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SOIL MOISTURE DETERMINATIONS AT PERMANENT WILTING POINT IN CALCAREOUS SOILS

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ABSTRACT: *Three methods called pressure membrane, biological and vapor pressure mthods have been used for soil moisture determination at the permanent wilting point (PWP) in calcareous soils. The effect of soil compontents such as coarse sand, fine sand, silt + clay, along with organic matter, total carbonate and salt contnet on the moisture at PWP have been studied. In addition, the relation between the moisture content at PWP which was determined using the previous methods were carried out. The statistical analysis revealed that; (i) the soil components affected the moisture content at PWP with differrent respoenses according to the method of determination, (ii) both the pressure membrane and the biological methods could be subsutituted by the vapor pressure method with high accuracy and less time consuming.*

Key words: *Permanent wilting point (PWP), pressure method, biological method, vapor pressure method and calcareous soils.*

INTRODUCTION

There are three different methods usually used for soil moisture determination at the permanent wilting point (PWP). These methods are named as pressure membrane, biological and vapor pressure equilibrium.

The first method, was the pressure membrane which determines moisture content at 15 bar at the permanent wiliting point for great groups of plants (Shawky,1967 and Al-Nabulsi & Helalla, 1998). The second method determines the moisture content at PWP using an indicator plant, usually a swarf sunflower. Also, the soil water tension at PWP presented in this method was shown to be approximately –1500 KPa. Evidence has been presnted showing that lower limit of the available water varies with the plant species and corresponds to different soil water pressures. Sykes and Loomis (1967) reported that soil water pressure at PWP ranging from about – 500 KPa for sunflower to less than – 3000 KPa for intermediate wheatgrass. For most soils except for some fine – textured ones, the change in soil water content between pressure of –800 and –3000 K Pa is negligible (McIntyre, 1974). By statistical correlation procedures, Lehane & Staple (1960) and Cassel & Sweeney (1974) observed that PWP measured by sunflower method is approximately equal to the soil water content of the disturbed sample placed on a permeable membrane or porous plate and equilibrated with an applied pressure of 1500 KPa.

The third method, was the vapor pressure equilibrium. This method involves equilibrium of soil samples with an atmosphere of known relative humidity in a closed chamber at constant temperature (20 °C). At equilibrium, the water content of the soil sample is determined and taken as the moisture content at PWP (Klute, 1986). The main objectives of this study are to: (i) make a simple and multiple correlation between different soil components (coarse sand, fine sand, silt + clay, total carbonate, organic matter and salts content) and moisture content at PWP which was determined using the three different methods, and (ii) finding the best fit equations between these components and the values of moisture content. (iii)in addition, comparison of the three methods was considered.

MATERIALS AND METHODS

One hunderd thirty seven samples from 42 sites were collected from several calcareous soils in the north coast of Egypt to achieve this study. Total $CaCO_3$ contnet ranged between 20-55%, and the distribution of total $CaCO_3$ within the samples were 41 samples contain 20-30%, 56 samples contain 31-40% and 40 samples contain 41-55%. The total soluble salts (EC dS/m) was determined according to Rhoades (1982). The EC ranged between 0.2-1.2 dSm^{-1} measured in 1:2.5 soil –water extract. The organic matter ranged between 0.4-2.5% and the particle size distribution showed that the coarse sand ranged between 5-25%, fine sand 30-60% and silt+clay 20-60%. The soil texture classified into three groups clay loam, silty clay loam and silty loam.

