New Calibrations For Soilless Substrates

TDR 310W

This report covers the characterization of soilless substrates using the TDR310W. The research was performed using both Charcoir and Cloud Coir in order to develop a calibration for all soilless substrates.

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Calibration Research Study In Charcoir

TDR 310W

Substrate Specific Calibration For Clour Coir In Charcoir
TDR 310W

Overview

This report covers the characterization of Charcoir growing blocks using the TDR310W. The deployed TDR310W was a standard 'off the shelf' model that used the standard firmware that yields precise VWC measurements in mineral soils. It was reported by customers that the TDR310W reported low readings in Charcoir media. This study verified those reports and derived a calibration correction to the TDR readings to bring them into close agreement with the actual water content of the Charcoir. The calibration equation is a simple expression that can be programmed into the data recorder to make the corrections.

During the process of gathering the data and forming the TDR calibrations a comparison was also made to the Teros 12 sensor using the recommended non-mineral calibration equation from the Teros 12 Manual. The n-m calibrated readings from the Teros 12 were more accurate than the uncalibrated readings from the Acclima sensor but still showed unacceptable errors in most of the explored VWC ranges. These errors did not follow a simple linear trend but were rather complex in their distribution across the explored range of tested water content.
Pore Water EC readings were also taken for the TDR310W. Although the initial readings were within about 10% accuracy above 25% VWC there was a significant under-estimation below 25%.

A compensation was developed that brought the accuracy to within about 10% accuracy across the whole tested range of 15% VWC to 92% VWC.
The Teros 12 does not report PWEC directly. It must be calculated externally using the Hilhorst equation. That equation derives PWEC from Teros 12 permittivity and BEC readings. Although the BEC readings reported by the Teros 12 are reasonably accurate the permittivity calculation provided in the Teros 12 manual is way off for Charcoir – causing the PWEC derivation to show extreme errors. This is because the permittivity equation given in the Teros 12 manual is for mineral soils and yields a serious error when used for Charcoir. Hence the Teros 12 PWEC accuracy was not explored in this testing but is known to be in serious error when using the derivations disclosed in the manual.

Charcoir Discoveries: Non-Uniform Wetting

Two significant findings regarding the properties of Charcoir were discovered during the testing. The first of these is the limited hydraulic conductivity of the material. Initial attempts to obtain consistent readings using both the TDR3120W and the Teros 12 were frustrating. Depending upon where the probes were inserted differences in VWC readings were as high as 20% indicating gross differences in water distribution throughout the block. To gain a better understanding of this I wetted a dry block from its upper surface on Friday and sealed it into a plastic bag to prevent evaporation. I opened the bag on Monday. The picture below shows the sealed block after soaking throughout the weekend.

After the weekend soak VWC measurements were taken with the Teros 12 and the TDR310W. Readings from different places on the block varied by more than 10 percentage points for both sensors. The calculated VWC for the whole block was 20.7%. Readings ranged from 0 to 15% depending on how and where the probes were inserted. The block was then taken apart and the cause of the non-homogenous readings was clearly seen. Figure 2 shows the inside of the block and the wet and dry areas within it. Even though the wetting from the surface was done carefully to insure uniform water distribution across the surface of the block, the water did not permeate the block evenly. Even after 3 days of soaking the water was still poorly distributed throughout the block. This certainly will cause non credible VWC readings using any probe. It will also lead to poor root development of the plant that is transplanted into the block. The block must be thoroughly wetted by immersion until the air is completely bubbled out before it can be used. Otherwise the readings from it will be in error and the plant growing in it will be disadvantaged. Once the block is thoroughly wet the hydraulic conductivity of the material increases and the water can reach all areas in the block easily.

Figure 1. Charcoir with 450ml of water after soaking 3 days in a sealing plastic bag.

Figure 2. Charcoir block containing 20.7% by volume of water after soaking in a sealed bag for 3 days. Note the poor distribution of the water.

Figure 3. Test cylinder filled with Charcoil after thoroughly mixing the Charcoil with salted water.

Because of the poor wetting uniformity in the Charcoir blocks – especially al lower VWC levels, the testing was done using the Charcoir material in loose form where it could be thoroughly hand-mixed with water and then compacted into a measurement cylinder as shown in Figure 3. The testing was started at low WVC levels (15%) and progressed to 92% VWC.

