ASSESSMENT OF EMPIRICAL PARAMETERS THAT DESCRIBE SOIL WATER CHARACTERISTICS

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Empirical equations for soil water characteristics were assessed using data from soils found in Canada. A considerable variation in measured soil water contents was observed within each textural group, although, considering the wide variety of soils included in each group, the results did not compare unfavorably with previously reported data. The coefficients of variation decreased from the coarse- to the fine-textured groups. Measured soil water characteristics could adequately be described by a power curve. The averaged coefficients that characterize this power curve were found to be similar to the ones reported by Clapp and Hornberger (1978). Regression analysis showed a satisfactory agreement between measured water contents and those predicted from the Clapp and Hornberger parametric equations for all textural groups, except the loamy sand and clay loam groups. A small modification of one of the parameters in the prediction equations produced satisfactory results for these groups. However, for specific, individual soils the prediction equations were found to be less applicable, and dependent upon the selected variability criteria.

INTRODUCTION

Soil water characteristics are required to describe the availability of soil water to plants and to model the movement of water and solutes in unsaturated soils. They constitute an input for hydraulic conductivity models (Marshall 1958; Millington and Quirk 1959; Brooks and Corey 1964) and are essential for calculating soil water diffusivity from water content data (Nielsen et al. 1964).

Measuring soil water characteristics is time consuming and consequently several efforts have been made to predict water retention data from easily and routinely obtainable soil properties. Soil water contents at various matric potentials have been successfully related to particle size distribution and organic matter contents (Jamison and Kroth 1958; De Jong 1967; Shaykewich and Zwarich 1968; Oosterveld and Chang 1980). Gupta and Larson (1979) used percent sand, silt, clay, and organic matter and bulk density to estimate the volumetric water content at given tensions. Rogowski (1971) proposed a procedure to estimate the entire soil water characteristic from measured water contents at air entry and at a tension of 1500 kPa. Unfortunately, the analytical data that are required for the above-described models are not frequently available. For example, in most Canadian soil survey reports, only one soil profile per soil series is analyzed in sufficient detail to reveal the required input data for these models.

A slightly different approach has been advanced by Clapp and Hornberger (1978), who presented parameters for a standardized empirical soil water characteristic for 11 textural groups. The advantage of their approach is that it does not require particle size distribution, organic matter content, bulk density or any other analytical data, but only an estimation of the soil’s texture.

The empirical prediction equations of Clapp and Hornberger (1978) were derived from desorption data reported by Holtan et al. (1968), whose data set consisted of 176 sampled soil types from 34 locations in the United States. However there are some indications that the dependence of soil water retention on soil components varies with the area in which the study was conducted, because of differences in mineralogy, types of organic matter, climatic effects, etc. (De Jong and Loebel 1982). The objective of the present investigation was to evaluate the applicability of the equations derived by Clapp and Hornberger to estimate soil water characteristics, using data selected from Canadian soils. This might reduce the need for extensive laboratory measurements of soil water characteristics for large areas of soil that display a certain degree of homogeneity in terms of texture.

METHODS

Equations and Parameters used by Clapp and Hornberger

Clapp and Hornberger (1978) described the soil water characteristic by a power curve:

\[ W = \psi_s \left( \frac{\theta}{\psi_s} \right)^b \]  

where \( \psi \) is the soil water suction, \( \theta \) the volumetric water content and \( \psi_s \) the saturated volumetric water content. Both \( \psi_s \), the ‘saturation’ suction, and the exponent \( b \) were empirical and had to be estimated by Clapp and Hornberger. Since the use of Eq. 1 implied a sharp discontinuity in tension near saturation, Eq. 1 was modified to account for gradual air entry: a value \( \theta_s \) was selected such that \( \psi_s = 0.92 \theta_s \), and a parabola for \( \psi(\theta) \) was fitted between \( \theta_s \) and \( \theta_e \), such that \( \psi(\theta) \) and its derivative were continuous at \( \theta_e \). On this interval

\[ \psi(\theta) = c(\theta/\theta_s - d)(\theta/\theta_s - 1) \]

where \( c \) and \( d \) were evaluated according to the conditions just specified, which requires that \( \theta_e/\theta_s > b/(b + 1) \).

