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Estimation of saturated hydraulic conductivity in silty clay loam soils from soil bulk density and soil porosity

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Abstract :

  Field experiment was conducted in 2009 on a bare soil to study the possibility of predicting the saturated hydraulic conductivity of the field soil (Ks) by using the easy field measured soil bulk density (BD) and porosity (St).This because of the complexity of the field measurement of (Ks); in addition to the fact that (Ks) field measurements cost a lot of money and efforts if the required measurements need to be done on the large scale field for example when irrigation or drainage system need to be designed.

  The results show the nonlinear power function has a good power to predict (Ks) from the measured (BD) with $R^2= 0.71$ which is significant at 0.05 probability level. The linear relation between measured and predicted (Ks) has an $R^2= 0.87$.

  Moreover; the results show the best fitted regression model for the relation between (Ks) and (St) is the nonlinear power function without intercept which has an $R^2=0.99$, and the linear relation between measured and predicted (Ks) has an $R^2=0.80$. These finding agree very well with previous finding of many researchers.

الخلاصة :

تم تنفيذ تجربه حقليه في عام 2009 على ارض جرداء لدراسة أمكانية التنبؤ بقيمة الايصاليه المائيه ألمشبعه للتربه (Ks) باستعمال قيم الكثافة ألظاهريه(BD) والمساميه (St) للتربه كلا على انفراد واللذان يعتبران من القياسات ألحقليه ألسهله مقارنة بالطبيعه ألمعقده للقياسات ألحقليه للايصاليه المائيه ألمشبعه حيث تحتاج إلى كثير من المال والجهد خاصة إذا كانت القياسات مطلوبه على مساحات حقليه واسعه مثلا عند تصميم شبكات الري والبزل.

أظهرت النتائج أن ألداله الاسيه الغير خطيه أعطت قوة تنبؤ عاليه ل (Ks) مع قيمة معامل ارتباط تقدر ب

($R^2=0.71$) حيث إن هذه ألقيمه معنويه باحتماليه مقدارها (0.05). كما إن ألمعادله ألخطيه التي تربط بين قيم (Ks) ألمقاسه والمتنبأ بها أعطت قيمه أرتباط مقدارها ($R^2= 0.87$).

كما أظهرت النتائج إن أحسن دالة منحنى للعلا قه بين (Ks) و (St) هي ألداله الاسيه الغير خطيه بدون قاطع حيث كانت قيمة معامل الارتباط تقدر ب ($R^2= 0.99$) وان العلا قه ألخطيه بين قيم (Ks) ألمقاسه و المتنبأ بها أعطت معامل ارتباط تقدر قيمته ب($R^2= 0.80$). إن هذه النتائج تتفق بشكل جيد مع ما وجده كثير من الباحثين.

Introduction :

  Saturated soil hydraulic conductivity (Ks) is an important soil parameter in models that simulate infiltration and runoff processes, in addition to solution of Darcy equation which required the values of the saturated conductivity of drainage water to the filed drains**.** This soil

parameter is difficult to measure and can be highly variable, necessitating a large number of samples. For this reasons indirect methods have held promise as an alternative to making direct measurements. A further advantage of indirect methods is that they allow researchers to obtain an estimate of the variability of saturated conductivities based on the variability of an easily measured predictor variable (Ahuja,et al 1989).

A number of relationships have been developed that can be used to calculate (Ks) with easily measured soil properties. Some are purely empirical and are often related to soil texture (Rawls et al, 1992; Puckett et al, 1985).

Other relationships used physically based equations, Ahuja et al, (1984, 1989) showed that modified Kozeny-Garman equation (Ks= B1* Øe^n) was applicable to a wide range of soils from the southern regions of U.S.A.

Several equations commonly applied to hydrologic analysis were summarized by Rawls et al (1992) and Hillel (1998).Gijsman et al (2002) reported an extensive review of eight modern estimating methods applicable to hydrologic and agronomic analysis. They observed significant discrepancy among the methods due to the regional data basis or methods of analysis thus creating doubt on the value of lab-measured water retention data for crop models. They concluded that (an analysis with a set of field-measured data showed that the method of Saxton et al (1986) performed the best).

