



SOIL MOISTURE SENSORS: WHY MEASUREMENTS DIFFER



INTRODUCTION

SOIL MOISTURE MEASUREMENT IS VITAL FOR EFFECTIVE TURF MANAGEMENT, ENSURING OPTIMAL IRRIGATION AND PLANT HEALTH. HOWEVER, READINGS CAN DIFFER SIGNIFICANTLY DEPENDING ON THE SENSOR TYPE, OFTEN CAUSING CONFUSION AMONG USERS.

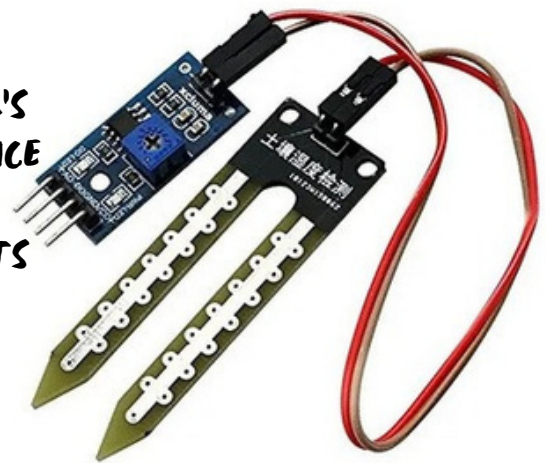
THESE VARIATIONS STEM FROM DIFFERENCES IN MEASUREMENT TECHNOLOGY, THE DEPTH AND VOLUME OF SOIL ASSESSED, AND THE SENSOR'S POSITIONING DURING DATA COLLECTION. A CLEAR UNDERSTANDING OF THESE FACTORS IS ESSENTIAL FOR ACCURATELY INTERPRETING DATA AND MAKING WELL-INFORMED IRRIGATION DECISIONS.



MEASUREMENT PRINCIPLES: DIELECTRIC PERMITTIVITY



SOIL MOISTURE SENSORS DETERMINE WATER CONTENT BY LEVERAGING DIELECTRIC PERMITTIVITY, WHICH REPRESENTS THE SOIL'S ABILITY TO TRANSMIT AN ELECTRIC FIELD. SINCE WATER HAS A MUCH HIGHER DIELECTRIC PERMITTIVITY THAN OTHER SOIL COMPONENTS (SUCH AS MINERALS, AIR, AND ORGANIC MATTER), VARIATIONS IN MOISTURE LEVELS SIGNIFICANTLY IMPACT THE SENSOR'S ELECTRICAL RESPONSE.(1,2,3,4,5).



1. TOPP, G. CLARKE, J. L. DAVIS, AND A. PETER ANNAN. "ELECTROMAGNETIC DETERMINATION OF SOIL WATER CONTENT: MEASUREMENTS IN COAXIAL TRANSMISSION LINES." *WATER RESOURCES RESEARCH* 16.3 (1980): 574-582.
2. BOSCH, DAVID D. "COMPARISON OF CAPACITANCE-BASED SOIL WATER PROBES IN COASTAL PLAIN SOILS." *VADOSE ZONE JOURNAL* 3.4 (2004): 1380-1389.
3. ROBINSON, DAVID A., ET AL. "A REVIEW OF ADVANCES IN DIELECTRIC AND ELECTRICAL CONDUCTIVITY MEASUREMENT IN SOILS USING TIME DOMAIN REFLECTOMETRY." *VADOSE ZONE JOURNAL* 2.4 (2003): 444-475.
4. SEYFRIED, M. S., ET AL. "DIELECTRIC LOSS AND CALIBRATION OF THE HYDRA PROBE SOIL WATER SENSOR." *VADOSE ZONE JOURNAL* 4.4 (2005): 1070-1079.
5. LOGSDON, S. D., ET AL. "HYDRA PROBE AND TWELVE-WIRE PROBE COMPARISONS IN FLUIDS AND SOIL CORES." *SOIL SCIENCE SOCIETY OF AMERICA JOURNAL* 74.1 (2010): 5-12.