Charcoir Discoveries: Disappearing Water

The second discovery relates to the under-estimation of VWC for electromagnetic sensors used in Charcoir. Most water content sensors measure VWC by measuring the permittivity of the soil-water mixture. Since the permittivity of a soil-water mixture is dominated by the permittivity of water this makes an excellent method of gaining highly accurate VWC readings from soil-water mixtures. One problem that exists in clay soils is that a portion of the water molecules becomes attracted to the tiny platelets of clay to the extent that they become somewhat immobilized. Their free rotation is inhibited and their availability for extraction by roots is also limited. This bound water phenomenon prevents the water molecule from rotating freely in aligning itself with an applied electric field. Since water is a polar molecule and has its own tiny electric field it naturally rotates to align its field with an applied field thus increasing the applied field. This increase is 'seen' by the sensor and facilitates the measurement of the water content. But if the water molecule does not rotate it cannot be 'seen'. Fortunately in clay soils the rotation is not permanent but rather 'sluggish'. The molecule rotates after a couple of nano-seconds delay. This delayed rotation can be seen in time domain waveforms and thus the bound water can be detected and added to the remaining 'free' water content.

TDR310W Waveforms Charcoir Derived From Coir/Water Mixtures

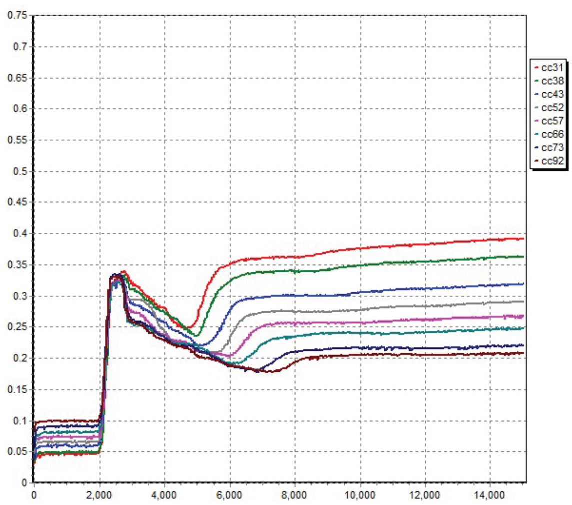

Figure 4. TDR waveforms from the TDR310W in Charcoir derived from coir/water mixtures ranging from 31% VWC to 92% VWC.

The knee of the reflected wave in the samples in Figure 4 appears much earlier than the water content would indicate. This means that a significant portion of the water in the mixture is not responding to the applied electric field and is thus 'invisible' to the sensor. Unlike clay soils the Charcoir seems to make this binding permanent. There is no delayed response. Thus Charcoir WVC readings are significantly below the actual VWC values by a significant amount.

4 Substrate Specific Calibration: Charcoir

Figure 5. TDR and Teros VWC Readings In Charcoir

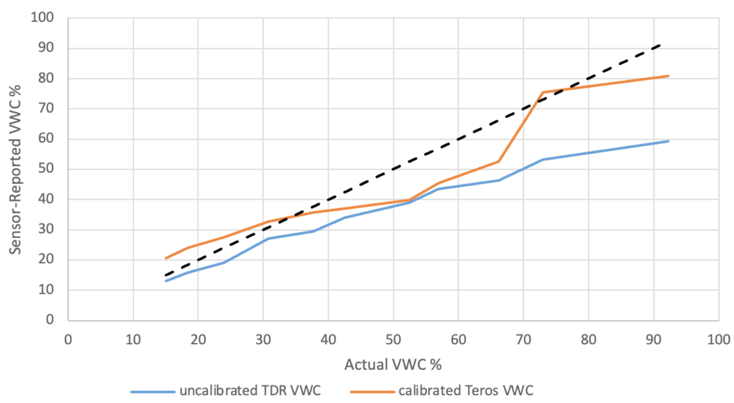

Figure 5. Readings of VWC in Charcoir for both the Teros 12 and the TDR310W. The dashed line represents 'truth'.

In Figure 5 it can be seen that the calibrated Teros 12 response is closer to the actual water content than is the TDR310W – which is not calibrated. The Teros 12 is very close to truth at about 35%, but then drifts in to larger errors below and above that. The uncalibrated TDR310W departs from 'truth' in a more linear fashion which allows for easy compensation.

Figure 6 shows the compensation values needed to correct the TDR310W. It also shows the percent error in the Teros 12 readings. Note that the Teros 12 sensor using its non-mineral calibration is accurate in Charcoir in the 35% VWC range and in the 75% range, but everywhere else thare are large errors.