The average values of \( b, \psi_s \) and \( \theta_s \), as derived by Clapp and Hornberger for 11 textural groups, are shown in Table I. Because in each group the \( \psi_s \) distribution had large standard deviations, and was strongly positively skewed, Clapp and Hornberger suggested that the average \( \bar{\psi}_s \) was probably better represented by the geometric mean of \( \psi_s \), i.e. \( \bar{\psi}_s \) (log). Therefore, the following results and discussion will refer only to those empirical soil water characteristics which use \( \bar{\psi}_s \) (log), unless noted otherwise.

The Data Set

The soil water characteristic parameters calculated by Clapp and Hornberger (1978) were derived from undisturbed samples. Since a significant difference exists between hydraulic properties of disturbed and undisturbed soils (Elrick and Tanner 1955; Salter and Williams 1965; Shaykewich 1970) it was decided that in order to test the applicability of the Clapp-
Hornberger parameters, only soil water characteristics from undisturbed samples would be used.

The data used in this study came from a number of investigators: Redfern (1969), Ayres (1970), DeKimpe et al. (1974), Topp (1977), Miller et al. (1978), Cameron (1979), Topp et al. (1980) and various unpublished reports. The data represent a fairly wide variety of Canadian soils from different geographical regions. The techniques employed to measure the soil water characteristics differed among the investigators, but they all used undisturbed samples, except at tensions above 50 kPa when in most cases disturbed samples were used. All investigators used the core method to determine the bulk density of the soil, except DeKimpe et al. (1974) who used the saran-coated clod method, similar to the procedure employed by Holtan et al. (1968).

Not all soils were included in the final analysis. The results for gravelly soils (20% gravel) were deleted, because Clapp and Hornberger (1978) also excluded 'rocky' soils in their analysis. The three samples that fell in the sandy clay loam texture were also deleted from the data set. There were no samples in the sandy clay group, and clays and heavy clays were grouped together and compared with the single clay texture described by Clapp and Hornberger (1978). In total, 271 soil samples were analyzed from 81 different locations.

Statistical Analyses

The assumption that the soil water characteristics of the present Canadian data set could adequately be described by a power curve was tested by taking the logarithm of both sides of Eq. 1 and performing linear regression on those samples that had at least five observations in the range of $0 < \theta/\theta_s < 0.92$. A correlation test was then carried out to see whether or not there was a significant relation between the variable $\log \psi$ and $\log \theta/\theta_s$. The significance of the parabolas for $\theta/\theta_s$ in the interval $0.92 < \theta/\theta_s < 1.0$ could not be tested due to insufficient test data in this interval.

Averaged parameters $b$, $\theta_i$, $\theta_s$ (log) and $\theta_s$ were derived for nine textural groups, using the same method as described by Clapp and Hornberger (1978). These parameters were compared with the ones reported by Clapp and Hornberger (1978) using a t-test for unpaired observations. Comparisons of averaged $\theta_i$ (log) values were excluded from the latter analysis due to the missing standard deviations of this parameter in the Clapp and Hornberger publication.

Measured soil water contents were compared with predicted ones using linear regression analyses. Null hypotheses regarding the intercept and the slope of the regression line were formulated and tested.

RESULTS AND DISCUSSION

Variability of the Soil Water Characteristics

The predicted soil water characteristics along with the measured ones are shown in Fig. 1 for nine textural groups. All curves were similar, inasmuch as they all had the same general shape and differed by the magnitude of the parameters $\psi_i$, $\theta_s$ and $b$ as defined in Eq. 1. Water contents at saturation ranged from 39.5% in the sand to 48.5% in the silt loam, while those at a tension of 1500 kPa ranged from 5.0% in the sand to 26.8% in the clay.