MEASUREMENT PRINCIPLES: DIELECTRIC PERMITTIVITY



THERE ARE THREE PRIMARY MEASUREMENT METHODS BASED ON THIS PRINCIPLE

TIME-DOMAIN REFLECTOMETRY (TDR)

TDR SENSORS SEND AN ELECTROMAGNETIC PULSE ALONG A METAL PROBE INSERTED INTO THE SOIL AND MEASURE THE TIME IT TAKES FOR THE SIGNAL TO RETURN (REFLECTION). SINCE WATER SLOWS DOWN THE SIGNAL IN PROPORTION TO ITS CONCENTRATION, THE VOLUMETRIC WATER CONTENT CAN BE ACCURATELY DETERMINED.

ADVANTAGES

- **HIGH ACCURACY, EVEN IN COMPLEX SOIL TEXTURES**
- **CAN MEASURE BOTH MOISTURE AND ELECTRICAL CONDUCTIVITY (HELPFUL FOR DETECTING EXCESS SALTS)**
- **WELL-ESTABLISHED AND WIDELY VALIDATED TECHNOLOGY**

LIMITATIONS

- **HIGH EQUIPMENT COST**
- **SENSITIVE TO INSTALLATION QUALITY: POOR SOIL CONTACT CAN REDUCE ACCURACY**
- **REQUIRES SOIL-SPECIFIC CALIBRATION FOR OPTIMAL PERFORMANCE**

MEASUREMENT PRINCIPLES: DIELECTRIC PERMITTIVITY



CAPACITANCE (FREQUENCY DOMAIN – FD) METHODS

THESE SENSORS ASSESS THE SOIL'S ABILITY TO STORE ELECTRICAL CHARGE IN RESPONSE TO AN ALTERNATING FIELD AT A SPECIFIC FREQUENCY. THE MEASURED ELECTRICAL CAPACITANCE CHANGES WITH WATER CONTENT, PROVIDING AN ESTIMATE OF SOIL MOISTURE (6).

ADVANTAGES

- MORE AFFORDABLE AND USER-FRIENDLY COMPARED TO TDR
- RAPID MEASUREMENTS, IDEAL FOR HIGH-FREQUENCY MONITORING
- SUITABLE FOR LARGE-AREA DEPLOYMENT

LIMITATIONS

- READINGS CAN BE AFFECTED BY SOIL SALINITY AND TEMPERATURE FLUCTUATIONS
- LESS PRECISE IN HETEROGENEOUS SOILS COMPARED TO TDR
- LIMITED MEASUREMENT DEPTH COMPARED TO TDR SENSORS

6. "COMPARISON OF CAPACITANCE-BASED SOIL WATER PROBES IN COASTAL PLAIN SOILS." VADOSE ZONE JOURNAL 3.4 (2004): 1380-1389.

MEASUREMENT PRINCIPLES: DIELECTRIC PERMITTIVITY



COAXIAL IMPEDANCE DIELECTRIC REFLECTOMETRY

THE SENSOR BASES THE SOIL MOISTURE CALIBRATION ON THE REAL DIELECTRIC PERMITTIVITY, WHILE MOST OTHER SOIL MOISTURE METHODS BASE THEIR SOIL MOISTURE ESTIMATION ON THE APPARENT PERMITTIVITY, WHICH IS A COMBINATION OF THE REAL AND IMAGINARY COMPONENTS (7). BASING THE SOIL MOISTURE CALIBRATION ON THE REAL DIELECTRIC PERMITTIVITY INSTEAD OF THE APPARENT PERMITTIVITY HAS MANY ADVANTAGES. BECAUSE THE COAXIAL IMPEDANCE DIELECTRIC REFLECTOMETRY SEPARATES THE REAL AND IMAGINARY COMPONENTS, SOIL MOISTURE CALIBRATIONS ARE LESS AFFECTED BY SOIL SALINITY, TEMPERATURE, SOIL VARIABILITY AND INTER-SENSOR VARIABILITY THAN OTHER METHODS.