The objective of this study is to develop method uses information from easily measured soil physical properties such as bulk density, porosity, and percentage of sand, silt, and clay to estimate the saturated hydraulic conductivity by using the different curve fitting methods.

Material and Methods :

This study was conducted in 2009 on a bare field near the college of agriculture building in the suburb of Hilia city. Many undisturbed core soil samples were taken on a straight line at 15 meter interval to assure the independency between measurements (Saddiq and Al-wotaify, 2010).

The bulk density of each soil sample is measured by using the core method (Blake, 1965). The soil texture of the soil samples was measured by the pipette method (Day, 1965).The soil texture of all samples was found as a silty clay loam. The saturated hydraulic conductivity of the soil samples was measured using the falling head method (Klute, 1965). The particle density of the soil samples was measured by pyconometer method (Blake, 1965).

The porosity of the soil sample was calculated by using the following equation:

$St = (1 - (\rho b/\rho s)) \times 100$

Where St is the total porosity (%), ρb is bulk density (gm/cm^3), ρs is the particle density (gm/cm^3).

The gravimetric water content was measured by the standard procedure Gardner,

(1965)

Results and Discussions :

The analysis of correlation between saturated hydraulic conductivity (Ks) and bulk density (BD), porosity% (St), silt%, sand%,and clay% of the soil shows a values of Person correlation coefficients R as follow : 0.74, - 0.38, 0.26, - 0.13,and - 0.30 respectively.

Moreover ; these values shows that the correlation coefficient between (Ks) and (BD) of the soil (R= 0.74) is the only value which is significant at 0.05 probability level, and the correlation coefficient between (Ks) and (St) is the next good value among them. This indicate that there is a good relationship between (Ks) and (BD) as shown in(figure 1) and a fair relationship between (Ks) and (St) as shown in (figure 4). These finding agree very well with Park and Smucker, 2005; Campbell, 1985; and others. Therefore many models have been fitted to the relationships between (Ks) and (BD), and between (Ks) and (St) to find the best regression model for these relationships as follows:

Saturated hydraulic conductivity and Bulk density :

Many models have been fitted for the relationship between (Ks) and (BD) as shown in figure 2. The values of the constants of these models and their regression coefficient (R^2) are shown in table 1. The best fitted models with $R^2=0.71$ was the nonlinear Power model. So; the power model was used to predict the values of the saturated hydraulic conductivity of the soil according to the following equation:

$$Ksp = 2.00 \times 10^{-11} \times (BD)^{18.21} \qquad\qquad R^2 = 0.71$$

Where: Ksp is the predicted saturated hydraulic conductivity of the soil   (cm/min)

BD is bulk density of the soil (gm/cm^3)

The linear relation between predicted and measured (Ks) was shown in figure 3 which fitted the following linear equation:

$$Ksm = Ksp \times 0.993 \qquad\qquad R^2 = 0.87$$

Where: Ksm is the measured saturated hydraulic conductivity (cm / min)

Ksp is the predicted saturated hydraulic conductivity (cm / min)

This result indicates that the power model has a good predictive ability and can be used to predict the (Ks) from the field (BD) measurements of the soil. Many researchers have found similar results. Campell, 1985 and Ahuja et al, 1984 used nonlinear empirical relationships to predicate the (Ks).

Saturated hydraulic conductivity and porosity :

Figure 4 shows the relationship between (Ks) and (St) of the soil samples. The correlation coefficient between the saturated hydraulic conductivity (Ks) and porosity (St) measurements is (R = - 0.38).To find the best fitted model for this relationship, many regression models has been fitted (figure 5). The regression constants and their regression coefficient was shown in table 2.The best fitted regression model for this relationship with regression coefficient ($R^2 = 0.99$) was the nonlinear power model without intercept according to the following equation:

$$Ksp = (St)^{-1.86} \qquad\qquad R^2 = 0.99$$

Where: Ksp is the predicted saturated hydraulic conductivity of the soil   (cm/min)

St   is the total porosity of the soil (%)

By using above equation the predict (Ks) from the field measurement of porosity (St) has been obtained. Figure 6 shows the linear relation between measured and predicted (Ks) according to the following equation:

$$Ksm = 1.255 \times Ksp \qquad\qquad R^2 = 0.80$$

This finding agree very well with the finding of (Park and Smucker, 2005; Ahuja et al, (1984).

