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SOIL DATA PREPARATION FOR CROP GROWTH MODELS

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Introduction

With the development of crop growth models for cotton, soybeans, and wheat (GOSSYM, Baker *et al.*, 1982; GLYCIM, Acock *et al.*, 1982; WHEAT, Baker, *et al.*, 1982) there is an increasing need for soil data sets. Whisler (1976) published a note on the methodology for getting soil hydraulic conductivity from water content-pressure head (or potential) relationships and saturated hydraulic conductivity. It has become increasingly apparent, however, that a step by step description of how this is done needs to be written. The purpose of this paper is to take a given data set and demonstrate how the needed soil parameters are derived.

Theory

It is assumed that the following relationships are to be used in the crop models: For hydraulic conductivity (Brooks and Corey, 1964):

$$K_i = K_s \qquad h_i \geq h_B \qquad \{1a\}$$

$$K_i = K_s \left(\frac{h_B}{h_i}\right)^{\eta} \qquad h_i < h_B \qquad \{1b\}$$

and for water content:

$$\theta_i = \theta_s \qquad h_i \geq h_B \qquad \{2a\}$$

$$\frac{\theta_i - \theta_r}{\theta_s - \theta_r} = \left(\frac{h_B}{h_i}\right)^{(\eta-2)/3} \qquad h_i < h_B \qquad \{2b\}$$

$$\ln\left(\frac{\theta_i - \theta_r}{\theta_s - \theta_r}\right) = \{(\eta-2)/3\}\ln\left(\frac{h_B}{h_i}\right) \qquad \{2c\}$$

where h is the pressure head (or soil water potential); h_B is the bubbling pressure or air entry value for the desorption water content-pressure head relationship; θ is the volumetric water content; θ_s is the field saturated (θ when $h = 0$) volumetric water content; K is the hydraulic conductivity; K_s is the saturated hydraulic conductivity; η is a soil characteristic parameter; and θ_r is the residual water content (usually at $h = -15$ bars). The subscript i denotes some intermediate value of the variable.

Due to the fact that K_i varies much more than the diffusivity (2 or 3 orders of magnitude) over a given range of water contents, the diffusivity form of Darcy's law is used in the crop models. The diffusivity-water content relationship (Gardner and Mayhugh, 1958) is:

$$D(\theta_i) = D_o \exp \beta(\theta_i - \theta_o) \qquad \{3\}$$

where D_o is the value of the diffusivity at some water content θ_o; and β is another soil characteristic parameter.

Procedures

With a given set of $h - \theta$ values, K_s and bulk density values, how do we get values for η, β, and D_o?

Table 1 is a set of typical data which might be collected for any soil horizon. This particular set is from A. Klute[1] for a Rago silt loam near Akron, Colorado used in the WHEAT

[1]Personal communication.

Table 1. Pressure head-water content, saturated hydraulic conductivity and bulk density data of the surface horizon of Rago silt loam, Akron, Colorado.[1]

Horizon Depth cm	h, Pressure head - cm θ, water content - cc/cc										K_s cm/day	Bd g/cc
	-1	-10	-30	-60	-100	-300	-600	-1000	-3000	-10,000		
0 - 22.5	0.42	0.42	0.415	0.4	0.378	0.313	0.262	0.240	0.210	0.185	14.4	1.52

model. The h - θ data are plotted in a normal or semi-log plot and the curve extended to -15,000 cm (or -15 bars) to get a value for θ_r (Figure 1.) A value of 0.168 was chosen. From such a plot it is also seen (or by just looking at the data table) that the water content remains almost saturated until h $\cong$ -30 cm. Thus h_B was chosen as -30 cm.[2] With these values and equation {2c}, Table 2 was constructed. Using the values in Table 2, Figure 2 was plotted. As can be seen there is some scatter in the data. The solid straight line was drawn by "eyeball" through the data points but giving greater weight to the points at the high water content (low values of $\ln \frac{\theta - \theta_r}{\theta_s - \theta_r}$) end. This is in response to earlier findings by Hanks and Bowers (1963) that the wet end of the θ - h curve is more important than the dry end for validating flow systems.