Figure 6. Teros Errors and TDR Corrections

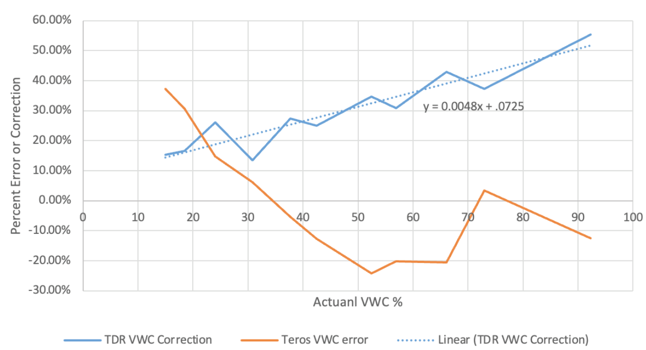

Figure 6. This graph shows the VWC reporting errors associated with the Teros 12 in Charcoir and also shows the compensation required to bring the TDR310W into accurate VWC readings.

TDR310W VWC Calibration In Charcoir

Calibration Equation 1

[illegible]

Where VWCc is the calibrated or corrected VWC value and VWCr is the uncorrected TDR reading.

The results of applying this correction are shown in Figure 7. Note that the calibrated TDR310W provides very accurate VWC readings across a remarkably broad range of VWC from 15% to over 90% VWC. The calibrated Teros 12 shows accuracy around 35% and again at around 75% but everywhere else shows significant errors up to more than 20 percent.

Equation 1 can be applied in the data recorder by multiplying the VWCr reading by 1.0725 and then dividing that by (1 - .0048 * VWCr).

Figure 7. Sensor VWC Reporting Accuracy vs. Actual VWC In Charcoir

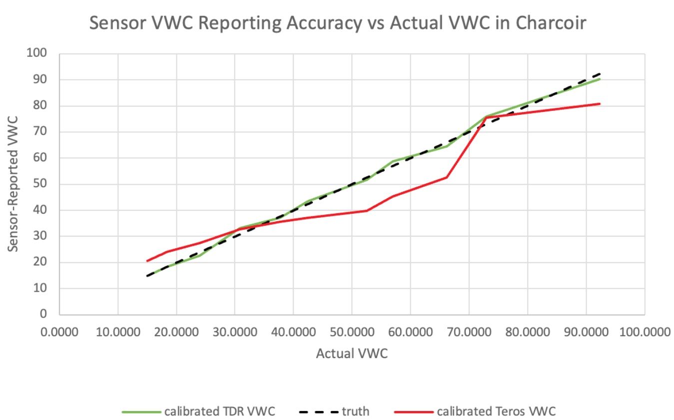

Figure 7. Compensated TDR310W and Teros 12 accuracy in Charcoir.

PWEC Reporting Accuracy

The PWEC reading for the TDR310W is reasonable even without calibration. It shows high accuracy in the 40 to 60 percent VWC range. The drier areas show more significant errors. Figure 8 shows these uncalibrated readings.

The calibrated PWEC readings are shown in Figure 9. The maximum error after calibration is about 10% but in most cases is less than 5%. The calibration equation for PWEC is:

Calibration Equation 2

[illegible]

Where PWECc is the calibrated PWEC in Charcoir, PWECr is the PWEC reading reported by the sensor and VWCc is the calibrated VWC as calculated in equation 1.

PWEC Reporting Cont...

Figure 8. Uncorrected TDR-Reported PWEC

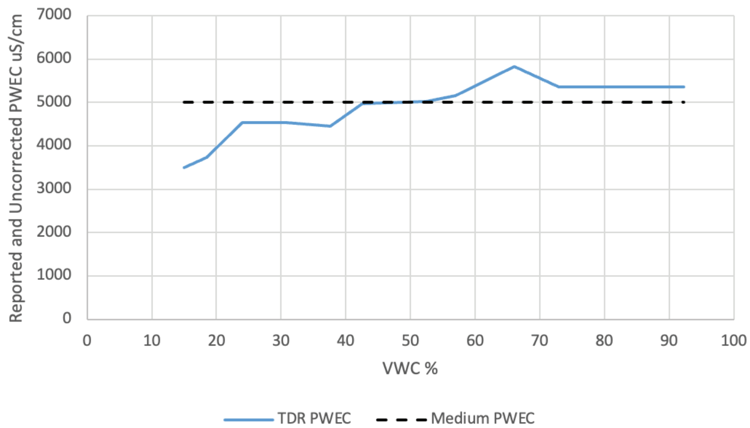

Figure 8. Uncalibrated PWEC Readings for the TDR310W in Charcoir.

