisture suction in situ. As well as ions of sodium and chlorine have the biggest effect on neutron moderation at high soil matric suction, and summation of $Na^+$ and $CL^-$ at each soil layer had correlated with C.R at different soil suction below field capacity on the following relation:

$$(C.R = A + B/\ \Sigma\ (Na^+ \text{ and } CL^-)$$

## INTRODUCTION

Soil moisture retention curve (SMRC) is a relationship between soil moisture content values ($\theta$) and soil matric suction (h). Many authors express SMRC in mathematical models (Brooks and Corey, 1964; King, 1965; Brutsaert, 1967; Taylor and Luthin, 1969; Farrell and Larson, 1972; Campbell, 1974; and Van Genuchten, 1980).

*Van Genuchten* (1980) was derived a model for SMRC which is depend on five parameters (i.e. residual soil moisture content ($\theta_r$); total soil porosity ($\phi$); bubbling pressure ($h_b$) and n, m which are constants depend on fitting curve

Many authors (i.e. *Paydar et al.* 1996; *Cresswell and Payder*, 1996; *El- Shafei*, 1997; and Rawls *et al., 1998*) used the mathematical models of

SMRC to determine the soil properties and study the effect of soil amendments on soil characteristics. *IAEA* (1976) used neutron calibration curve of neutron moisture meter and tensiometers to determine the soil characteristic curve in situ.

The objectives of this work are to correlate the neutron count ratio and soil matric suction to predict the soil matric suction up to wilting point. Other object is to study the effect of soil matrix and effect of $Na^+$ and $CL^-$ on neutron moderation.

**Theory Basis**

Mualem (1976) introduced the dimensionless water content parameter (Se) which can be obtained from the soil moisture retention curve as:

$$S_e = (\theta - \theta_r) / (\phi - \theta_r) \quad (1)$$

Where:

$\theta$ = the soil water content at soil moisture suction(h, mbar)

$\theta_r$, = the residual soil moisture content, $cm^3\ cm^{-3}$,and

$\phi$ = the total porosity

*Van Genuchten* (1980) introduced also Se (h) function as:

$$S_e = [1 / (1 + (\alpha h)^n)]^m \quad (2)$$

Where:

$\alpha$, n and m are taken to be the fitting parameters. By combination eq. 1 and 2 yields a new model eq.3 for expressing soil moisture retention curve:

h: is the soil matric suction, mbar (taken positive),

$$(\theta - \theta_r) / (\phi - \theta_r) = [1 / (1 + (\alpha h)^n)]^m \quad (3)$$

Rearrangement parameters in eq. 3 to be h ($\theta$) as in eq. 4:

$$h,_{mbar} = h_b [(\theta - \theta_r)^{-1/m} (\phi - \theta_r)^{1/m} - 1]^{1/n} \quad (4)$$

Where, $h_b = 1/\alpha$

Substituting $\theta$ in eq. 4 by its equal from the regression equation of neutron calibration curve (are represented regression equation, i.e. $\theta$ = a C.R +b) yields eq.5:

$$h,_{mbar} = h_b [\{(a\ C.R + b) - \theta_r\}^{-1/m} (\phi - \theta_r)^{1/m} - 1]^{1/n} \quad (5)$$

Where, C.R is the neutron count ratio.

## MATERIALS AND METHODS

This study was conducted in the experimental station of desert research center at Ras Sudr area, South of Sinai. An area of 100 $m^2$ was over irrigated after installing an access tube and tensiometers as illustrated in Fig (1). Some physical and chemical soil properties are shown in Tables (1 and 2) according to the standard methods (Black, 1965).

**Fig (1): Experimental layout, where A, B, C and D are tensiometers on soil depths of 30,45,60,and 75 cm, as well as R1, R2, and R3 are replicates for tensiometer sets and the circle in the center of plot is neutron access tube**

**Table (1): Some physical and hydrophysical properties of Ras Sudr soil**

| Soil layer Cm | Particle size distribution % | | | Textural class | Ks, Cm/day | ρb $g/cm^3$ | ϕ % | F.C % |
|---|---|---|---|---|---|---|---|---|
| | Sand | Silt | Clay | | | | | |
| **0-15** | 35.05 | 49.11 | 15.84 | Loamy | 5.8 | 1.560 | 42.12 | 26.04 |
| **15-30** | 77.09 | 8.02 | 14.89 | Sandy loam | 5.8 | 1.635 | 36.15 | 32.64 |
| **30-45** | 88.24 | 1.23 | 10.53 | Loamy sand | 3.6 | 1.719 | 35.14 | 19.86 |
| **45-60** | 58.30 | 25.87 | 15.83 | Sandy loam | 7.0 | 1.658 | 37.43 | 19.86 |
| **60-75** | 36.39 | 53.17 | 36.39 | Silty loam | --- | 1.729 | 34.74 | 27.64 |