From equation {2c}, we see that the slope of the line in Figure 2 is $\frac{\eta - 2}{3}$. In our case that is $\frac{.2}{(-1.63 + 2.27)} = 0.313$ and solving for η gives 2.94. As was shown in Whisler (1976) the diffusivity function is:

$$D_i = A\ (|h_i|)^{(1-2\eta)/3} \qquad \{4\}$$

where

$$A = -\ \{K_s(\theta_s - \theta_r)^{-1}(|h_B|)^{(2 + 2\eta)/3}\}\ \frac{3}{2-\eta} \qquad \{5\}.$$

Keeping h_B and K_s in cm and cm/day, respectively, we get $A = 1.385 \times 10^6$.

If we substitute this value into {4} and evaluate it at $h_i = h_B$ to get D_s, we have $D_s = 5.472 \times 10^3$ cm^2/day. If we

[2] In many data sources, one may not find water contents at such high values of h. The only solution is to use the highest value of h for h_B and the corresponding water content as θ_s.

evaluate {4} at h_i = -15,000 cm, we get $D_{-15,000} = 2.223 \times 10^{-1}$ cm^2/day. Now if we assume that θ_o in {3} is approximately equal to θ_r we can evaluate β in {3}. Taking the natural log of both sides of {3} we see that:

$$\beta = \frac{\ln (D_s/D_{15,000})}{\theta_s - \theta_r} = 40.12$$

and $D_o \approx D_{15,000} = 2.223 \times 10^{-1}$.

In practice we actually use θ_r a little less than θ_o so that we don't get into trouble in the CAPFLO subroutines. Thus the data set for this horizon used for WHEAT which is set to convert from h in cm to bars is as follows:

D_o = 0.2223 cm^2/day

θo = 0.168 cc/cc

β = 40.12 --

depth = 22.5 cm

θ_s = 0.420 cc/cc

θ_r = 0.160 cc/cc

h_B = -30.0 cm

η = 2.94 --

Bulk Density 1.52 g/cc

The card image for the data file is: (E format)

