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# PENETRATION RESISTANCE AND SOIL WATER RELATIONS IN CALCAREOUS SOILS

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## ABSTRACT

Pocket penetrometer can be useful tool to quantify the evaporation rate from calcareous soil and help the user in decision of irrigation scheduling espicially, for vegetable crops grown in greenhouses. The multiple linear equations showed significant correlation between penetration resistance values (PR), ranging between zero and 4.5 Kg. cm$^{-2}$, and evaporation, that equal soil moisture depletion (SMD), volumetric moisture content ($\theta_v$), calcium carbonate, wet bulk density and soil fractions.

## INTRODUCTION

The change in porosity (E) was directly proportional to change in the logarithm of maximum compressive pressure (Pm) in soil (Sȯehne, 1958) as follows: $E = -A \log (Pm) + C$ where, A is a value that tends to remain constant for a given soil type, and C is a value which changes in soil moisture content.

The linear regression between gravimetric soil moisture content ($\theta w$,%) and cone index (CI, kPa) with r of 0.73 was obtained by Voohees and Walker (1977) as follows: $CI = 4527.75 - 187.09 (\theta w)$. The highest strength was recorded in the surface layer of soil (Hartge et. al., 1978). Also, Hayes and ligon (1981) reported the following equation which related soil type and zero centimeter cone index ($CI_{zero}$, kPa) = $[ - 5.98 + 12.39 (f_b) + 0.294\ \theta w] * CONV$ where, CONV is a conversion factor from Spi to kPa, $f_b$ is a dry bulk density, Mg.m$^{-3}$ and $\theta w$ is the moisture content on dry basis, (%). Sadaka, (1988) found linear relation, with high correlation coefficient, between soil bulk density $fb$ (Kg.m$^{-3}$) and penetration resistance, Kg.cm$^{-2}$ for sandy clay soil at El-Nubaria region as follows: $fb = 1405.0 + 0.6567 * (PR)$ $r = 0.986$.

There is a strong variation in penetration resistance at and close to soil surface. Penetration resistance showed negative relationship with gravimetric moisture content of soil ($\theta w$ %) as it varies through out the year Spain *et al.* (1990).Also, they found a multiple regression between penetration resistance and bulk density ($f_b$), and soil moisture content ($\theta w$), %.

In arid regions, the process of drying involves considerable losses of water and the moisture content at the end of the period of constant drying rate $\Delta\theta/\Delta t$ and constant temperature of the soil speciments is correlated with the frist critical potential of water in the soil (Kapinos *et al.* 1991). The measurement of moisture suction at the soil surface reflects the dryness due to evaporation, but it is difficult to measure it directly, at soil surface. There fore, the measurement of penetration resistance of soil surface is easy mean to reflect the dryness of soil surface.

Hence, the present study aimed to find out quantitative relationship between penetration resistance of soil surface and soil moisture depletion

(SMD) of subsurface soil during the period of drying cycles, that is equal evaporation. This might be useful to predict the soil moisture depletion of root zone at any time during the irrigation intervales by using simple tool. Hence, we can decide how much amount of irrigation water should be added in a certain time particulary, for agriculture in greenhouse.

## MATERIALS AND METHODS

Twenty seven of undisturbed soil samples were collected from three depths (0-20 cm, 20-40 cm, and 40-60 cm) in 3 sites at Sugerbeet region (calcareous soil). Nine composed disturbed soil samples were air dried and passed through a 2mm sieve. Particle size distribution was determined $(f_b)$ by the hydrometer method (Gee and Bauder, 1986), bulk density by the core method (Blake and Hartge, 1986), hydraulic conductivity $(K_s)$ determined by the constand head method (Klute, 1965), mean weight diameter (MWD) was calculated from data obtained from wet sieve technique (Singh, 1980), and plasticity index (PI) was determined using ASTM standard, 1961. Total calcium carbonate was estimated using the collins calcimeter, EC and pH were measured using conductivity and pH meter, respectivity.Table (1) shows the physical and chemical properties of soil samples.