The measurements of the saturated hydraulic conductivity whether it was in the field or in the laboratory are time consuming and it need a lot of moneys and efforts, therefore using simple soil measurements like bulk density or porosity to predict the saturated hydraulic conductivity of soil have been considered as a big achievement, it save a lot of moneys and efforts, especially if these (Ks) values has been used in designing a large field Irrigation system or drainage system which required many field saturated hydraulic conductivity measurements.
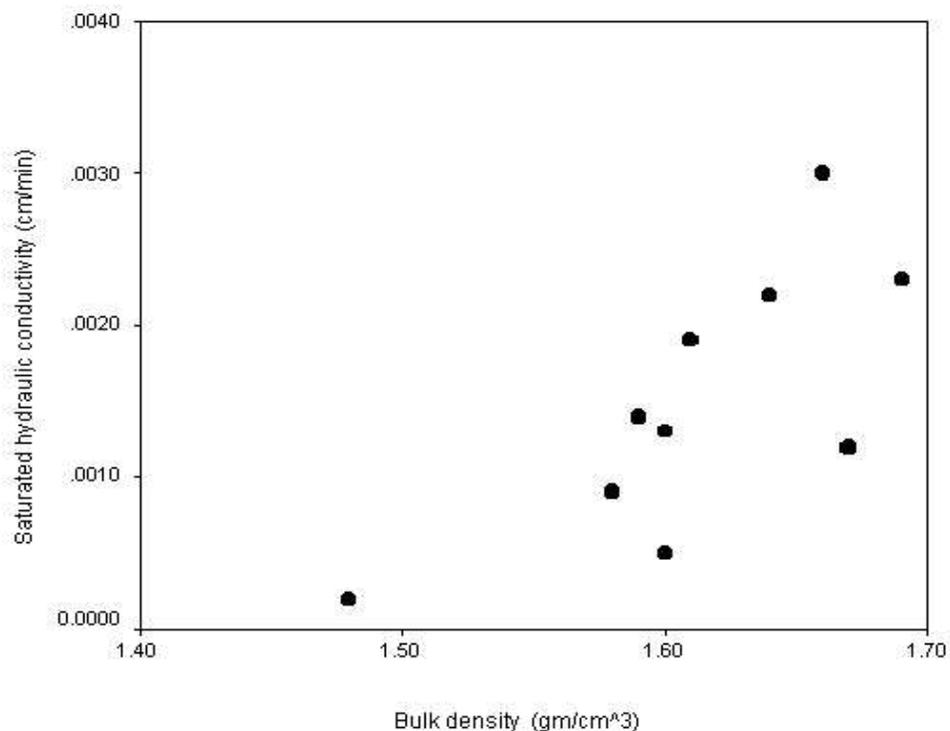
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Figure 1: The relation between measured saturated hydraulic