ADVANTAGES	LIMITATIONS
• HIGHLY ACCURATE ACROSS DIFFERENT SOIL TEXTURES AND SALINITY LEVELS • SIMULTANEOUS MEASUREMENT OF MOISTURE, SALINITY, AND TEMPERATURE • STABLE AND CONSISTENT PERFORMANCE WITHOUT REQUIRING SOIL-SPECIFIC CALIBRATION	• MORE EXPENSIVE THAN CAPACITANCE-BASED SENSORS • REQUIRES SPECIALIZED INTERPRETATION OF DIELECTRIC DATA • SLIGHTLY LONGER RESPONSE TIME COMPARED TO CAPACITANCE METHODS

7. "LOGSDON, S. D., ET AL. "HYDRA PROBE AND TWELVE-WIRE PROBE COMPARISONS IN FLUIDS AND SOIL CORES." SOIL SCIENCE SOCIETY OF AMERICA JOURNAL 74.1 (2010): 5-12.

MEASUREMENT PRINCIPLES: DIELECTRIC PERMITTIVITY



SENSOR	ABBREVIATION	MANUFACTURER	TYPE	F (MHZ)	RODS' LENGTH
THETAPROBE SOIL MOISTURE SENSOR	ML3	DELTA-T	J	100	60 MM
HYDRAPROBE SOIL MOISTURE SENSOR	HYDRAPROBE	STEVENS	J	50	57 MM
TDR150/350 SOIL MOISTURE METER	TDR 150/350	SPECTRUM TECH.	TDR	N/A	38 MM 76 MM 120 MM 200 MM
TEROS12 SOIL MOISTURE	TEROS12	METER GROUP	C	70	55 MM
HYDRA100 SCOUT	HYDRA100	SOIL SCOUT	C	N/A	N/A
SGL TURDPOD	TURFPOD	SGL	N/A	N/A	76 MM
TORO TURFGUARD	TURFGUARD	TORO	C	50	64 MM

INFLUENCE VOLUME OF MEASUREMENT



THE INFLUENCE VOLUME OF A SOIL MOISTURE SENSOR REFERS TO THE PORTION OF SOIL FROM WHICH THE SENSOR COLLECTS SIGNALS AND GENERATES A READING. THIS PARAMETER IS CRUCIAL BECAUSE IT DETERMINES THE REPRESENTATIVENESS OF THE COLLECTED DATA: A LARGER INFLUENCE VOLUME PROVIDES AN AVERAGED ESTIMATE OVER A BROADER SOIL AREA, WHILE A SMALLER INFLUENCE VOLUME ALLOWS FOR DETAILED ANALYSIS OF SPECIFIC LAYERS.

ML3 - Thetaprobe
Rod: 60 mm



TDR 150
Rod: 76 mm



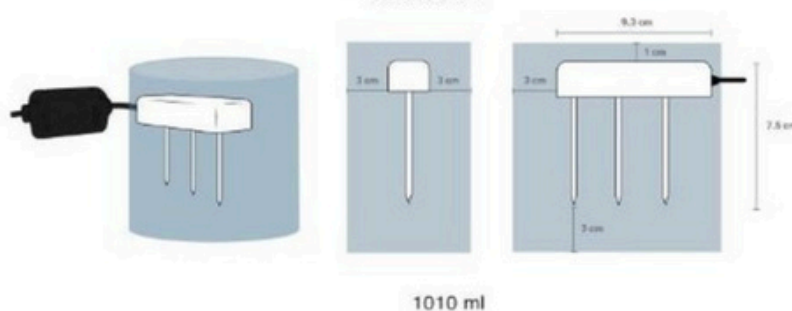
Hydra Probe
Rod: 56 mm



TDR 150
Rod: 38 mm



Teros 12
Rod: 55 mm



INFLUENCE VOLUME OF MEASUREMENT



THE IMAGE MAKES IT PARTICULARLY INTUITIVE TO UNDERSTAND WHY COMPARING DIFFERENT SOIL MOISTURE PROBES AND EXPECTING IDENTICAL READINGS CAN BE CHALLENGING. BEYOND THE DIFFERENCES IN MEASUREMENT TECHNOLOGY, THE VOLUME OF SOIL ANALYZED PLAYS A CRUCIAL ROLE IN THE ACCURACY AND CONSISTENCY OF THE MEASUREMENT ITSELF. FURTHERMORE, AN EXPERIMENT PUBLISHED BY ROMAIN GIRAUD (2020)⁽⁸⁾ ILLUSTRATES THIS POINT EFFECTIVELY. THE STUDY TESTED THREE DIFFERENT PROBES ON A SUBSTRATE COMPOSED OF 50% MOIST SOIL AND 50% DRY SAND. THE EXPERIMENT WAS CONDUCTED TWICE, ALTERNATING THE POSITION OF THE WET SOIL AND DRY SAND BETWEEN THE UPPER AND LOWER LAYERS.