**Table 1 : Main Physical and chemical properties of soil samples.**

| Site No. | depth of soil Layer, Cm | EC, $dS.m^{-1}$ | PH | CaCO 3,% | $f_b$, $Mg.m^{-3}$ | | Ks, $m.d^{-1}$ | MWD, mm | P.I | Soil Separates,% Sand | Silt Clay | Textural class |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S1 | 0-20 | 9.4 | 7.9 | 29.2 | 1.1 | 0.7 | 0.53 | 0.10 | 68 | 14 | 18 | Sandy Loam |
| | 20-40 | 3.7 | 7.7 | 37.9 | 1.3 | 0.4 | 0.41 | 0.12 | 64 | 20 | 16 | |
| | 40-60 | 5.9 | 7.8 | 17.9 | 1.3 | 0.6 | 0.37 | 0.14 | 67 | 20 | 13 | |
| S2 | 0-20 | 0.6 | 7.9 | 30.2 | 1.3 | 1.1 | 0.53 | 0.16 | 78 | 9 | 13 | |
| | 20-40 | 1.4 | 7.8 | 34.6 | 1.4 | 1.2 | 0.39 | 0.11 | 74 | 8 | 18 | |
| | 40-60 | 0.9 | 8.1 | 31.6 | 1.4 | 0.5 | 0.52 | 0.13 | 76 | 8 | 16 | |
| S3 | 0-20 | 1.6 | 8.1 | 20.8 | 1.3 | 0.7 | 0.37 | 0.14 | 51 | 24 | 25 | Sandy Clay Loam |
| | 20-40 | 0.7 | 8.3 | 16.9 | 1.3 | 0.6 | 0.34 | 0.15 | 43 | 22 | 35 | Clay Loam |
| | 40-60 | 0.8 | 8.1 | 16.6 | 1.4 | 0.1 | 0.19 | 0.21 | 32 | 23 | 45 | Clay Loam |

$f_b$ = bulk density, $K_s$ = saturated hydraulic conductivity,
MWD = mean weight diameter , $P_I$ = Plasticity Index.

The undisturbed soil samples were soaked in water, enough time, to become completely saturated by capillary rise. The columns were left to drain free of water out, and reach to field capacity then the measurement of penetration resistance of top soil columns using calibrated pocket penetrometer was started. The weight of soil columns, volumetric moisture content of soil columns, degree of saturation, soil moisture depletion, wet bulk density, and air filled porosity also were determined. The end of drying cycle controlled by reaching the reading of pocket penetrometer to 4.5kg. $cm^{-2}$ (maximum reading can be obtained from the pocket penetromter). Richardson (1976) found that, in laboratory, the repeating wetting and drying cycles usually lead to increasing break down, drying was more severe than in the field, and wetting more rapid. So, he concluded that when soil columns subjected to 3 alternative wetting and drying cycles only can avoid the inereasing of break down of soil samples.

The statistical analysis were processed using the computer program to evaluate the interdependence of hydrophysical properties effects on penetration resistance (PR) of soil tilth by the aid of performing multiple linear regression and correlation techniques. The R squared was calculated to measure the contribution of the independent variables SMD(=E), θv, $(f_b)_W$, total $CaCO_3$ and silt fraction to the variations of the dependent variable (PR). It is usually expressed in percentage. For example if R square = 0.94, that means 94% of the total variation of the dependant variable can be accounted for by a linear function, involving the independant soil variables. 570 readings were used for multiple linear regression analysis.

## RESULTS AND DISCUSSION

The results of soil-water relations and penetration resistance of undisturbed soil columns which were collected from different three sites and subjected to three wetting and drying cycles were depicted as average values in tables 2, 3 and 4. The average moisture depletion (SMD) that equal evaporation (E) after 15 days of drying was 25.9 mm for whole undisturbed soil columms (0-20cm) which represent site 1 as shown in table (2).