Figure 9. TDR310W Corrected PWEC Reporting vs VWC

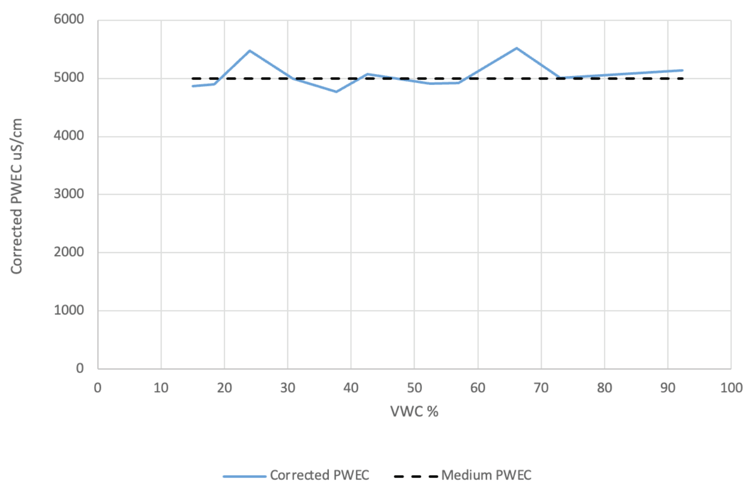

Figure 9. Calibrated PWEC readings for the TDR310W in Charcoir.

Calibration Research Study In Cloud Coir

TDR 310W

Substrate Specific Calibration For Clour Coir In 50/50 Media
TDR 310W

Overview

This report covers the characterization of Cloud 50/50 growing medium using the TDR310W. The deployed TDR310W was a standard 'off the shelf' model that used the standard firmware that yields precise VWC measurements in mineral soils. It was reported by customers that the TDR310W reported low readings in Cloud 50/50 media. This study verified those reports and derived a calibration correction to the TDR readings to bring them into close agreement with the actual water content of the Cloud 50/50. The calibration equation is a simple expression that can be programmed into the data recorder to make the corrections.

During the process of gathering the data and forming the TDR calibrations a comparison was also made to the Teros 12 sensor using the recommended non-mineral calibration equation from the Teros 12 Manual. The n-m calibrated readings from the Teros 12 were more accurate than the uncalibrated readings from the Acclima sensor but still showed unacceptable errors in the wetter VWC ranges (above 40% VWC). These errors did not follow a simple linear trend but were rather complex in their distribution across the explored range of tested water content.

Pore Water EC readings were also taken for the TDR310W. Although the initial readings were within about 10% accuracy above 25% VWC there was a significant under-estimation below 25%. A compensation was developed that brought the accuracy to within about 10% accuracy across the whole tested range of 15% VWC to 72% VWC. The Teros 12 does not report PWEC directly. It must be calculated externally using the Hilhorst equation. That equation derives PWEC from Teros 12 permittivity and BEC readings. Although the BEC readings reported by the Teros 12 are reasonably accurate the permittivity calculation provided in the Teros 12 manual is way off for Cloud 50/50 – causing the PWEC derivation to show extreme errors. This is because the permittivity equation given in the Teros 12 manual is for mineral soils and yields a serious error when used for Cloud 50/50. Hence the Teros 12 PWEC accuracy was not explored in this testing but is known to be in serious error when using the derivations disclosed in the manual.

Cloud 50/50 Bound Water Issue

Cloud 50/50 exhibits a bound water phenomenon similar to Charcoir but to a lesser extent. Figures 1 and 2 show the difference. In Figure 1 the TDR response shown as the blue line indicates a 'bound water' deficiency that gradually increases with increasing water content. The offset error is quite linear. In Charcoir (Figure 2) the offset is more severe with increasing water content. Because of this difference the Cloud 50/50 compensation is different than that used with Charcoir. The green line in Figure 1 shows the corrected VWC readings for the TDR sensor. The correction brings the accuracy to about 1 percentage point. The teros12 using the non-mineral calibration shows remarkable accuracy in this soil out to 40% VWC. Beyond that its accuracy diminishes.

Figure 1. TDR and Teros Readings In Cloud 50/50

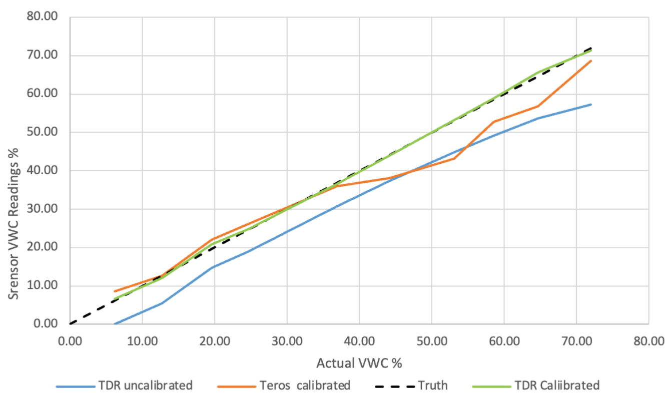

Figure 1. VWC Responses of the TDR310W and Teros 12 in Cloud 50/50 medium The dashed line represents 'truth'.