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2.223E-1 0.168E+0 4.012E+1 2.250E+1 0.420E+0 0.160E+0 -3.00E+1 2.940E+0 1.520E+0.
```

Table 2. Calculated ln - ln* values for η* evaluation. Assume $h_B^* = -30$ cm; $\theta_s^* = 0.42$ and $\theta_r^* = 0.168$.

h_i	$\ln h_B/h_i$	$\ln \frac{\theta_i - \theta_r}{\theta_s - \theta_r}$
-60	-0.693	-0.083
-100	-1.204	-0.182
-300	-2.303	-0.553
-600	-2.996	-0.986
-1,000	-3.507	-1.253
-3,000	-4.605	-1.792
-10,000	-5.809	-2.696

* ln - the natural logarithm

η - a soil parameter, ie. calculated from the slope of the ln - ln plot of the data above.

h_B - the bubbling pressure value of the pressure head

θ_s - the saturated volumeteric water content

θ_r - the residual volumeteric water content

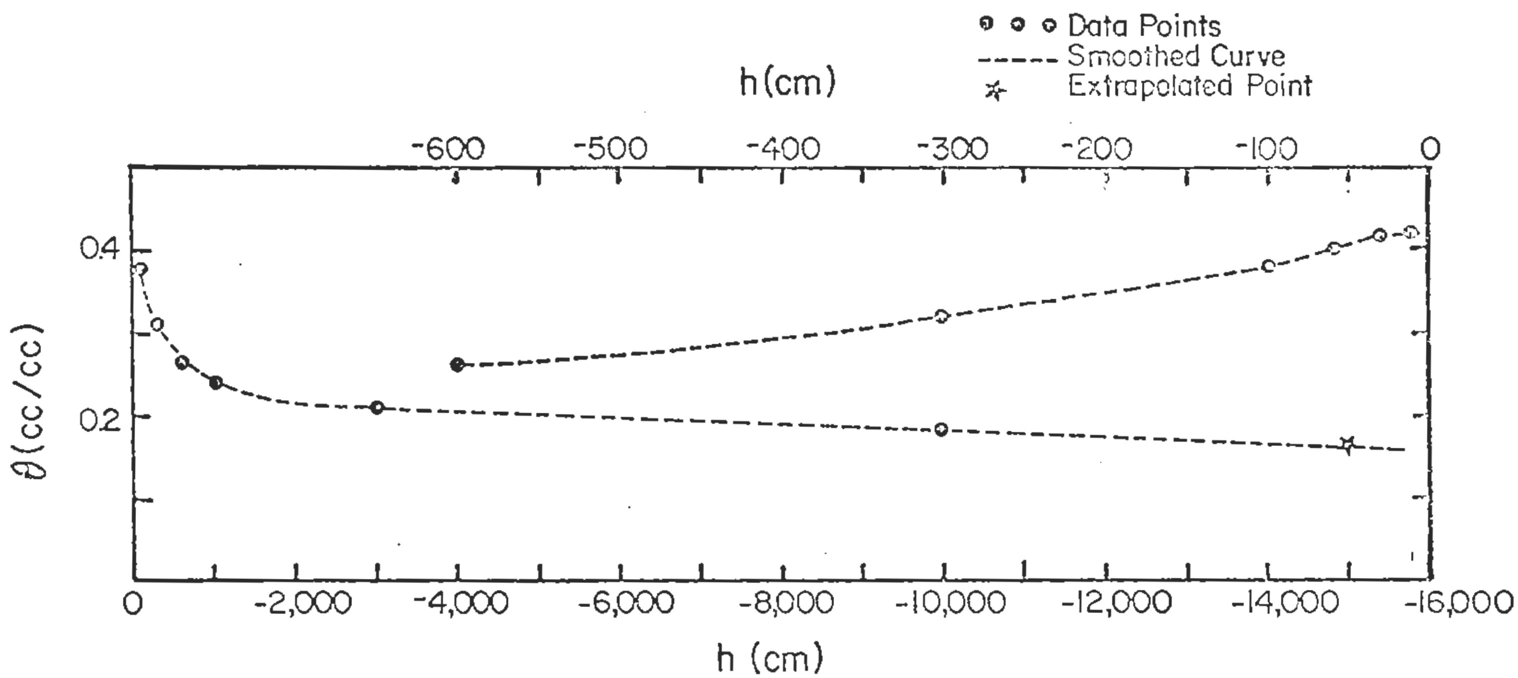

Figure 1. Water content versus pressure head at 15 cm in a Rago silt loam. The upper scale goes with the upper right hand curve. The lower scale goes with the lower left hand curve.

REFERENCES

Acock, B., V. R. Reddy, F. D. Whisler, D. N. Baker, J. M. McKinion, H. F. Hodges and K. J. Boote. 1982. The soybean crop simulator GLYCIM. DOE Publication. (In review)

Baker, D. N., J. R. Lambert and J. M. McKinion. 1982. GOSSYM. Clemson Agr. Exp. Sta. Bul. (In press)

