Comment on “Comparison of Three Methods to Calibrate TDR for Monitoring Solute Movement in Undisturbed Soil”

Today time domain reflectometry (TDR) is probably the only technology that enables simultaneous measurement of both water content and solute concentration distribution in a wide range of soil moisture and textures. Hundreds of users routinely apply TDR for dozens of purposes related to hydrology, engineering, environmental issues, construction, industry, and even for road maintenance (O’Connor et al., 1994).

Mallants et al. (1996) skillfully presented and compared three methods to calibrate TDR for monitoring soil solute content: (1) the application of a solute pulse long enough for the concentration in the soil to become equal to the input concentration; (2) a numerical integration of the observed response to a tracer pulse input function; and (3) determination of the soil impedance ($Z_0$) using an independently measured relationship between $Z_0$ and the solute concentration.

However, when Mallants et al. (1996, Fig. 9) compared $Z_0$ estimated by Method 3 to the observed $Z_0$ (either by Method 1 or 2), they found a systematic discrepancy. The following comments are aimed strictly toward clarifying two aspects of Method 3 calculations that may improve monitoring salt movement in the laboratory and in the soil profile.

Rearranging Eq. [7], $EC_j - EC_f$ Mallants et al. (1996) and substituting $1/\theta$, where $\theta$ is soil water content, with $F$ results in

$$EC_w/F = EC_a - EC_i$$

where $EC_a$, $EC_v$, and $EC'_i$ are the electrical conductivity of the bulk soil, the pore solution, and the exchangeable ions residing on the solid surfaces contributing to $EC_a$, respectively. The formation factor, $F$, is defined as “the ratio of the electrical conductivity of an electrolyte solution to that of a fictitious solid matrix that has the same geometry as the actual porous medium of interest” (Cremers et al., 1996). The latter also used Burger’s equation for relating $F$ to porosity ($\varphi$):

$$F = 1 + k (1 - \varphi)/\varphi$$

when assuming that particles are oblate ellipsoids; $k$ is a geometric factor. It should be noted that this definition would not permit negative $F$ values.

According to Eq. [1], two possible circumstances may cause erroneously underestimated $Z_0$ values: (i) underestimated $EC_a$ values increase the $EC_a - EC_i$ term of Eq. [1], and thus reduce $Z_0$ values; (ii) the lower the $EC_a$ value is, the more pronounced this effect, and (ii) the same is correct for $F$ values: underestimated $F$ values increase $EC_i/F$ (left term of Eq. [1]), thus resulting in overestimated $EC_a$ values, causing lower $Z_0$.

The process of calculating $Z_0$ for the various combinations of $\theta$ and solute employed the $EC_a - EC_i$ and $F$ relationships similar to that of the sandy loam used in this study (Magnuson, 1993).

Bulk soil electrical conductivity is a sensitive indicator of changes in soil structure. Using $Z_0$ values of Mallants et al. (1996) at the minimum and steady-state calculated $EC_a$ values for soils wetted with (SF) water or 1.4 dS m$^{-1}$ solution (Table 1).

The soil at the six depths (Table 1) had similar ($\theta$ and $EC_a$) conditions. Previous change in measured $EC_a$, caused by structural changes in four soil types, and an approximate 5% change in $EC_a$ similar to the sandy loam used in this study are tentatively shown (Mallants et al., 1996). These modern $EC_a$ values may be explained by the different effect of structural changes on macro- vs. microaggregates. The calculated soil came from the same depth (0-0.25 m) according to $EC_a$ values of Table 1, only a small part of $Z_0$, mismatch of Fig. 9 may be explained by this difference.

The following four causes may have directly contributed to the disparity in $Z_0$ of Fig. 9.

1. An extreme mismatch, sometimes approaching an order of magnitude, between the ranges of parallel calibrations and the ranges in which they were used. This gap is exemplified in Fig. 2 and 4. In the calibration range was 0 to 14 dS m$^{-1}$ while the minimum $EC_a$ was <0.6 dS m$^{-1}$ (according to the $0.17 \Omega$, namely 0.54 dS m$^{-1}$). In Fig. 4, the scale for $EC_a$ was 0 to 4 dS m$^{-1}$, while the experimental value was 0.6. The scale for $EC_a$ was 0 to 18 dS m$^{-1}$, while the total salt pulse was 1.4 dS m$^{-1}$. The scale for $EC_a$ was 0 to 4 dS m$^{-1}$, while, under the experimental steady-state conditions, the range was between 0.312 and 0.318 (Fig. 7).

2. Assumption of linearity for the $EC_a$ vs. $EC_w$ relations. These relations were assumed to be linear (0-50 dS m$^{-1}$) at a given $\theta$. To cite just one example (Mallants et al., 1996) from a long list: “$EC_a$ contribution affected by three factors: (i) reduction in cross sectional area (0-50 dS m$^{-1}$) at a given $\theta$. To cite just one example (Mallants et al., 1996) from a long list: “$EC_a$ contribution affected by three factors: (i) reduction in cross sectional area...” (Cremer et al., 1996). The latter also used Burger’s equation for relating $F$ to porosity ($\varphi$):

$$F = 1 + k (1 - \varphi)/\varphi$$

when assuming that particles are oblate ellipsoids; $k$ is a geometric factor. It should be noted that this definition would not permit negative $F$ values.

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Table 1. Bulk soil electrical conductivity ($EC_a$) of the salt-free water (SF) or salt pulse (1.4 dS m$^{-1}$) solutions and their differences. Calculations used Mallants et al. (1996) data.

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>$EC_a$ (dS m$^{-1}$)</th>
<th>SF</th>
<th>SF</th>
<th>Pulse</th>
<th>Pulse</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
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<td>0.05</td>
<td>0.05</td>
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</tr>
<tr>
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<td>0.30</td>
<td>0.30</td>
<td>0.30</td>
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</tr>
</tbody>
</table>

Table 2 is based on the $EC_a$ and $\theta$ data from Mallants et al. (1996) at the minimum and steady-state $EC_a$.