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Supplementary Material

Moisture-Conductivity Calibration for Electrical Imaging of Horticultural Substrate

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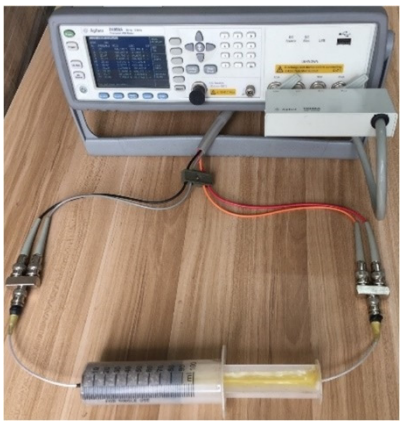
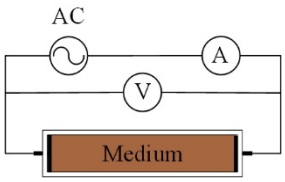
Supplementary Experimental Setup and Procedures

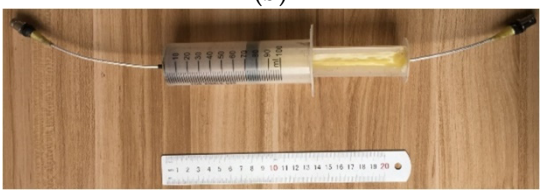
The experimental setup for measuring the impedance of substrate using two-electrode method with controllable dry density and volumetric water content (VWC) is shown in Figure S1a. A precision inductor-capacitor-resistor (LCR) meter (E4980A, Keysight Technologies, Inc., Santa Rosa, CA, USA) was applied for the impedance measurements. Moreover, in order to be available for use in a two-electrode measurement (Figure S1b), the LCR meter was extended using its official 16048A test leads and two bayonet neill-concelman (BNC) connectors. Furthermore, a user-fabricated sample fixture (Figure S1c) was attached to the two-terminal port. For the fixture based on a 100 mL syringe, there were two 0.2-mm-thick circular electrodes, and the diameter of each electrode was the same as the inside diameter of the barrel. One electrode was fixed at the inner bottom of the barrel, and another one was fixed at the rubber piston of the plunger. Thus, the volume of a measured sample could be changed to control the dry density and VWC. Besides, to achieve well electromagnetic shielding, each electrode was connected to one BNC connector via a RG-316 coaxial cable.



(**a**)



(**b**)



(**c**)

Figure S1. Impedance measurement of substrate sample using two-electrode method with controllable dry density and volumetric water content. (**a**) Photograph of the measurement setup; (**b**) schematic of the two-electrode measurement; (**c**) photograph of the user-fabricated sample fixture.

About 2 kg of relatively dry substrate was prepared. Firstly, a certain amount of tap water with the conductivity of 0.0348 S/m (DDSJ-308A conductivity meter, INESA Scientific Instrument Co., Ltd, Shanghai, China) was added to the substrate to improve its moisture content (i.e., gravimetric water content). To make the moisture distribution as uniform as possible, a spraying procedure was applied, and a mixing procedure was performed simultaneously [20]. Secondly, the impedance spectra of the sampled substrate at different dry densities and VWCs were measured. A required amount of substrate was weighed using an analytical balance (TB-215D, Denver Instrument Co., Bohemia, NY, USA), and then it was loosely and homogeneously filled into the barrel. Next, the sample was successively compressed to a series of volumes (Table S1). For the sample at each volume, the impedances at 201 logarithmically entered sweep frequency points ranging from 20 Hz to 2 MHz were obtained using a constant voltage level of 1 V and a measurement function of R-X. Thirdly, the temperature of the sample in the barrel was measured using a thermometer (52 K/J, Fluke Co., Everett, WA, USA), and the wet weight of the sample taken out from the barrel and its dry weight after drying at 105°C for 24 hours via a heating and drying oven (DHG-9011A, Shanghai Jing Hong Laboratory Instrument Co., Ltd., Shanghai, China) were recorded to calculate the moisture content, dry densities and VWCs. For the substrate at a certain moisture content, three samples with the same amount were obtained in total to perform the related measurements above. Thus, the average values of the measurements could be achieved to minimize the effects of the related errors. The above process was repeated until the moisture content of the substrate reached approximately 87%. Table S1, Table S2 and Table S3 list the dry densities, VWCs and temperatures of the compressed substrates for each moisture content.