**Table 2:Soil-Water relations, on average basis,during the drying cycles of undisturbed soil columns collected from site (1) at sugerbeet area.**

| Time of dryiny cycle, day | Hydrophysical properties<br>$\theta_v$, % | E*, % | Sd, % | (/b)$_w$, Mg.m$^{-3}$ | SMD, mm | Pr, Kg. m$^{-2}$ |
|---|---|---|---|---|---|---|
| | | | 0 - 20 cm | | | |
| 0 | 51.1 | 0.0 | 100 | 1.6 | 0.0 | 0.05 |
| 5 | 29.9 | 21.2 | 58.5 | 1.4 | 10.6 | 0.75 |
| 7 | 25.9 | 25.2 | 50.7 | 1.4 | 12.6 | 1.00 |
| 12 | 18.2 | 32.9 | 35.6 | 1.3 | 16.4 | 1.25 |
| 13 | 16.3 | 34.8 | 31.9 | 1.3 | 17.4 | 2.25 |
| 14 | 14.3 | 36.8 | 28.0 | 1.3 | 18.4 | 3.25 |
| 15 | 10.6 | 40.5 | 20.7 | 1.2 | 30.25 | 4.05 |
| | | | 20 - 40 cm | | | |
| 0 | 42.5 | 0.00 | 100 | 1.6 | 0.00 | 1.25 |
| 3 | 32.0 | 10.5 | 75.3 | 1.5 | 4.75 | 1.05 |
| 4 | 28.8 | 13.7 | 67.8 | 1.5 | 6.86 | 1.75 |
| 5 | 25.9 | 16.6 | 60.9 | 1.4 | 8.03 | 2.25 |
| 7 | 22.3 | 20.2 | 52.5 | 1.4 | 10.01 | 3.25 |
| 9 | 19.3 | 23.2 | 45.4 | 1.4 | 11.06 | 3.05 |
| 10 | 17.5 | 25.0 | 41.9 | 1.3 | 12.35 | 4.05 |
| | | | 40 - 60 cm | | | |
| 0 | 40.7 | 0 0 | 100 | 1.7 | 0.00 | 0.75 |
| 4 | 31.0 | 9.7 | 76.2 | 1.6 | 4.05 | 1.00 |
| 6 | 29.1 | 11.6 | 71.5 | 1.5 | 5.08 | 1.25 |
| 7 | 24.1 | 16.6 | 59.2 | 1.5 | 8.03 | 1.05 |
| 9 | 20.9 | 19 8 | 51.3 | 1.4 | 9.65 | 2.25 |
| 10 | 19.1 | 21.6 | 46.9 | 1.4 | 10.08 | 2.05 |
| 12 | 16.6 | 24.1 | 40.8 | 1.4 | 12.05 | 3 25 |
| 13 | 14.2 | 26.5 | 34.9 | 1.4 | 13.25 | 4.05 |

$\theta_v$ = volumetric moisture content , E* = air - Filled porosity
Sd = degree of saturation , (/b) = bulk density
Pr ˝penetration , SMD = soil moisture depletion

So, the average volumetric moisture content ($\theta v$) and wet bulk density $(f_b)_w$ decreased from 51.1% to 10.6% and from 1.6 to 1.2 Mg.m$^{-3}$, respectively. The average air-filled porosity ($E^*$) increased to 40.5% during this period of drying process. Hence, the values of the penetration resistance increased from 0.5 to 4.5 kg.cm$^{-2}$ during 15 days of drying cycles.