Three methods were selected and used for soil moisture determination at PWP at high tension level. The first method was pressure membrane which used the moisture content at 15 bars is used as the permanent wilting point for great groups of plants according to, Shawky (1967) and Al-Nabulsi & Helalia (1998). The second method bioloigical which used the sunflower as an indicator plant to determine the permanent wilting point. At this limit the sunflower wilts and does not recover turgor when the plant is put into a humid atmosphere overnight. At this water content the matric potential is found to be about -15 bars in most soils (Bayers, 1976, Hsiao et al., 1970, and Klute A., 1986). The third method was the vapor pressure equilibriium. This method depends on exposing a small disturbed sample 5-50g (in this work 5 g soil was used) to an atmosphere of known relative humidity inside closed chamber. At equilibrium (after 72 hrs), the water content of the soil sample is determined and taken as the moisture content at PWP (Marshall and Holmes, 1979). They illustrated that when the relative huidity is 98%, matric potential is approximately –1500 KPa or 15 bares which lied in the region of PWP of plants in soils. Control of relative humidity is achieved with water – salt solutions of known potential. Saturated salt solutions are convenient for this purpose. In this work an over saturated ammonium oxalate solution which give certain humidity (98%) was used. The range of measurement is in the very dry range at water potentials less than about -1500 KPa or 15 bar solution which ranked as the region of permanent wilting point of plants (Marshall, 1979 and Klute. A., 1986).

RESULTS AND DISCUTION

The values of gravimetric soil moisture content at PWP as a dependet variable in the three methods under study and its relation to the different soil components (coarse sand, fine sand, silt+clay, organic matter, total carbonate and salts content) as an independent variable were statistically correlated and the results are represented in Table (1).

The first method is the pressure membrane method (15 bar) which has a highly significant negative correlation (r=-0.5**) between the moisture content at PWP and the coarse sand content with the best fit exponential equation $Y=17.3\ e^{-0.02X}$ where Y is the moisture content at the permanent wilting point (PWP) and X is the percent of coarse sand.

The behavior of coarse sand was due to the very low specific surface area, which decreases the matrix potential. However, the fine sand and the low organic matter contents didn't play a role on the moisture contents which remained in the soil at PWP. There is a highly significant positive correlation (r=0.48**) between the moisture content at PWP and silt + clay content which have high specific surface area. Consequently the matrix potential increased and the best fit power equation was $Y=2.3\ X^{0.5}$, where X is the percent of silt + clay.

The total $CaCO_3$ has a highly significant positive correlation (r=0.36**) with the moisture content at PWP and the best fit is the logarithmic equation $Y=-4.1 + 5.2 \ln X$ Where X is the percent of total calcium carbonate. This behavior could lead to the believe that the form of $CaCO_3$ was an active form in particular, the fine fraction of $CaCO_3$, so it increases the matrix potentials.

Finally, there is a highly significant negative correlation (r=-0.25**) between the moisture content at PWP and EC dS/m which increase the osmotic potentials) and the best fit logarithmic equation was $Y= 13.4-1.4 \ln X$, Where X is the electrical conductivity dS/m.

Table (1): Simple correlation (r) and the best fit equations between the moisture content values at PWP and the soil component.

Soil components	Pressure membrane method		Sunflower method		Vapor pressure method	
	Best Fit Equation	(r)	Best Fit Equation	(r)	Best Fit Equation	(r)
Coarse sand	$Y=17.3e^{-0.02x}$	-0.5**	$Y=6.7e^{-0.01x}$	- 0.44**	$Y=8.7e^{-0.02x}$	- 0.55**
Fine sand					Y=10.3–0.07X	- 0.27**
Silt + clay	$Y=2.3X^{0.5}$	0.48**	$Y=1.84X^{0.36}$	0.42**	$Y= 0.7\ X^{0.6}$	0.65**
Organic m.			$Y=5.4X^{0.08}$	0.16*		
$CaCO_3$	Y=-4.1+5.2lnx	0.36**			$Y= 1.3\ X^{0.47x}$	0.39**
EC	Y=13.4-1.4lnx	-0.25**	Y=5.5+0.4X	0.36**	Y=6.3+0.98X	0.58**

The previous equations indicated that the dominant factors which affect water adsorption at PWP using the pressure membrane were silt+clay, $CaCO_3$, coarse sand and EC. The multiple correlation and the step wise regression explained that, there is a highly significant correlation (r=0.56**) between moisture content at PWP and the more effective factors as shown by the following equation Y= 12.9 – 0.14 (coarse sand%) + 0.05 (silt+clay%) + 0.05 ($CaCO_3$%)- 0.7 EC, dS/m).