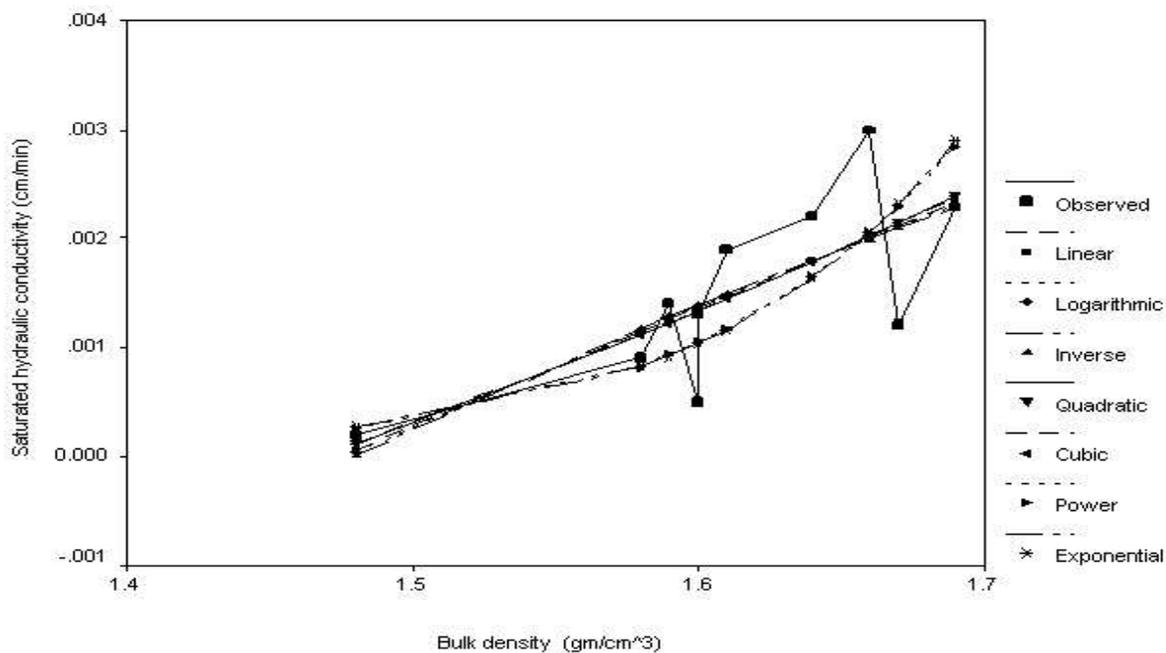conductivity and bulk density of the soil

Figure 2: The relation between the bulk density and saturated

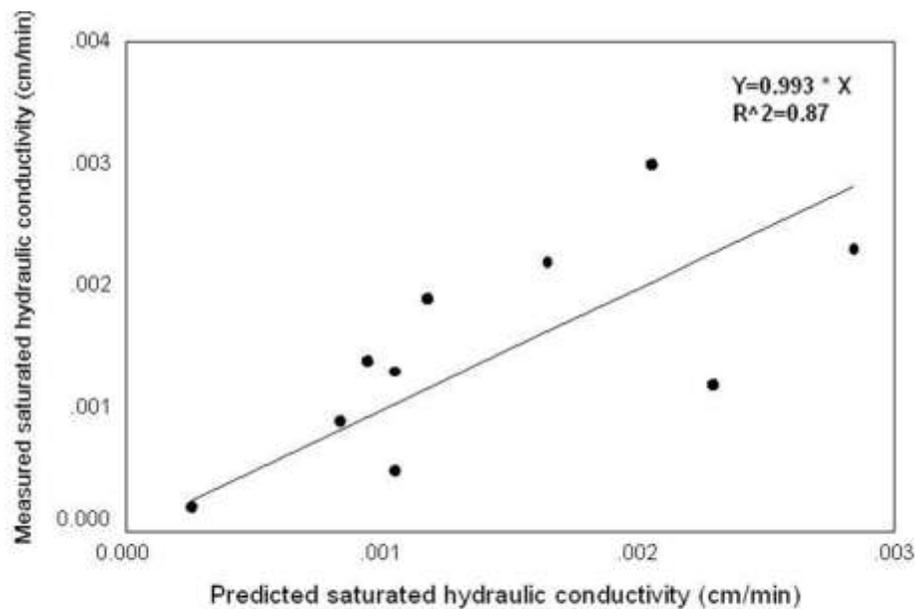hydraulic conductivity for diffirent fitted models