The range in measured water contents varied considerably among textural groups and given tension values. For example, coefficients of variation (CV) of the measured water contents at saturation ranged from 5.0% in the sand to 17.7% in the clay + heavy clay group, while at 1500 kPa they ranged from 14.7% in the silty clay loam to 44.7% in the sand (Table II). However, in light of the wide geographical distribution of the soils included in the present analysis, the results do not compare unfavorably with data reported in the literature: at saturation, CVs calculated for the textural groups presented by Clapp and Hornberger (1978) range from 10.4% for the clay to 19.8% for the sandy loam group. Nielsen et al. (1973), who presented results for variation in soil water characteristics for a 150-ha area of Panoche silty clay loam, found that their average CVs varied from 10% at saturation to 23.8% at 20 kPa. Averaged CVs calculated for a Maddock sandy loam (Carlvallo et al. 1976) ranged from 7.3% at saturation to 18.1% at 43 kPa.

The CVs at tensions above 2.0 kPa were generally larger in the coarse-textured soils as compared to the medium- and fine-textured soils. This might possibly be explained by the fact that small variations in organic matter content in the coarse-textured soils would have a much larger effect on water retention, than similar variations in medium- and fine-textured soils.

The considerable variation in measured water contents at given tensions within a textural group is an indication that particle size distribution is not the only factor which determines the soil water characteristic. Other factors like organic matter content, clay mineralogy and soil structure also influence its shape and magnitude (Salter and Williams 1965; Kutilek 1973).

Evaluation of Eq. 1

The highly significant correlation between the variables $\log \psi$ and $\log \theta/\theta_s$, con-
Figure 1. Soil water characteristics for various textural groups. A = 1 observation, B = 2 observations, etc. ————, predicted by the Clapp-Hornberger (1978) parametric equations.
Figure 1. (Continued.)
firmed the assumption that soil water characteristics can adequately be described by the power curve (Eq. 1) in the range 0 < \text{v} < 0.92. However, the same analyses also revealed that for some samples, all fine-textured soils, the value \text{b}(b + 1) exceeded \text{v} = 0.92. In those cases a parabola (Eq. 2), subject to the conditions specified previously, could not possibly be fitted to the data in the range 0.92 < \text{v} < 1. This suggests that rather than having an arbitrarily fixed inflection point \text{v}, relative to \text{v}, it might be more appropriate to let \text{v} vary with \text{b}, such that the condition \text{v} = \text{v} = 0.92 is met.

**Comparison between Measured and Predicted Soil Water Characteristics**

Within each textural group there were no statistically significant differences (at the 5% level) between the individual parameters \text{b}, \text{v}, and \text{v}, as derived by Clapp and Hornberger (1978), compared to the ones derived from the current Canadian data set (Table I), which indicates that both data sets came from similar populations. However the current data set, which is relatively small, showed a near normal distribution of \text{v}, within each group, whereas Clapp and Hornberger (1978) reported a strongly positively skewed one, leading them to suggest that \text{v} (log) was probably a better average to use. Except for the loamy sand and clay loam group, the \text{v} (log) values reported by Clapp and Hornberger (1978) and calculated ones from the current data agree reasonably well (Table I).

The soil water characteristics predicted with the Clapp and Hornberger coefficients generally fell within the range of the measured soil water contents (Fig. 1). Except in the silty clay loam textural group, all predicted water contents fell within 5% of the mean measured water contents. At a tension of 1500 kPa the predicted water contents fell within 2.5% of the mean measured ones. At intermediate tensions, the water content predictions were generally under- as well as over-predicted in various textural groups.