The second method was the sunflower method, in which a highly significant negative correlation (r=-0.44**) between the moisture content at PWP and the coarse sand. The best fit equation obtained is exponential equation, $Y= 6.7\ e^{-0.01X}$, where X is the coarse sand %. However in this method fine sand and total carbonate didn't show any effect on the moisture content at PWP but silt+clay played an effective role. There is a highly significant positive correlation (r=0.42**) between silt + clay and the moisture content at PWP and the best fit equation is the power relation $Y= 1.48\ X^{0.36}$, where X is the (silt + clay%).

The organic matter has a highly significant effect on the mentioned moisture content and the best fit power equation is $Y= 5.4\ X^{0.08}$ (r=0.16**), where X is the organic matter %. Similarly, there is a highly significant positive correlation (r=0.36**) between EC and the mentioned moisture content whereas the best fit linear equation is Y=5.5+ 0.4X, where X is the EC dS/m.

The multiple correlation and the step wise regression explained that the moisture content is affected mainly by contents of coarse sand, silt + clay and EC and the relation was explained as follows:

Y=5.7-0.06 (coarse sand %) + 0.01 (silt%+clay%)+0.4(ECdS/m),r =0.54**

The third method was the Vapor pressure method in which a highly significant negative correlation between both coarse and fine sand and the moisture at PWP was found due to the low specific surface area of sand (low matrix potential). The best fit equations are the following exponential and linear equation respectively:

$Y= 8.7 e^{-0.02X}$ (r= -0.55**)

and $Y= 10.3 - 0.07X_1$ (r= -0.27**)

Where, X coarse sand % and X_1 Fine sand %.

Silt+clay fractions showed high effect on the moisture content at PWP as they have a very high specific surface area (high matrix potential). The best fit is the power equation, $Y=0.7\ X^{0.6}$ where X is silt+clay % and r=0.65**. Similarly, a highly significant correlation (r=0.39**) is found between the studied moisture content and $CaCO_3$%. The best fit power equation was $Y = 1.3\ X^{0.47}$. Finally, there is a highly significant positive correlation (r=0.58**) between EC and the studied moisture content at PWP. This behavior may be due to the ability of salts to adsorb water vapor molecules, whereas the organic matter existing doesn't has the pervious effect. The best fit linear equation is Y = 6.3 + 0.98 X where X is EC dS/m.

The multiple correlation show that the main factors which affect the studied moisture content at PWP using this method are coarse sand, silt + clay and EC. The relation is expressed in the following equation:

Y=3.7-0.04 (coarse sand %) + 0.08 (silt + clay %) + 0.9 (EC), r = -0.77**.

Where Y is the gravimetric moisture content at PWP followed vapor pressure method.

Comparing the moisture content at the PWP obtained using the three methods of determination adopted showed that the highest moisture content obtained by using the pressure membrane method. However, the lowest moisture contents found with by using the vapor pressure method. Meanwhile, values obtained from the biological method were in between the two methods and didn't needs special apparatus for the determination of moisture content at PWP but it is not easy to control the growth of sunflower.

The data in Table (2) show that, there is a highly significant correlation between the vapor pressure method and the other two methods. Statistically the best fit relation between vapor pressure (x) and the pressure membrane

(y) was the following power equation $Y= 1.1X^{1.4}$. Similarly, the relation between the vapor pressure and the sunflower (biological) method showed the highest significant correlation obtained (r=0.67**). The power relation obtained was $Y=1.7\ X^{0.6}$ where Y is the sunflower method and X is the vapor pressure method. It could be observed that the sunflower method could be substituted by the vapor pressure method with high accuracy and less time consuming. Also, this will overcome the dependence of biological method on the growth environment (light, temperature, water, wind and fertilizers) which affect the vigorousness of sunflower.