Baker, D. N., D. E. Smika, A. L. Black, W. O. Willis and A. Bauer. 1982. WHEAT, USDA, Agristars Publication. (In press)

Brooks, R. H. and A. T. Corey. 1964. Hydraulic properties of porous media. Hydrology Papers. Colorado State Univ. 3:1-27.

Gardner, W. R. and M. S. Mayhugh. 1958. Solutions and tests of the diffusion equation for the movement of water in soil. Soil Sci. Amer. Proc. 22:197-201.

Hanks, R. J. and S. A. Bowers. 1963. Influence of variations in the diffusivity-water content relation on infiltration. Soil Sci. Soc. Amer. Proc. 27:263-265.

Whisler, F. D. 1976. Calculating the unsaturated hydraulic conductivity and diffusivity. Soil Sci. Soc. Amer. J. 40:150-151.

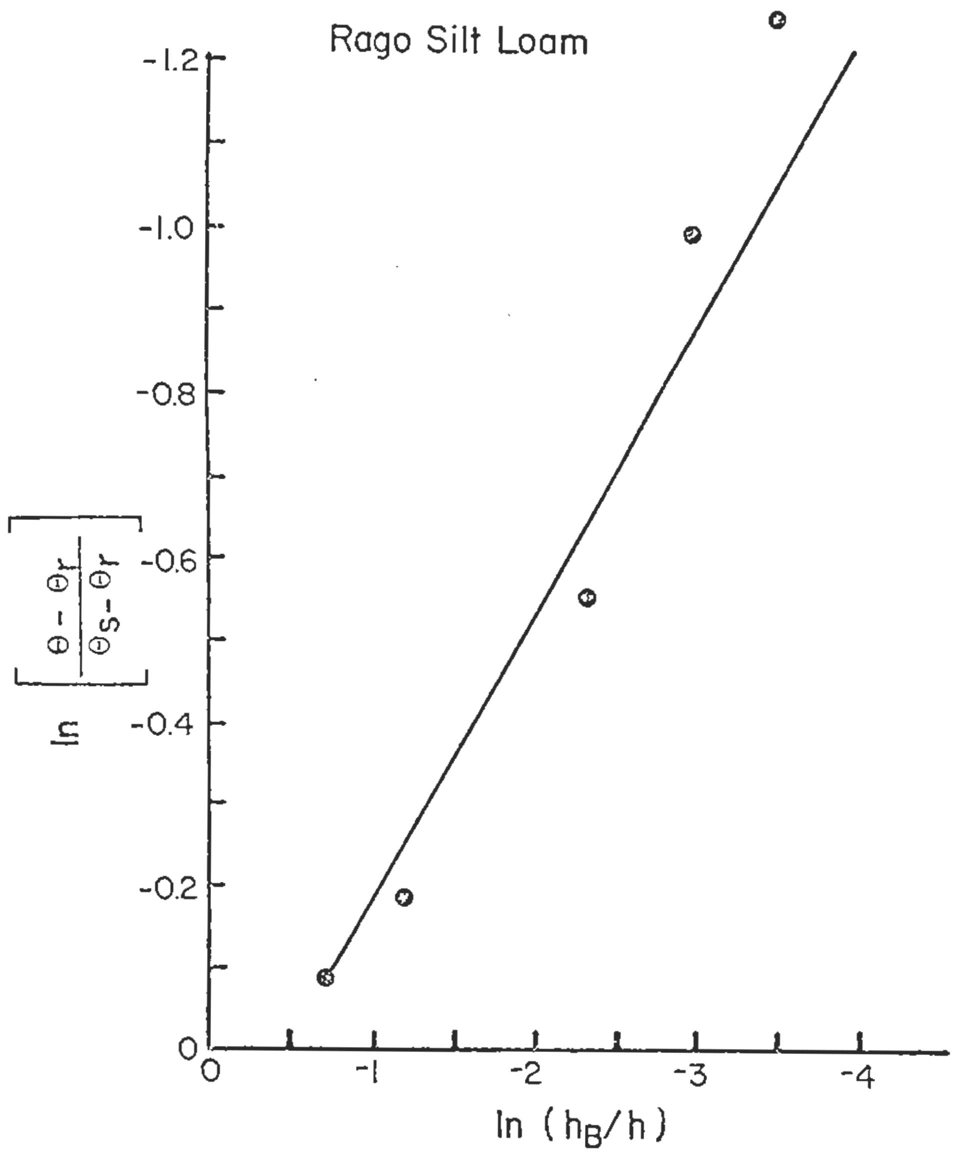

Figure 2. The natural logs of the dimensionless water content versus the dimensionless pressure head for a Rago silt loam. The slope of the line is related to η.

Table 1. Soil water content versus matric potential. Dr. Jenkin's Plots, North Farm. Plots sampled on 7-29-83.

Condition or Matric Potential	Volumetric Water Content, Soil depth (cm): 15	50
bar	cm^3/cm^3	
Saturation	0.717	0.696
-0.10	0.342	0.327
-0.33	0.272	0.294
-0.50	0.254	0.239
-0.67	0.218	0.208
-1.00	0.204	0.198
-5.00	0.168	0.164
-10.00	0.166	0.131
-15.00	0.164	0.130
Air-dry	0.016	0.015