The linear regression analysis of measured water contents versus those predicted by the Clapp and Hornberger parametric equations tests the validity of the total soil water characteristic, as opposed to the t-test (results shown in Table I) where the individual components of the \text{v}(\text{v}) relationship were tested. The results of the former analysis for three textural groups are presented in Table III. Except for the loamy sand and clay loam groups, the intercept \text{a}, was not significantly different from 0.0, while for all textural groups the slope, \text{b}, was not significantly different from 1.0. The agreement among measured and predicted water contents for the loamy sand group could be improved, up to the point where the intercept was not significantly different from 0.0, by using the average saturation suction, \text{v}, instead of the geometric mean, \text{v} (log). For the clay loam group, a satisfactory agreement could be obtained by using a \text{v} value of 11.6, which is the average \text{v} (log) of the sandy clay loam and the silty clay loam group. The large standard errors of the regression lines is again an indication of the large variability encountered in the measured soil water characteristics within any textural group.

The results of the above analyses suggest that the parameters for the soil water characteristics, as derived by Clapp and Hornberger (1978), are applicable for the "typical" soil textural groups as employed in this study. This is useful, particularly in those cases where one deals with water modelling of large areas of soil.

**TABLE II. COEFFICIENTS OF VARIATION (%) OF MEASURED VOLUMETRIC WATER CONTENTS AT SELECTED TENSIONS**

<table>
<thead>
<tr>
<th>Tension (kPa)</th>
<th>S</th>
<th>LS</th>
<th>SL</th>
<th>L</th>
<th>Sil</th>
<th>SICL</th>
<th>CL</th>
<th>SIC</th>
<th>C - HVC</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>5.0</td>
<td>12.6</td>
<td>13.7</td>
<td>14.5</td>
<td>12.1</td>
<td>14.9</td>
<td>12.6</td>
<td>8.5</td>
<td>17.7</td>
</tr>
<tr>
<td>0.5</td>
<td>9.6</td>
<td>13.9</td>
<td>12.5</td>
<td>13.8</td>
<td>11.2</td>
<td>17.7</td>
<td>10.2</td>
<td>7.1</td>
<td>11.7</td>
</tr>
<tr>
<td>1.0</td>
<td>11.5</td>
<td>14.2</td>
<td>13.2</td>
<td>14.4</td>
<td>13.7</td>
<td>13.8</td>
<td>12.1</td>
<td>7.4</td>
<td>15.6</td>
</tr>
<tr>
<td>2.0</td>
<td>15.4</td>
<td>14.7</td>
<td>13.9</td>
<td>11.2</td>
<td>10.9</td>
<td>11.2</td>
<td>9.7</td>
<td>9.8</td>
<td>10.2</td>
</tr>
<tr>
<td>6.0</td>
<td>29.4</td>
<td>24.1</td>
<td>15.8</td>
<td>10.9</td>
<td>11.7</td>
<td>10.5</td>
<td>10.5</td>
<td>11.1</td>
<td>10.8</td>
</tr>
<tr>
<td>10.0</td>
<td>33.4</td>
<td>26.8</td>
<td>21.0</td>
<td>8.5</td>
<td>13.4</td>
<td>10.5</td>
<td>10.1</td>
<td>12.1</td>
<td>11.4</td>
</tr>
<tr>
<td>22.5</td>
<td>36.1</td>
<td>28.7</td>
<td>22.0</td>
<td>10.1</td>
<td>26.7</td>
<td>11.2</td>
<td>11.4</td>
<td>9.3</td>
<td>17.6</td>
</tr>
<tr>
<td>50.0</td>
<td>43.1</td>
<td>29.0</td>
<td>29.2</td>
<td>11.2</td>
<td>35.0</td>
<td>10.1</td>
<td>11.6</td>
<td>10.5</td>
<td>12.1</td>
</tr>
<tr>
<td>100.0</td>
<td>22.4</td>
<td>40.3</td>
<td>24.5</td>
<td>16.4</td>
<td>19.8</td>
<td>12.4</td>
<td>17.9</td>
<td>8.4</td>
<td>7.2</td>
</tr>
<tr>
<td>1500.0</td>
<td>44.7</td>
<td>25.4</td>
<td>35.8</td>
<td>27.4</td>
<td>28.1</td>
<td>14.7</td>
<td>31.0</td>
<td>20.2</td>
<td>19.0</td>
</tr>
</tbody>
</table>
for which little or no analytical data are available, and one has to resort to generalized soil textural data. The results should also be of interest to workers, who, in the initial stages of soil water model development and testing, need generalized hypothetical, but nevertheless realistic soil water characteristics (Hayhoe and De Jong 1982).