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Figure 3: The relation between measured and predicted saturated hydraulic conductivity by power model
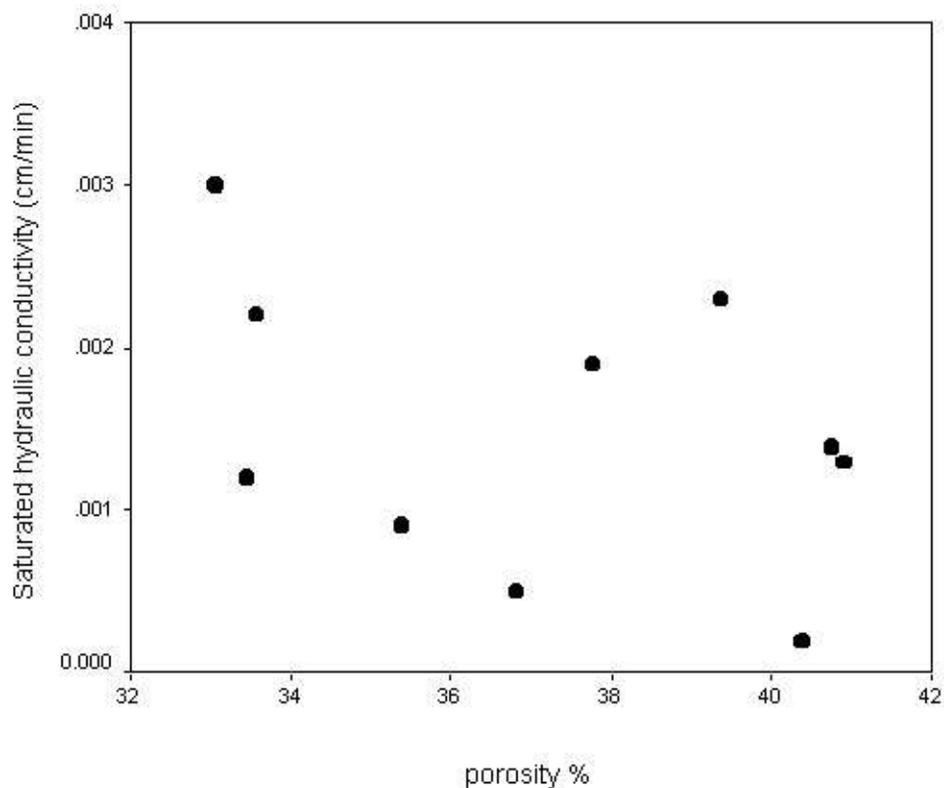