The data showed that the power relation was the best fit equation with a highly significant correlation (r=0.26**) when comparing the pressure membrane (X) and the biological method (Y) and the equation obtained is $Y= 3.1\ X^{0.23}$. Even though the last equation showed a highly significant correlation between the pressure membrane and the biological method, the correlation (r=0.26**) was not very high. Therefore the biological method could be substituted with the vapor pressure method. That could be fast, easy and more accurate. The third method (pressure membrane) has many obstacles such as adjusting the pressure and the long time of determination especially at heavy textured soil which induced high variations between the replicates.

Table (2): Correlation coefficients and the best fit relations between the values of moisture content determined at PWP using the three methods under study.

Methods (Y)	The Best Fit Relation			
	Pressure membrane	(r)	Vapor pressure	(r)
Pressure membrane			$Y= 1.1X^{1.4}$	0.56**
Sunflower	$Y=3.1X^{0.23}$	0.26**	$Y= 1.7\ X^{0.6}$	0.67**

CONCLUSION

The statistical analysis revealed that the dominant factors which affect soil moisture content at the permanent wilting point (using the pressure membrane method) were silt + clay and $CaCO_3$ which have positive effects followed by EC and coarse sand which have a negative effects. On the other hand, when the sunflower was used the (silt + clay) and EC were the dominant factors followed by organic matter contents. These factors have positive effects, whereas the coarse sand has a negative effect. Finally, when the vapor method was used the silt + clay, EC and total carbonate were the dominant factors (have the positive effect). Similarly the coarse sand followed by fine sand have the negative effect. Generally, by using the three different methods, the ability to held water at PWP has the following order: (silt + clay) > coarse sand > EC > $CaCO_3$ > organic matter. The statistical analyses between the three different methods explain that the sunflower method could be substituted by the vapor pressure method with high accuracy and less time consuming. Also, the vapor method is more consistent than pressure membrane method which has a problem in pressure adjustment and the long time for determination in heavy textured soils besides the variability between replicates.

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تقديرات الرطوبة عند نقطة الذبول الدائم فى الأراضى الجيرية

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الملخص العربى:

لقد تم دراسة ثلاثة طرق لتقدير رطوبة التربة عند نقطة الذبول فى الأراضى الجيرية. وهذه الطرق هى طريقة حلة غشاء الضغط، الطريقة البيولوجية (زراعة عباد الشمس)، والطريقة الكيماوية (إتزان عينة التربة مع بخار أكسالات الأمونيوم المشبع). وقد درست تأثير مكونات التربة من الرمل الخشن، الرمل الناعم، السلت+الطين، المادة العضوية، كربونات الكالسيوم الكلية، وكذلك محتوى التربة من الأملاح الذائبة على نسبة الرطوبة عند نقطة الذبول بالطرق الثلاثة السابقة. وتبين من التحليل الإحصائى أن تأثير مكونات التربة المختلفة على الرطوبة عند نقطة الذبول كان متبايناً تبعاً لطريقة تقدير الرطوبة. كما إتضح أن الطريقة الكيماوية ذات إرتباط عالى المعنوية مع كل من الطريقتين الآخريتين (حلة الضغط والبيولوجية) وإنها أسهل وأسرع وأدق من كليهما ولذا يمكن استبدال هاتين الطريقتين بالطريقة الكيماوية. وعليه يمكن التغلب على عقبات النمو وطول مدة القياس فى الطريقة البيولوجية وكذلك يمكن التغلب على مشاكل حلة الضغط سواءاً من ناحية ثبات الضغط وكذلك طول مدة القياس (وخاصة فى الأراضى ثقيلة القوام) وكذلك الاختلافات الواضحة بين نتائج المكررات.