**Ks = the saturated hydraulic conductivity,**
**ρb = the soil bulk density,**
**ϕ = the total porosity , and**
**F.C = field capacity at 330 mbar**

**Table (2): Some chemical properties of the studied soil and Calcium carbonate content**

| Soil layer Cm | $CaCO_3$ % | PH in soil paste | EC $DSm^{-1}$ | $Na^+$ meq $L^{-1}$ | $CL^-$ meq $L^{-1}$ |
|---|---|---|---|---|---|
| **0-15** | 54.7 | 7.6 | 11.41 | 57.19 | 71.38 |
| **15-30** | 53.3 | 7.7 | 7.74 | 36.97 | 39.89 |
| **30-45** | 51.8 | 7.7 | 4.06 | 16.74 | 8.39 |
| **45-60** | 47.4 | 8.2 | 1.41 | 8.40 | 5.81 |
| **60-75** | 65.3 | 8.8 | 1.96 | 13.20 | 10.32 |

**Table (3): Neutron regression equations for neutron calibration curves at different soil depths**

| Soil depth, Cm | Neutron regression equation | Correlation coefficient |
|---|---|---|
| **30** | $\theta_v = 0.2532$ C.R + 0.0579 | 0.994 |
| **45** | $\theta_v = 0.3378$ C.R + 0.0773 | 0.997 |
| **60** | $\theta_v = 0.3236$ C.R + 0.0225 | 0.967 |
| **75** | $\theta_v = 0.2778$ C.R + 0.0067 | 0.997 |

Soil moisture contents were determined by using neutron moisture meter (Model 4302 serial No. 443, Troxler) and neutron regression equations (Table 3) were calculated according to (*IAEA*, 1976).

Twelve tensiometers in three replicates (R1, R2, and R3) as shown in Fig (1) were installed at 30, 45, 60, and 75-cm depths 50-cm around the neutron access tube. Soil moisture contents and soil matric potential values were recorded (were represented in empirical equation for soil characteristic curves at the same soil depths, Table 4).

**Table (4): Empirical equations for soil characteristics curve at different soil depths up to 1000 mbar**

| Soil depth, Cm | Regression equation | Corr. Coeff. |
|---|---|---|
| **30** | $H_{mbar}=1530.493\times 10^{6}$ EXP$(-47.0278\times\theta_v)$ | -0.9074 |
| **45** | $h_{mbar}=4413$ EXP$(-9.3661\times\theta_v)$ | -0.8984 |
| **60** | $h_{mbar}=2443$ EXP$(-10.0820\times\theta_v)$ | -0.9831 |
| **75** | $h_{mbar}=15116$ EXP$(-13.8382\times\theta_v)$ | -0.9014 |

By using a method of *Breakensiek* (1977) the pore size index values ($\lambda$) for Brook and Corey (1964) were calculated for the soil depths under study. We took into consideration the corresponding parameters for Van Genuchten's model, which were assumed by *Rawls and Breakensiek* (1985). The total soil porosity values ($\phi$) were calculated by using total porosity equation ($\phi = 1 - P_b / P_s$), where $P_b$, is the soil bulk density, g cm$^{-3}$ and $P_s$ is the soil particle density, g cm$^{-3}$ (taken 2.65 g cm$^{-3}$). The residual soil moisture content values ($\theta_r$) were also determined at 15000 mbar.

## RESULTS AND DISCUSSION

Data in Table (5) includes $h_b$, $\theta_r$, and $\phi$ as soil constants, m, and n as constants for fitting of soil moisture retention curves, as well as a and b are the regression coefficient and intercept for neutron calibration curve, respectively. These constants are used in eq.5 at 30, 45, 60, and 75-cm depths.