The maximum readings of penetrometer (4.5 kg.cm$^{-2}$) reached after 10 days of drying soil columns (20-40 cm depth) collected from the same site (1) and SMD was 29.5mm as the $\theta v$ was reduced from 42.5% to 17.8%. Therefore, the $E^*$ incresed to 25% and $(f_b)_w$ decreased to 1.2Mg.m$^{-3}$. This might be due to the high content of calcium carbonate (37.9%) which led to reduce the hydraulic conductivity to 0.4m.d$^{-1}$ and mean weight diameter to 0.41mm and it was more compacted compared to the surface soil where the values of penetration resistance at starting time of drying was 1.25 kg.cm$^{-2}$. The penetration resistance of soil columns collected from 40-60 cm depth was 0.75 Kg. cm$^{-2}$ after 13 days of drying. SMD and $E^*$ values reached to 26.3 and 28.5%, respectively.

The results in table (3) show the change of penetration resistance of soil surface associated to the changes of hydrophysical parameters in undisturbed soil columns collected from site 2 at sugerbeet. PR, $\theta v$, $E^*$, $(f_b)_w$ and SMD values were 4.5 kg. cm$^{-2}$, 18.3%, 32.9%, 1.6 Mg. m$^{-3}$ and 23.1 mm at the surface layer (0-20 cm depth) after 13 days of dr ying cycles. For the soil samples of 20-40 cm depth, nine days was sufficient to bring the PR values to 4.5 kg. cm$^{-2}$ and SMD to 15.2 mm and $E^*$ to 21.9% and $(f_b)_w$ to 1.6 Mg. m$^{-3}$. The soil layers from 40 to 60cm depth, which represented site (2), were highly compacted so that, four days only were enough to let the soil surface dry and PR values reached to 4.5 kg. cm$^{-2}$. SMD was only 9% and $(f_b)_w$ was 1.7 Mg.m$^{-3}$ and $E^*$ was 13.3%.

**Table 3:Soil-Water relations,on average basis,during the drying cycles of undisturbed soil columns collected from site (2) at sugerbeet area.**

| Time of dryiny cycle, day | $\theta_v$, % | $E^*$, % | Hydrophy sical properties<br>Sd, % | $(f_b)_w$, Mg.m$^{-3}$ | SMD, mm | Pr, Kg. m$^{-2}$ |
|---|---|---|---|---|---|---|
| | | | 0 - 20 cm | | | |
| 0 | 51.2 | 00.0 | 100 | 1.9 | 0.00 | 0.75 |
| 3 | 40.1 | 11.1 | 78.3 | 1.8 | 5.55 | 1.0 |
| 6 | 29.5 | 21.7 | 57.6 | 1.7 | 10.85 | 1.25 |
| 7 | 27.1 | 24.1 | 52.9 | 1.6 | 12.05 | 2.0 |
| 9 | 24.4 | 26.8 | 47.7 | 1.6 | 13.40 | 2.5 |
| 10 | 22.7 | 28.5 | 44.3 | 1.6 | 14.25 | 3.75 |
| 12 | 20.0 | 31.2 | 39.1 | 1.6 | 15.06 | 4.25 |
| 13 | 18.3 | 32.9 | 35.7 | 1.6 | 16.45 | 4.5 |
| | | | 20 - 40 cm | | | |
| 0 | 43.0 | 00.0 | 100 | 1.8 | 0.00 | 1.0 |
| 3 | 31.4 | 11.8 | 73.0 | 1.7 | 5.08 | 1.75 |
| 4 | 28.9 | 14.1 | 67.2 | 1.7 | 7.05 | 2.75 |
| 5 | 26.8 | 16.2 | 62.3 | 1.7 | 8.01 | 3.0 |
| 7 | 23.9 | 19.1 | 55.6 | 1.6 | 9.55 | 3.75 |
| 9 | 21.9 | 21.1 | 50.9 | 1.6 | 10.55 | 4.5 |
| | | | 40 - 60 cm | | | |
| 0 | 46.2 | 00.0 | 100 | 1.8 | 0.00 | 1.25 |
| 2 | 38.4 | 07.8 | 83.1 | 1.8 | 3.09 | 2 |
| 3 | 35.4 | 10.8 | 76.6 | 1.7 | 5.04 | 2.25 |
| 4 | 32.9 | 13.3 | 71.2 | 1.7 | 6.65 | 4.5 |