Whereas the previous analyses have shown that the parametric equations of Clapp and Hornberger are in satisfactory agreement with averaged measured data from similar textured soils, the situation changes when one looks at individual soils. Each individual soil has its own soil water characteristic that deviates from the predicted one for the texture under consideration. Whether or not the parameters derived by Clapp and Hornberger (1978) are applicable to a specific soil depends on the selected variability criteria. Rogowski (1972) suggested that soils may be considered uniform if the coefficient of variation does not exceed 10% at air entry and 15% a 1500 kPa tension. Assuming that air entry occurred at 2.0 kPa, which was calculated as the logarithmic average of \( \psi_1 \) of all textural groups, it was found from Fig. 1 that 53% of the measured water contents at 2.0 and 1500 kPa tension did not meet the suggested variability criteria. When the variability criteria were relaxed to CVs of 15% at 2.0 kPa and 20% at 1500 kPa, 44% of the measured water contents did not meet the criteria. This means that, for more than 44% of the time, the parameters derived by Clapp and Hornberger (1978) cannot be used to approximate the soil water characteristic of a specific, individual soil. In those cases where soil water characteristics of specific soils are needed, the approach advocated by Rogowski (1972), where the measured water content at 1500 kPa and at air entry (or any other specified tensions) are required input parameters to the model, might be more useful.

### TABLE III. REGRESSION ANALYSES (Y = a + bX) OF OBSERVED (Y) AND PREDICTED (X) WATER CONTENTS FOR NINE TEXTURAL GROUPS

<table>
<thead>
<tr>
<th>Texture</th>
<th>( a \pm SE )</th>
<th>( b \pm SE )</th>
<th>Syx</th>
<th>( R^2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>S</td>
<td>-0.030 ± 0.020</td>
<td>1.164 ± 0.095</td>
<td>0.104</td>
<td>0.793</td>
</tr>
<tr>
<td>LS</td>
<td>0.061* ± 0.201</td>
<td>0.999 ± 0.104</td>
<td>0.126</td>
<td>0.574</td>
</tr>
<tr>
<td>SL</td>
<td>0.031 ± 0.015</td>
<td>0.888 ± 0.058</td>
<td>0.105</td>
<td>0.756</td>
</tr>
<tr>
<td>L</td>
<td>0.034 ± 0.017</td>
<td>0.990 ± 0.056</td>
<td>0.077</td>
<td>0.818</td>
</tr>
<tr>
<td>SIL</td>
<td>-0.008 ± 0.007</td>
<td>0.916 ± 0.046</td>
<td>0.071</td>
<td>0.808</td>
</tr>
<tr>
<td>SiCL</td>
<td>0.010 ± 0.019</td>
<td>1.109 ± 0.056</td>
<td>0.057</td>
<td>0.797</td>
</tr>
<tr>
<td>CiCL</td>
<td>-0.055* ± 0.032</td>
<td>1.122 ± 0.078</td>
<td>0.088</td>
<td>0.719</td>
</tr>
<tr>
<td>SiC</td>
<td>0.035 ± 0.031</td>
<td>0.956 ± 0.078</td>
<td>0.085</td>
<td>0.683</td>
</tr>
<tr>
<td>C + HvC</td>
<td>0.058 ± 0.044</td>
<td>0.896 ± 0.108</td>
<td>0.120</td>
<td>0.479</td>
</tr>
</tbody>
</table>

*Significantly different from 0.0 at the 5% probability level.

### REFERENCES


