Project Title: Soil Moisture Sensor Testing Protocol, 1st Draft

Project No.: 1000-8 (sen/03)

Date: June 17, 2003

Subject: Review of Comments by Individuals

Item	Comment/Observations	Accept	Reject	Explanation
(#)				
1	If a sensor provides useable data in the lab tests how can we be sure it will function satisfactorily in the field	✓		Lab tests address the impact of soil moisture content, temperature, and water conductivity on sensor readings. This test is meant to verify the scientific logic of the sensor design. Those sensors with favorable results would be recommended for a second phase of testing where they would be used with a control system to produce satisfactory turf grass.
2	How do we evaluate the sensor based system's ability to deal with soil and microclimate variability?	✓		Both soil and microclimate variability must be dealt with by all currently available control concepts. Some variability will be built into the Phase 2 field study. Also factors not identified in the lab study will be addressed in the field study.
3	Sensors should be tested for tolerance to freezing conditions	✓		Added to standard as paragraph 6.3.1c
4	2.0 No gravimetric soil moisture content referenced	✓		To be added
5	3.0 include a definition of "Soil Water Potential"	✓		To be added
6	Table 1 concerned about two few replications	✓		Made a modest increase in replications (from 2 to 3 & 1 to 2)

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7	6.0 question fundamental methodology of using containment box. Notes the moisture redistributing effect of roots in a natural environment.		✓	The box is meant to geometrically represent a section of turf root zone. Drying occurs through moisture loss at the surface and through drain holes in the bottom. To that end it represents the root zone in the field except for the presence of roots. The fact that the root zone does not dry out uniformly should not affect the results as long as the sensor is placed in the same relative position for all drying runs.
8	6.0 soil variability could affect results		✓	Soil sample is oven dried and screened and hand placed and tamped. It should be free of stones, roots, and other debris.
9	6.0 it would be helpful to have a copy of the soil containment box	✓		Copy of drawing added to appendix
10	6.0 how is sensor depth of placement determined in the absence of roots?		✓	Soil depth in containment box is approximately 6½ in deep. Sensor is placed at a depth of 3 in. or as specified by the manufacturer. See also #28 & # 29. This is meant to simulate a well irrigated root zone
11	Recommend installing a plug of turf grass on the surface of the containment box		✓	This lab test is meant to be a short term screening test. Adding turf would create serious logistical questions involving time and lab space. Questions of performance under actual turf management demands will be addressed in a proposed Phase 2 study involving both sensors and controllers.
12	6.2.1a why use de-ionized water? Why not use a real world water like rainwater?		✓	We need to use water of a fixed and known conductivity as a base. Thus DI is used.

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13	How do you deal with the question of a variety of units, (e.g. volumetric moisture content, metric potential, dielectric constant, TDR, etc.)?	✓		Manufacturers are free to put whatever label on the calibration reading that they want. The protocol is only interested in how the calibration readings correlate with soil mass (or volumetric) moisture content. Each sensor will be evaluated on its ability to accurately correlate with soil moisture content when subjected to variations in temperature, conductivity and soil type.
14	What type of least squared regression will be completed? Will it be based on a linear regression?			The program uses a curve fit routine that evaluates the data against a fit to 25 equation forms and 3 polynomials. Best fit results in the highest correlation coefficient (R^2).
15	Could a pressure plate apparatus also be included?		✓	Moisture retention curves will be run on the three soil types involved. Individual sensor's calibration curves will be checked against the moisture retention curves to verify that the range of the sensor's curve covers the stress values involved in managing turf and landscape.
16	TDR probes of significant length integrate moisture content over the length of the probe. This could be an advantage in actual field use.	✓		Other sized containment boxes may be required for sensors sampling large soil volumes. In the field studies planned for Phase 2 of the test program, the importance of sampling larger soil volumes can be evaluated.
17	Could add basic equations involved in the appendix	✓		Included in the definitions

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18	Some soil moisture sensors do not have data recording features but operate to interrupt irrigation at predetermined set points.	✓		The protocol needs to be modified to include this type of sensor. In this case the evaluation will be made to determine repeatability of the set points over the range of the test conditions covered in the protocol. A discussion will be held with the manufacturer to determine if set point actuations can be sensed and recorded electronically. It would be desirable to sense all 16 set points with a single wetting run.
19	How will the protocol handle sensors that may have a different response curve for different soil types, water conductivity values, or temperature?	✓		The protocol will determine the repeatability of the sensors calibration for each of the variables involved (soil type, temperature, and water conductivity). The manufacturer will have to explain how this is useful in a water management scheme using a sensor with a matrix of calibration curves. They may also have to deal with transient conditions such as a fertilizer round.
20	Life tests are required to determine the stability of the sensors calibration overtime	✓		This will be suggested for inclusion in the Phase 2 study where sensors with controllers are responsible for the quality of turf in test plots
21	Soil moisture sensor must be easily adjustable to levels of watering that the user decided are adequate.			The protocol will describe the operational characteristics of the sensor with associated controller to allow for familiarization with the concept. The fundamental purpose of the Phase 1 protocol is to determine if the sensor is based on soil physics principals as demonstrated by providing a repeatable calibration curve when subjected to variable field conditions.
22	Reiterate the need for stability over time without the need for re-calibration.	✓		Time related issues to be included in Phase 2 of study with turf plots irrigated for say 3-5 years.