$\theta_v$ = volumetric moisture content , $E^*$ = air - Filled porosity
Sd = degree of saturation , $(f_b)$ = bulk density
Pr = penetration , SMD = soil moisture depletion

The results in table (4) show the changes of soil - water relations of whole soil columns and PR of top surface layer in site 3. The time of drying cycle extended to 24 days for 0-20 cm and 20-40 cm depth because of high water holding capacity of these soils. At the end of drying PR was 4.5 kg. cm$^{-2}$, SMD were 30.7% and 33.1%, $(/_b)_w$ were 1.5 and 1.6 Mg. m-3 and E* were 46.7 % to 51.7% in 0.20cm and 20-40cm depth respectively. When the soil columns for 40-60 cm depth were subjected to 10 days of drying cycles the PR, SMD, $(/_b)_w$ , and E* were 4.5kg. cm$^{-2}$, 23.7mm, 1.9 Mg. m$^{-3}$, and 32%, respectively. The variation of soil properties with depth was due to the compaction, aggregation and the amout of organic matter and clay content.

**Table 4:** Soil-Water relations,on average during the drying cycles of undisturbed soil columns collected from site (3) at sugerbeet area.

| Time of dryiny cycle, day | $0_v$, % | E*, % | Hydrophysical properties | | | |
|---|---|---|---|---|---|---|
| | | | Sd, % | $(/b)_w$, Mg.m$^{-3}$ | SMD, mm | Pr, Kg. m$^{-2}$ |
| 0 - 20 cm | | | | | | |
| 0 | 72.2 | 0.0 | 100 | 2.0 | 0.00 | 0.50 |
| 3 | 58.8 | 13.4 | 81.4 | 1.9 | 6.07 | 0.75 |
| 7 | 50.7 | 21.5 | 70.2 | 1.8 | 10.75 | 1.00 |
| 9 | 46.5 | 25.7 | 64.4 | 1.7 | 12.85 | 1.25 |
| 10 | 44.4 | 27.8 | 61.5 | 1.7 | 13.91 | 1.05 |
| 11 | 42.7 | 29.5 | 59.1 | 1.7 | 14.75 | 1.75 |
| 14 | 34.9 | 37.3 | 48.3 | 1.6 | 18.65 | 2.25 |
| 23 | 26.7 | 45.5 | 37.0 | 1.6 | 22.75 | 3.00 |
| 24 | 25.3 | 46.9 | 35.0 | 1.5 | 23.45 | 4.05 |
| 20 - 40 cm | | | | | | |
| 0 | 96.5 | 0.0 | 100 | 2.1 | 0.00 | 0.50 |
| 3 | 79.5 | 17.0 | 82.4 | 1.9 | 8.05 | 0.75 |
| 7 | 69.8 | 26.7 | 72.3 | 1.8 | 13.35 | 1.00 |
| 11 | 59.5 | 37.0 | 61.7 | 1.8 | 18.50 | 1.50 |
| 13 | 56.4 | 40.1 | 58.4 | 1.7 | 20.05 | 2.00 |
| 14 | 54.5 | 42.0 | 56.5 | 1.7 | 21.00 | 2.05 |
| 23 | 46.6 | 46.9 | 48.3 | 1.6 | 24.95 | 2.75 |
| 24 | 44.8 | 51.7 | 46.4 | 1.6 | 25.85 | 4.05 |
| 40 - 60 cm | | | | | | |
| 0 | 97.1 | 0.0 | 100 | 2.3 | 0.00 | 0.75 |
| 4 | 82.6 | 14.5 | 85.1 | 2.2 | 7.25 | 1.50 |
| 7 | 75.4 | 21.7 | 77.6 | 2.1 | 10.85 | 2.25 |
| 9 | 67.6 | 29.5 | 69.6 | 2.0 | 14.75 | 3.00 |
| 10 | 65.1 | 32.0 | 67.0 | 1.9 | 16.00 | 4.50 |