Table S1. Dry densities of the compressed substrates for each moisture content.

Moisture Content (%)	Dry Density (g/cm³) Compressed Volume (mL)									
	92	90	86	84	80	78	74	72	68	66
18.2	0.387	0.396	0.414	0.424	0.445	0.456	0.481	0.495	0.524	0.539
23.3	0.388	0.396	0.415	0.425	0.446	0.457	0.482	0.495	0.525	0.540
28.3	0.388	0.397	0.415	0.425	0.446	0.458	0.483	0.496	0.525	0.541
32.9	0.387	0.396	0.414	0.424	0.445	0.457	0.481	0.495	0.524	0.540
38.1	0.401	0.410	0.429	0.439	0.461	0.473	0.498	0.512	0.542	0.559
42.8	0.386	0.395	0.413	0.423	0.444	0.455	0.480	0.493	0.522	0.538
47.7	0.389	0.397	0.416	0.426	0.447	0.459	0.483	0.497	0.526	0.542
53.1	0.387	0.396	0.414	0.424	0.445	0.456	0.481	0.494	0.524	0.539
59.3	0.383	0.391	0.409	0.419	0.440	0.451	0.476	0.489	0.518	0.533
63.4	0.383	0.392	0.410	0.420	0.441	0.452	0.477	0.490	0.519	0.535
69.8	0.385	0.393	0.412	0.421	0.443	0.454	0.478	0.492	0.521	0.536
75.9	0.379	0.387	0.405	0.415	0.436	0.447	0.471	0.484	0.513	0.528
80.7	0.380	0.389	0.407	0.416	0.437	0.448	0.473	0.486	0.514	0.530
87.5	0.379	0.387	0.405	0.415	0.435	0.447	0.471	0.484	0.512	0.528

Table S2. Volumetric water contents of the compressed substrates for each moisture content.

Moisture Content (%)	Volumetric Water Content (cm³/cm³) Compressed Volume (mL)									
	92	90	86	84	80	78	74	72	68	66
18.2	0.070	0.072	0.075	0.077	0.081	0.083	0.087	0.090	0.095	0.098

23.3	0.090	0.092	0.096	0.099	0.104	0.106	0.112	0.115	0.122	0.126
28.3	0.110	0.112	0.117	0.120	0.126	0.129	0.136	0.140	0.148	0.153
32.9	0.127	0.130	0.136	0.140	0.147	0.150	0.159	0.163	0.172	0.178
38.1	0.153	0.156	0.163	0.167	0.176	0.180	0.190	0.195	0.207	0.213
42.8	0.165	0.169	0.177	0.181	0.190	0.195	0.205	0.211	0.224	0.230
47.7	0.185	0.190	0.198	0.203	0.213	0.219	0.231	0.237	0.251	0.259
53.1	0.205	0.210	0.220	0.225	0.236	0.242	0.255	0.262	0.278	0.286
59.3	0.227	0.232	0.243	0.248	0.261	0.267	0.282	0.290	0.307	0.316
63.4	0.243	0.248	0.260	0.266	0.279	0.286	0.302	0.310	0.328	0.338
69.8	0.269	0.275	0.287	0.294	0.309	0.317	0.334	0.343	0.363	0.374
75.9	0.286	0.292	0.306	0.313	0.329	0.337	0.355	0.365	0.387	0.399
80.7	0.307	0.314	0.328	0.336	0.353	0.362	0.381	0.392	0.415	0.428
87.5	0.331	0.339	0.354	0.363	0.381	0.391	0.412	0.423	0.448	0.462

Table S3. Temperatures of the compressed substrates for each moisture content.

Temperature (°C)													
Moisture Content (%)													
18.2	23.3	28.3	32.9	38.1	42.8	47.7	53.1	59.3	63.4	69.8	75.9	80.7	87.5
25.3	26.0	25.8	25.7	26.7	26.1	27.1	26.6	26.3	26.9	25.9	26.1	26.9	25.9