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23	Suggest making a distinction between absolute and relative soil moisture sensor.	✓		We understand the distinction between absolute and relative soil moisture sensors to be as follows: **<u>Absolute Soil Moisture Sensor</u>** This sensor is sensitive to soil moisture changes only and not affected by soil type, water conductivity, or temperature. Using moisture retention curves, the sensor can then be used to set limits on root zone tension at values known to provide quality turf with efficient water use. **<u>Relative Soil Moisture Sensor</u>** This sensor is sensitive to soil moisture changes and other factors including for example soil texture, water conductivity and temperature. This sensor must be calibrated "in situ" by an iterative process of adjusting water applications and making observations on turf quality. Related factors such as water conductivity changes during fertilization could change threshold stress and require a change of threshold setting values by the operator. The prime objective of the protocol is to characterize the sensors repeatability under known controlled conditions.
24	6.1.1 "Representative Bulk Densities (range 1.2 to 1.4)". What is the significance of the bulk density range?			Bulk density must be known and controlled to be representative of typical field conditions. Soil water content measurements are expressed on a mass water content basis (wcm) and some are expressed on a volume water content basis (wcv). The relationship between the two measurements involves bulk density (bd) as per the following equation: wvc = wcm (bd)
25	6.1.1 It would be interesting to record the depth of sensor placement.	✓		Documentation added to the protocol

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26	Should consistency in the depth of placement be expected between manufacturers?			The root zone drying curve varies with depth. A sensor placed near the surface must have a wider range of moisture content measuring capabilities than one placed deeper. We believe the manufacturer should be free to select the optimum location giving due consideration to all factors including for example the practice of mechanical aeration.
27	Need to be able to assess turf quality as relates to soil moisture sensor controlled systems.	✓		Phase I of this study is to assess the scientific qualities of the sensor. We have added a Phase 2 to the study that requires soil moisture sensor manufacturers to provide a controller-sensor unit to demonstrate an ability to satisfactorily control irrigations on actual turf grass plots.
28	A 6-7 in. root zone depth seems too deep. Extensive field studies in So. California show an average root depth of 3.9 in.	✓		The test box is meant to simulate a potential root zone section 5 ½ in. long by 20 ½ in. long by 6-7 in. deep. The manufacturer is free to simulate any root zone depth they feel is appropriate by where they place the sensor. The wisdom of the manufacturer's judgment will be tested in Phase 2 when actual turf plots are grown.
29	What difference would a shallower root system have on the tests?			We will ask the manufacturer to commit to a sensor depth of placement in Phase 1 and use that same placement depth in Phase 2. In so far as possible, we will set the water management scheme to encourage a rooting depth of approximately 3.9 in. Phase 2 will "model" the most representative field situation as relates to soil type, grass variety, root zone depth, irrigation system and water management scheme. It will take some discussion and perhaps additional tests to establish how well a general characterization fits the range of field conditions.

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30	The sensors should be evaluated on the same climatological basis as the controllers. The test should demonstrate the sensors ability to manage the effective control of the valves.		✓	The control concepts, climatological inputs vs. soil moisture status input, are based on integrating the readings of different sensors. We have added a Phase 2 to the soil moisture sensor which requires the growing of a turf plot. We could add a similar Phase 2 to the controller protocol if we cannot agree that the computer simulation is adequate. In side-by-side tests they would both experience the same ET. A question for the committee to discuss.
31	Protocol looks good. It addresses the issues dense clay/sand and high TDS	✓		Agree
32	Should more than one soil type be used for the conductivity test?	✓		The protocol has been changed to characterize susceptibility to a conductivity of 1.5 dS/m for fine and coarse textured soils to compare with medium.
33	Sensors should be graded on the same basis as climate controlled controllers (i.e. water consumed, run-off, etc.)			We agree, sort of. We have added a Phase 2 to the sensor protocol that requires the manufacturer to provide a control system capable of growing a quality turf grass plot. This evaluation will include tracking real time ETc values, and flow meters so as to estimate the application efficiency. Measuring application uniformity and appraising grass quality will also be part of the study.
34	Real world problems of installing sensors in typical field conditions where compaction may be encountered should be addressed	✓		Phase 2 will require the manufacturer to deal with this problem or suffer the consequences.
35	Soil moisture sensors must be tested in the field to demonstrate reliability	✓		We agree. The protocol Phase 1 is meant to sort out the sensors with scientific merit. We have added a Phase 2 to that involves the ability off the sensor with related control system to grow a plot of turf. The effectiveness of the system would be quantified.