THE RESULTS REVEALED THAT THE INFLUENCE OF THE WET SOIL ON THE MEASUREMENT DIMINISHES NON-LINEARLY AS THE LENGTH OF THE PROBE INSERTED INTO THE GROUND DECREASES. THIS SUGGESTS THAT MOST OF THE SENSOR'S SIGNAL IS PRIMARILY AFFECTED BY THE SOIL VOLUME CLOSEST TO THE SENSOR'S PINS. IN OTHER WORDS, SENSORS TEND TO GIVE MORE WEIGHT TO THE SOIL IMMEDIATELY SURROUNDING THE ELECTRODES, AT LEAST ACCORDING TO THIS SMALL-SCALE EXPERIMENT. THIS FINDING HAS PRACTICAL IMPLICATIONS: IF THE SURFACE LAYER OF TURF IS TOO DRY, BUT THERE IS SUFFICIENT MOISTURE AROUND THE SENSOR'S PINS, THE READING MAY BE SKEWED, UNDERESTIMATING THE ACTUAL LEVEL OF DROUGHT STRESS.

ULTIMATELY, THIS FURTHER REINFORCES THE IDEA THAT COMPARING DIFFERENT PROBES IS HIGHLY COMPLEX, AS EACH SENSOR INTERACTS DIFFERENTLY WITH ITS SURROUNDING SOIL VOLUME, LEADING TO VARIATIONS IN MEASUREMENT OUTCOMES.

8. [HTTPS://CLINIQUEDUGAZON.FR/INDEX.PHP/2020/09/10/ILLUSTRATION-DU-VOLUME-D'INFLUENCE-DES-SONDES-D'UMIDITE-EXEMPLE-AVEC-LA-TDR150/](https://cliniquedugazon.fr/index.php/2020/09/10/illustration-du-volume-d'influence-des-sondes-d'humidite-exemple-avec-la-tdr150/)

INFLUENCE OF SOIL MOISTURE SENSOR ORIENTATION



THE DISCREPANCY IN MOISTURE READINGS BETWEEN HAND-HELD SENSORS AND IN-GROUND SENSORS IS THEIR PLACEMENT AND METHOD OF MEASUREMENT. THE PRIMARY REASON FOR THE VARIATION IN READINGS BETWEEN THESE SENSOR TYPES LIES IN THE DIFFERENCES IN SOIL PROPERTIES AT DIFFERENT DEPTHS AND THE FUNDAMENTAL WAY THESE SENSORS OPERATE.

SOIL PROFILE VARIABILITY

SOIL COMPOSITION CHANGES SIGNIFICANTLY FROM THE SURFACE TO DEEPER LAYERS. THE TOP LAYER, WHERE HAND-HELD SENSORS ARE INSERTED, TYPICALLY CONTAINS HIGHER CONCENTRATIONS OF ORGANIC MATTER, WHICH HAS A GREATER CAPACITY TO RETAIN WATER. ORGANIC MATERIAL INFLUENCES SOIL STRUCTURE, INCREASING ITS WATER-HOLDING CAPACITY AND ALTERING THE DIELECTRIC PROPERTIES THAT SENSORS USE TO ESTIMATE VOLUMETRIC WATER CONTENT (VWC).

IN CONTRAST, IN-GROUND SENSORS ARE INSTALLED AT SPECIFIC DEPTHS WHERE ORGANIC MATTER CONTENT IS LOWER. THESE DEEPER LAYERS GENERALLY CONSIST OF MORE MINERAL SOIL COMPONENTS (SAND, SILT, CLAY), WHICH HOLD WATER DIFFERENTLY THAN THE ORGANIC-RICH TOPSOIL (9). BECAUSE HAND-HELD SENSORS MEASURE MOISTURE NEAR THE SURFACE WHILE IN-GROUND SENSORS MEASURE DEEPER LAYERS, IT IS NATURAL FOR THEM TO PROVIDE DIFFERENT MOISTURE READINGS.