**Table (5):Soil variables and constants were used in eq. 5 at different soil depths**

| Soil depth, Cm | $h_b$ cm | A | B | $\theta_r$ $cm^3\ cm^{-3}$ | $\phi$ $cm^3\ cm^{-3}$ | m | N |
|---|---|---|---|---|---|---|---|
| **30** | 12.4429 | 0.2532 | +0.0579 | 0.1272 | 0.4182 | 0.0879 | 1.0964 |
| **45** | 100.9412 | 0.3379 | -0.0775 | 0.1151 | 0.4018 | 0.3710 | 1.5899 |
| **60** | 78.4976 | 0.3236 | -0.0225 | 0.0467 | 0.3820 | 0.3830 | 1.6207 |
| **75** | 55.3692 | 0.2778 | -0.0067 | 0.1023 | 0.4324 | 0.2728 | 1.3751 |

The obtainable empirical equations, which express the relationship between h and C.R, are calculated at 30,45,60,and 75 cm as the following:

$$h_{30\ cm} = 12.4429\ [7.960\times10^{-7}(0.2532C.R - 0.0693)^{-11.3766} - 1]^{0.9121}$$
$$h_{45\ cm} = 100.9412\ [0.0344\ (0.3378\ C.R - 0.1924)^{-2.6954} - 1]^{0.6290}$$
$$h_{60\ cm} = 78.9576\ [0.0577\ (0.3236\ C.R - 0.0692)^{-2.6110} - 1]^{0.6170}$$
$$h_{75\ cm} = 55.3692\ [0.0172\ (0.2778\ C.R - 0.1090)^{-3.6657} - 1]^{0.7272}$$

Where, C.R is the neutron count ratio

Fig. (2) illustrates the output data using these equations at 30,45,60, and 75-cm soil depths. These functions are inversely functions. The neutron count. ratios fast decreased through the tensiometric range (up to 850 mbar), and the curves become flat up to 15000-mbar approximately.

**Fig (2): The relationship between soil matric suction and neutron count ratio at different soil depths**

The soil matrix effected on the neutron count ratios via the soil matric suction and ions which were adsorbed around the surface of soil particles (see the .gradient in the slope that occurred for the curves at 30,45, 75, and 60- cm soil depths in Fig.2). Water films around soil partials decrease with increasing the soil matric suction. Sodium and Chlorine ($Na^+$ and $CL^-$) have the biggest effect on neutron moderation at high soil matric suction (Tables 6 & 7). Summation of $Na^+$ and $CL^-$ at each soil layer had correlated with C.R at different soil suction below field capacity (High significance effect, P. at 0. 01) Table (6). The relation is:

$$\mathbf{(C.R = A + B/\Sigma\ (Na^+\ and\ CL^-)}$$

The correlation coefficients were nonsignificant at 0 and 330 mbar, that is due to the hydrogen effect on neutron moderation, because above field capacity the macropores are full of water and there are extra of free water, so, there were no any effect on $Na^+$ and $CL^-$.

**Table (6): Correlation coefficients of the relationship between Σ ($Na^+$ and $CL^-$) and C.R at different soil matric suction for different soil depths**

| Matric suction (mbar) | Soil depth, Cm | | | | Corr. Coff. |
|---|---|---|---|---|---|
| | 30 | 45 | 60 | 75 | |
| | Σ ($Na^+$ and $CL^-$), meq/L | | | | |
| | 78.86 | 25.13 | 14.21 | 23.52 | |
| | C.R(eq. 5) | | | | |
| **0** | 1.423 | 1.418 | 1.250 | 1.581 | -0.5078 |
| **100** | 1.203 | 1.135 | 0.838 | 1.1993 | -0.8581 |
| **330** | 1.109 | 0.930 | 0.587 | 0.966 | -0.9682** |
| **850** | 1.038 | 0.795 | 0.438 | 0.809 | -0.9882** |
| **1000** | 1.026 | 0.777 | 0.418 | 0.7861 | -0.9905** |
| **2000** | 0.978 | 0.711 | 0.350 | 0.699 | -0.9965** |
| **3000** | 0.951 | 0.682 | 0.320 | 0.656 | -0.9981** |
| **5000** | 0.918 | 0.653 | 0.292 | 0.611 | -0.9987** |
| **8000** | 0.890 | 0.633 | 0.272 | 0.576 | -0.9982** |
| **10000** | 0.877 | 0.626 | 0.265 | 0.561 | -0.9976** |
| **15000** | 0.854 | 0.614 | 0.254 | 0.537 | -0.9962** |