$0_v$ = volumetric moisture content , E* = air - Filled porosity
Sd = degree of saturation , (/b) = bulk density
Pr * penetration , SMD = soil moisture depletion

The linear regression technique is related to the estimation and testing the significance of the independent parameters in the multilinear regression equation (Gomez and Gomez 1983). Data used in the current investigation are soil moisture depletion (SMD), volumetric moisture content ($\theta v$), wet bulk density $(f_b)_w$, $CaCO_3$, and silt % which have proved to show significant contributions to the variation in the dependent variable penetration resistance of soil tilth (PR). The followings are the multiple linear regression equations which predict the values of PR in $Kg.cm^{-2}$ from soil-water relation based on the multiple regression and stepwise regression technique:

$$PR\ (Kg\ .cm^{-2}) = -0.0253\ CaCO_3^{***}\% + 0.0869\ \theta_v^{***}\ (\%) + 0.2126\ SMD^{***}\ (m\ m)$$
$$-1.442^{*}\ fb\ (Mg.m^{-3}) - 0.0159^{***}\ silt\ (\%) \qquad R^2 = 0.9438$$
$$PR\ (Kg\ .cm^{-2}) = -0.0360\ CaCO^{***}{}_3\% + 0.0522\ \theta_v^{**}\ (\%) + 0.1707\ SMD^{***}\ (m\ m)$$
$$-0.0945\ silt^{***}\ (\%) \qquad R^2 = 0.927$$
$$PR(Kg.cm^{-2}) = 0.0388\ CaCO_3^{***}\% + 0.09982\ SMD^{***}(mm) \qquad ns$$
$$-0.0945\ silt\ (\%) \qquad R^2 = 0.8926$$
$$PR\ (Kg\ .cm) = 0.0312\ CaCO^{***}{}_3\% + 0.0944^{***}\ SMD\ (mm) \qquad R^2 = 0.889$$
$$PR\ (Kg\ cm^{-2}) = 0.0777\ CaCO^{***}{}_3\% \qquad R^2 = 0.763$$
$$R\ (Kg.cm^{-2}) = -0.184 + 0.102\ SMD^{**}\ (mm) \qquad R^2 = 0.694$$

The above estimated multiple linear regressions are significant at 1% level. Thus the combined linear effects of SMD, $CaCO_3$, $(f_b)w$, $\theta v$ and silt % contribute highly significant to variation in PR. The value of R squared in the first equation 0.944 indicates that 94.40% of the total variation in PR can be attributed to $CaCO_3$, $\theta v$, SMD, $(f_b)w$ and silt%. Likewise can be explained for the othere due to the increase of the $R^2$ figure. So, the present study might be considers the soil-water relations that contributing by 76.3-94.38% to the variation in PR values.

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## مقاومة الأختراق وعلاقات مياه التربه فى الأراضى الجيرية

**أحمد فريد سعد**

**قسم الأراضى والمياه ـ كلية الزراعة (الشاطبى) ـ جامعة الأسكندرية**

يمكن إستخدام جهاز الأختراق الجيبى كوسيلة مفيدة فى تحديد معدل البخر من الأراضى الجيرية تحديدا كميا ويساعد المنتفعين فى جدولة الرى خاصه فى زراعات الخضر المحميه (الصوب الزجاجية). واتضح من المعادلات الخطية المتعددة أن هناك علاقة أرتباط معنوية بين قيم مقاومة الأختراق الواقعة بين صفر و ٤,٥كجم/ سم٢ وكل من البخر التجميعى (الماء المستنفذ) والمحتوى الرطوبى الحجمى ونسبة الكربونات لكلية والكثافة الظاهرية والنسب المئوية لحبيبات الأرض المعدنية.