9. BEARD, J. B. "TURFGRASS: SCIENCE AND CULTURE." (1973).

INFLUENCE OF SOIL MOISTURE SENSOR ORIENTATION



ADDITIONALLY, SOIL COMPACTION AND LAYERING AFFECT MOISTURE RETENTION AT VARIOUS DEPTHS. IF A COMPACTED LAYER EXISTS BELOW THE SURFACE, IT CAN IMPEDE WATER INFILTRATION, LEADING TO MOISTURE ACCUMULATION NEAR THE SURFACE (WHERE HAND-HELD METERS MEASURE), WHILE DEEPER LAYERS MIGHT BE RELATIVELY DRIER. (10) THEREFORE, EVEN WHEN USING THE SAME SENSOR, THE ACQUIRED DATA WILL DIFFER BECAUSE THE MEASURED SAMPLE VARIES.

MEASUREMENT METHODOLOGY

HAND-HELD SENSORS:

THESE SENSORS REQUIRE MANUAL INSERTION INTO THE SOIL, MEANING THAT EACH READING REPRESENTS A SINGLE POINT IN TIME AND ONE SPECIFIC LOCATION IN THE SOIL PROFILE. THE ADVANTAGE OF THIS APPROACH IS THAT MULTIPLE READINGS ACROSS DIFFERENT AREAS CAN ASSESS THE SPATIAL VARIABILITY OF SOIL MOISTURE.

- CAN BE MOVED EASILY TO DIFFERENT SPOTS FOR COMPARATIVE ANALYSIS
- DETECTS IRRIGATION INEFFICIENCIES, SUCH AS UNEVEN COVERAGE, CLOGGED NOZZLES, OR IMPROPER SPRINKLER HEAD PLACEMENT
- PROVIDES AN INSTANTANEOUS SNAPSHOT OF SOIL MOISTURE AT A GIVEN MOMENT

10. CHRISTIANS, NICK E., AARON J. PATTON, AND QUINCY D. LAW. FUNDAMENTALS OF TURFGRASS MANAGEMENT. JOHN WILEY & SONS, 2016.

INFLUENCE OF SOIL MOISTURE SENSOR ORIENTATION



IN-GROUND SENSORS:

THESE SENSORS ARE PERMANENTLY INSTALLED AT A FIXED DEPTH AND CONTINUOUSLY MONITOR SOIL MOISTURE OVER TIME. THIS ALLOWS FOR TRACKING TRENDS AND MOISTURE FLUCTUATIONS, PROVIDING HISTORICAL DATA THAT CAN PREDICT WHEN IRRIGATION IS NEEDED.

- EXCELLENT FOR MONITORING LONG-TERM MOISTURE TRENDS
- OFFERS PREDICTIVE IRRIGATION SCHEDULING BASED ON DATA TRENDS
- LESS EFFECTIVE FOR ASSESSING SPATIAL VARIABILITY, AS THEY REMAIN IN ONE LOCATION

CONCLUSION

COMPARING SENSOR READINGS, EVEN ON THE SAME TYPE OF SOIL, PRESENTS CHALLENGES AND MAY LEAD TO INCONSISTENCIES IN IRRIGATION CONTROL, AS VARIATIONS BETWEEN PROBES CAN BE SIGNIFICANT.

SIMILARLY, MOISTURE MEASUREMENTS TAKEN IN SOILS WITH DIFFERENT PHYSICAL PROPERTIES—SUCH AS PARTICLE SIZE, BULK DENSITY, AND ORGANIC MATTER CONTENT—CAN YIELD INCONSISTENT RESULTS WHEN USING DIFFERENT SENSOR MODELS. EVEN WHEN USING THE SAME MODEL, DISCREPANCIES MAY STILL OCCUR, THOUGH TO A LESSER DEGREE.

TO ENSURE RELIABLE MOISTURE MONITORING ON SPORTS FIELDS AND GOLF COURSES, IT IS ADVISABLE TO USE A SINGLE TYPE OF SENSOR. ADDITIONALLY, FAMILIARIZING ONESELF WITH THE CHARACTERISTIC MOISTURE LEVELS OF THE SPECIFIC SUBSTRATE USING THAT SENSOR WILL IMPROVE ACCURACY AND CONSISTENCY IN IRRIGATION MANAGEMENT.





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