Figure 2. TDR and Teros VWC Readings in Charcoir

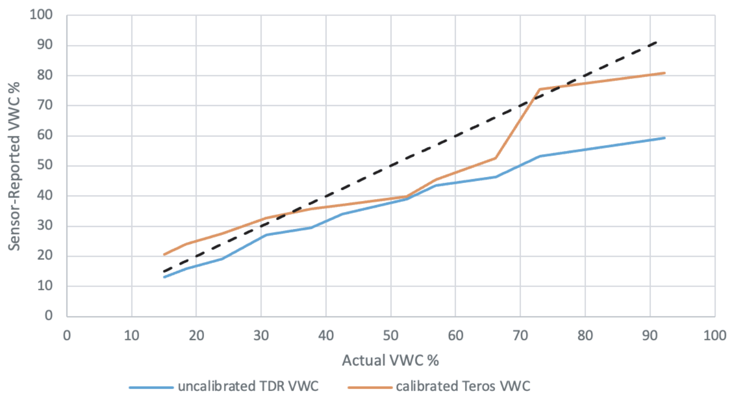

Figure 2. Readings of VWC in Charcoir for both the Teros 12 and the TDR310W. The dashed line represents 'truth'.

PWEC Reporting Accuracy

The PWEC reading for the TDR310W in Cloud 50/50 is reasonable in the range 15% VWC to 70% VWC even without calibration. It shows accuracy of better than 5% in the 20 to 45 percent VWC range. The drier areas show more significant errors. Since the 20 to 45% VWC range needs no calibration two separate calibration equations are provided – one for the range 10% to 25% VWC and the other for the range 45% to 65% VWC. The maximum error after calibration is about 10% at 12% VWC but in all other areas is less than 5%.

Figure 3. TDR 310W PWEC Readings in Cloud 50/50

Figure 3. Uncalibrated and Calibrated PWEC Readings for the TDR310W in Cloud 50/50. The EC of the water used to flood the bag was 5000 uS/cm..

PWEC Calculations

[illegible]

[illegible]

Where PWECc is the calibrated PWEC in Cloud 50/50, PWECr is the PWEC reading reported by the sensor and VWCc is the calibrated VWC as calculated in equation 1.

Customer Test

After completing the tests necessary to obtain the calibration equations for the Cloud 50/50 soil a 'customer' test was performed. Figure 4 shows a bag filled with wetted Cloud 50/50 material. The wetting occurred from the top using a sprinkler. Calculations from the bag dimensions were made to determine the volume of the material. The water content of the material was determined by weighing the bag and subtracting the dry material weight. The dry material was estimated to have about 11% VWC. The wet material was then calculated to contain 56% VWC.

Figure 4.

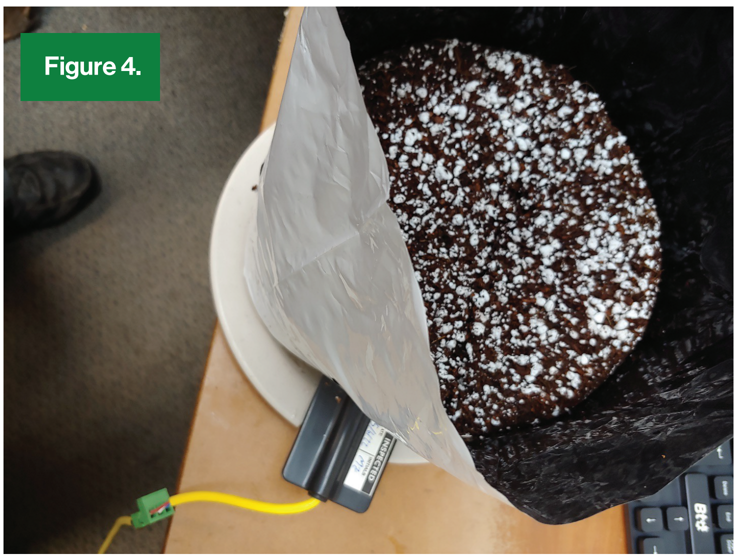

Figure 4. Cloud 50/50 material packed in a bag and wetted from the top using a sprinkler..

TDR and Teros VWC Readings in Charcoir

The TDR310W measured 58% VWC when inserted into the side of the bag.
The readings obtained are as follows:

Water content derived through weighing:	56%
Water Content Reported by Acclima TDR:	58%
Water Content Reported by Teros 1:	43%