Figure 4: The relation between measured saturated hydraulic

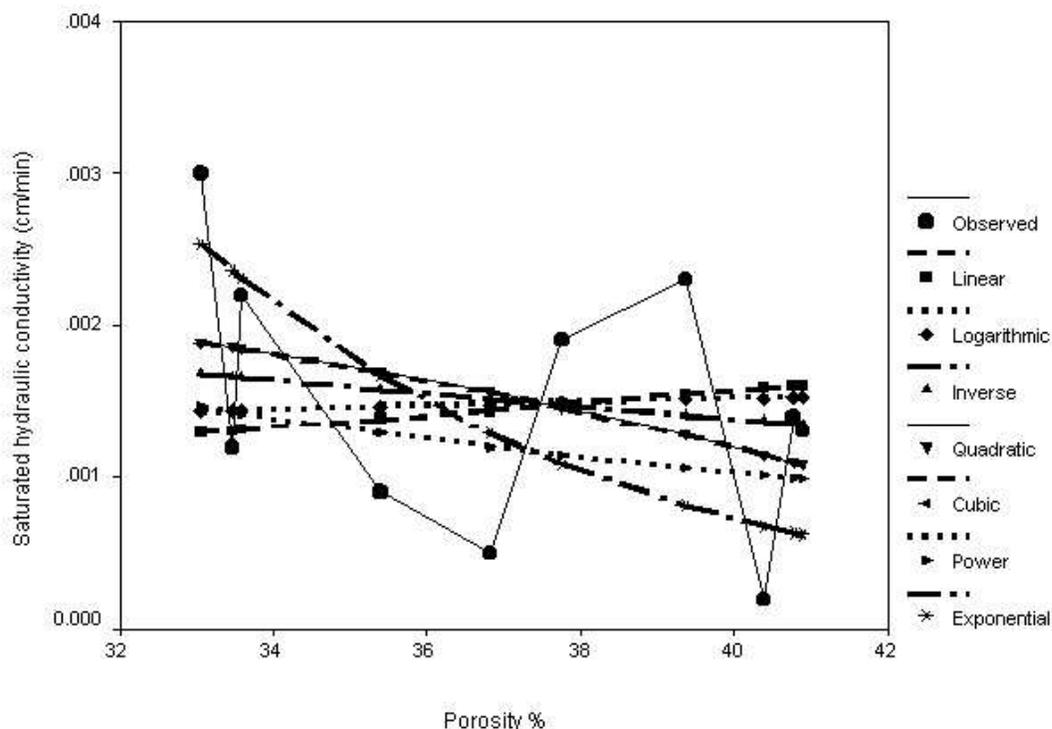conductivity and porosity% of the soil

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Figure 5: The fitted models for the relation between saturated

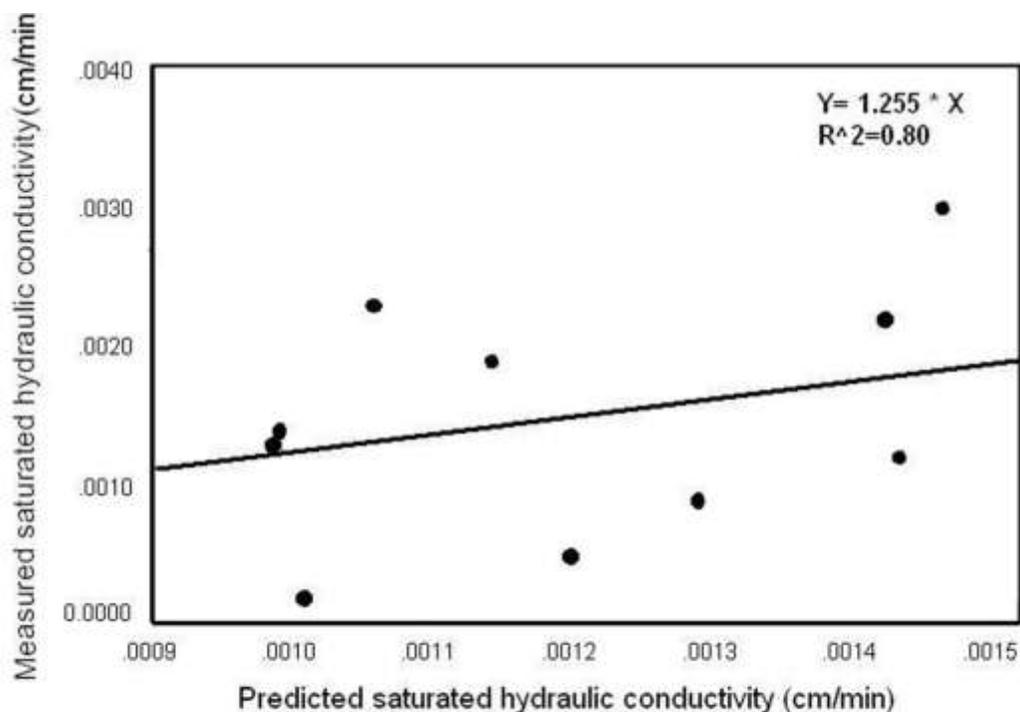hydraulic conductivity and porosity% of the soil

Figure 6: The relation between measured and predicted
saturated hydraulic conductivity by power model

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Table 1: The fitted models for the relation between bulk density and saturated hydraulic conductivity of the
　　　　soil and their constants

Model	Equation	R^2	B0	B1	B2	B3
Linear model	Y=B0+B1*X	0.55	-0.0159	0.0108		
Logarithmic model	Y=B0+(B1*ln X)	0.55	-0.0067	0.0171		
Inverse model	Y=B0+(B1/X)	0.55	0.0183	-0.0270		
Quadratic model	Y=B0+B1*X+B2*X^2	0.55	0.0031	-0.0132	0.0076	
Cubic model	Y=B0+B1*X+B2*X^2+B3*X^3	0.55	-0.0037	-0.0007		0.0015
power model	Y=B0*(X^B1)	0.71	2.00E-11	18.2065		
Exponential model	Y=B0*(e^(B1*X))	0.70	1.20E-11	11.4185		