**** P = 0.01 (Bisher and El-Robi, 1979)**

**Table (7): Intercept (A), regression coefficient (B) and correlation Coefficient (r) for the inversely function (C.R = A + B/ Σ ($Na^+$ and $CL^-$) at different soil matric suctions.**

| H, mbar | A | B | R |
|---|---|---|---|
| **0** | ------- | ------- | -0.5078 |
| **100** | ------- | ------- | -0.8581 |
| **330** | 1.2738 | -9.0717 | -0.9682 ** |
| **850** | 1.2022 | -10.4338 | -0.9882 ** |
| **1000** | 1.1898 | -10.5780 | -0.9905 ** |
| **2000** | 1.1376 | -10.9416 | -0.9965 ** |
| **3000** | 1.1078 | -10.9935 | -0.9981 ** |
| **5000** | 1.0717 | -10.9375 | -0.9987 ** |
| **8000** | 1.0409 | -10.7921 | -0.9982 ** |
| **10000** | 1.0254 | -10.7019 | -0.9976 ** |
| **15000** | 0.9999 | -10.5060 | -0.9962 ** |

The neutron moderation process above field capacity is very high by hydrogen molecules (in water). *IAEA* (1976) mentioned that the neutron moderation follows the next series: - H >> Na > CL. As for below field capacity where the soil moisture decreases (reduction of hydrogen molecules) the sodium and chlorine on the soil matrix effected on neutron count ratios (neutron moderation) tables (6 &7).

The C.R values at wilting point (15000 mbar) were calculated. They were 0.8537, 0.61395, 0.25375, and 0.53760 at 30, 45, 60, and 75- cm depth, respectively.

## CONCLUSION

- Neutron probe can be used to predict the soil matric suction up to 15 bar in situ .
- Cations and Anions must be taken in consideration in saline soils to interpret the relationship between neutron count ratio and soil matric suction below field capacity.
- The derivative equation is considered a faster method to predict the soil matric suction by knowledge the parameters of Van Genuchten's model for soil moisture retention curve.

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# رصد قيم الشد الرطوبي الأرضي باستخدام جهاز الرطوبة النيوتروني وتأثير بعض الأيونات على معدل العد النيوتروني

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يهدف هذا العمل إلى إمكانية اشتقاق معادلة تجريبية خاصة بالموقع تحت الدراسة لمتابعة قيم الشد الرطوبي الأرضي ( جهد مادة الأرض )، وذلك باستخدام جهاز الرطوبة النيتروني ( طريقة تشتت النيترونات ) حقلياً وتأثير أيونات الصوديوم والكلور ين على معدل العد النيوتروني . وتمكننا هذه المعادلة المشتقة من التنبؤ بقيم الشد الرطوبي حتى نقطة الذبول ( 15 بار ) حقلياً . والمعادلة المشتقة على الصورة التالية .

$$h,_{Cm} = h_b\,[\{(a\,C.R + b) - \theta_r\}^{-1/m}(\phi - \theta_r)^{1/m} - 1]^{1/n}$$

**حيث :-**

$h$ = جهد مادة الأرض ( الشد الرطوبي الأرضي )، ملي بار

$h_b$ = جهد الضغط الفقاعي ( جهد دخول الهواء ) ، ملي بار

$a$ = معامل ارتداد منحني المعايرة النيتروني للعمق موضع الدراسة .

$b$ = طول القاطع من المحور الرأسي (y) الممثل للمحتوي الرطوبي الأرضي .

C.R = نسبة العد النيتروني

$\theta r$ = المحتوي الرطوبي المتبقي حجماً

$\phi$ = المسامية الأرضية الكلية ( المحتوي الرطوبي عند التشبع ، حجماً )

m,n= ثوابت تحدد شكل منحني الشد الرطوبي لمعادلة فان جنشتن

لذلك أقيمت هذه الدراسة بمنطقة رأس سدر جنوب سيناء لأعماق أرضية مختلفة (30،45،60، 75 سم).

وقد اوضحت النتائج أن العلاقة بين قيم الشد الرطوبي ( كقيمة موجبة ) ونسبة العد النيتروني هي دالة عكسية . وأنه يمكن التنبؤ بقيم الشد الرطوبي فوق المدى التنشيومتري ( 0- 850 ملي بار) حتى نقطة الذبول ( 15000 ملي بار ) وتعتبر المعادلة المشتقة أداة سريعة لتنفيذ جدولة الري حقلياً في حالة متابعة قيم الشد الرطوبي الأرضي .وان أيونات كل من الصوديوم والكلور ين لها تأثير عالي على عملية التباطؤ النيوتروني عند القيم العالية لقيم الشد الرطوبى، كما وجد أيضا أن مجموع تركيز كل من الصوديوم والكلور ين لكل طبقة أرضية فقد ارتبطت مع معدل العد النيوتروني عند قيم الشد الرطوبى الأقل قيمة من السعة الحقلية بالعلاقة الآتية:

$$(C.R = A + B/\,\Sigma\,(Na^+ \text{ and } CL^-)$$