Table 2: The fitted models for the relation between porosity% and saturated hydraulic
　　　　conductivity of soil and their constants

Model	Equation	R^2	B1	B2	B3
Linear model	Y=B1*X	0.74	3.9E-05		
Logarithmic model	Y=B1*ln X	0.76	0.0004		
Inverse model	Y=B1/X	0.79	0.0556		
Quadratic model	Y=B1*X+B2*X^2	0.80	0.0002	-4.0E-06	
Cubic model	Y=B1*X+B2*X^2+B3*X^3	0.80	0.0002	-4.0E-06	0.0000
power model	Y=X^B1	0.99	-1.8653		
Exponential model	Y=e^(B1*X)	0.98	-0.1807		

References

Ahuja,L.R., D.K. Cassel, R.R.Bruce, and B.B.Barnes. 1989. Evaluation of   spatial distribution of hydraulic conductivity using effective porosity data. Soil   Sci. 148:404-411

Ahuja,L.R., J.W. Naney, R.E. Green, and D.R. Nielsen.1984. Macro porosity   to characterize spatial variability of hydraulic conductivity and effects of land   management.

Blake, G.R., 1965. Bulk density. In: Method of soil analysis. Part 1. C.A.   Black (ed). Amer.Soc. of Soil Sci.,Madison, Wisconsin. PP 374-390

Campbell,G.S., 1985. Soil physics with BASIC: Transport methods for soil –   plant systems, pp 150, Elsevier press, New York

Day,P.R., 1965. Particle Fractionation and particle-size analysis. In: Method   of soil analysis,C.A. Black (ed).Amer. Soc. Of Agron.,Madison,Wisconsin.,   pp 545-567

Gardner, W.H., 1965. Water content. In: Method of soil analysis, Part 1. C.A.   Black (ed). Amer. Soc. Of Agron., Madison, Wisconsin. pp 82-125

Gijsman,A.J., S.S. Jagtap, and J.W. Jones. 2002. Wading through a swamp   of complete confusion: How to chose a method for estimating soil water   retention parameters for crop models. Eur.J.Agron. 18:75-105

Grossman, R.B., D.S. Harms, G.A. Seybold, and J.E. Herrick. 2001.Coupling   use-dependent and use-invariant data for soil quality evaluation in the United   States. J. Soil Water Conservation. 56(1): 63-68

Hillel,D. 1998. Environmental soil physics. Academic Press, San Diego, CA

Klute,A. 1965. Laboratory measurement of hydraulic conductivity of   saturated soil. In: Method of soil analysis, part 2. C.A. Black (ed).   Amer.Soc.of Agron., Madison, Wisconsin. pp 374-390

Park,E.J., and A.M. Smucker. 2005. Saturated hydraulic conductivity and porosity within macro aggregates modified by tillage. Soil Sci. soc. Amer. J. 69:38-45

Puckett, W.E., J.H. Dane, and B.F. Hajek. 1985. Physical and mineralogical   data to determine soil hydraulic properties. Soil Sci. Soc. Amer. J. 49:831-   836

Rawls,W.J., L.R. Ahuja, and D.L. Brakensiek. 1992. Estimating soil hydraulic   properties from soil data. Int. workshop on indirect methods foAr estimating   the hydraulic properties of unsaturated soils. Riverside, CA., 11-13 Oct., 1989, USDA and Univ. of California, Riverside.

Rawls,W.J.,D.Gimenez,and R.Grossman.1998. Use soil texture, bulk density, and slope of water retention curve to predict saturated hydraulic conductivity. Tran. ASAE 41:983-988

Saddiq,M.H., and A.S. Al-Wotaify. 2010. Spatial variability of the water content and bulk density of soil in Babylon governorate. In press, Babylon University Journal. 19 (1)

Saxton, K.E., W.J. Rawls, J.S. Romberger, and R.I. Papendick. 1986.   Estimating generalized soil water characteristics from soil texture. Trans. ASAE 50:1031-1035