Performance of a New Capacitance Soil Moisture Probe in a Sandy Soil

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Introduction:

- ECH$_2$O EC-5 and TE-5 are new capacitance type soil water probes introduced by Decagon Devices, Pullman, WA
- These probes have been modified to minimize sensitivity to fertilizer induced salinity, soil temperature variations, and electrical interference in the field
- The operational frequency is the main difference between the EC-20 and EC-5 probes. The EC-20 operates at ~ 10 MHz measurement frequency and the EC-5 and TE-5 at 70 MHz
- Higher frequencies can lower the probe sensitivity to salinity and temperature fluctuations, but increasing production cost limits frequency change
- The price of the new probes which operate at a higher frequency is comparatively low ($60 – 100 per probe)
- The central Florida ridge area has sandy soils with >95% sand and <3% clay.
- The water holding capacity is ~8% and the wilting point ~ 2% by volume. Therefore, the available water is 0.06 m³ m⁻³ *(California citrus soils can hold ~3 times more water than Florida soils)*
- Monitoring soil water within this range using a sensor is a challenge
- An earlier version of ECH$_2$O probes called EC 20 could not perform optimally in this sandy soil.

Advantages of ECH2O probes:
- Relatively low cost
- Easy to install
- Minimal maintenance requirement
- Can be read continuously with data loggers
- The configuration of these probes make them ideal for testing in the laboratory and field

Objectives

New probes were evaluated for the following properties and where possible, compared the with already tested EC-20 probes:

1) Probe to probe signal variability and performance during calibration
2) Response to fertilizer induced salinity
3) Soil volume sampled by the probes
4) Sensitivity to pockets of air or dry soil
5) Response to compaction (bulk density changes)
6) Response to changes in soil temperature
7) Sensor performance after installation in the field

Methods

Tests were conducted in the laboratory and in the field

1) Laboratory:
- Test 1: Probe response (*"raw count"*) in air and water and in soil within 0.02-0.12 m³ m⁻³ θv range (Calibration) using 12 individual EC-5 probes.
- Test 2: Probe response to salinity using a soil column (Fig. 1)
- Test 3: Sampling soil volume (and tests 4 through 7) using a plastic box (Fig. 2)
- Test 4: Probe response to air-dry soil lens trapped close to sensor surface
- Test 5: Probe response to air pockets close to sensor surface
- Test 6: Probe response to bulk density changes
- Test 7: Probe response to temperature fluctuations

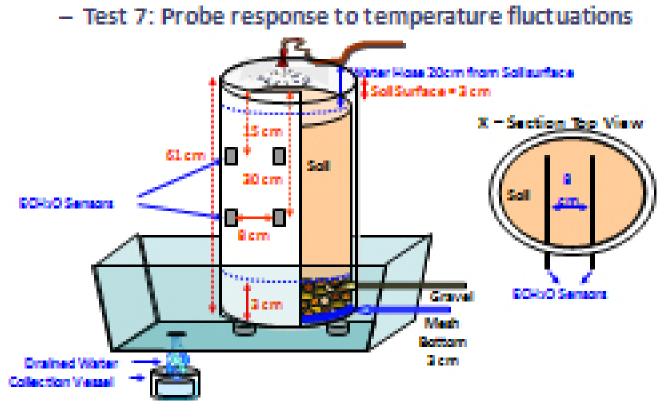


Fig. 1: Column setup to evaluate probe response to induced salinity during fertigation

- Drier and wetter soil were separated during packing using plastic slides that were removed before sensor measurement
- Packing to different bulk densities was done using a linear scale along the height of the plastic box
- Plastic box, soil, sensor and the datalogger setup was kept inside a temperature controlled chamber during the temperature test

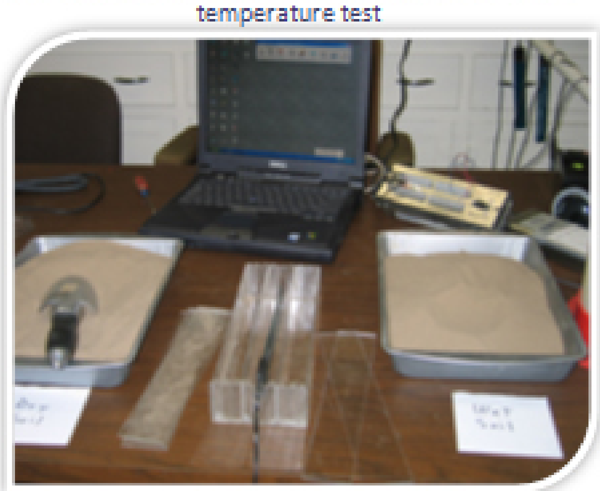


Fig. 2: Plastic box, sensor, datalogger & computer setup

Field Testing

The validity of the laboratory calibration and probe performance after installation was tested in the field.

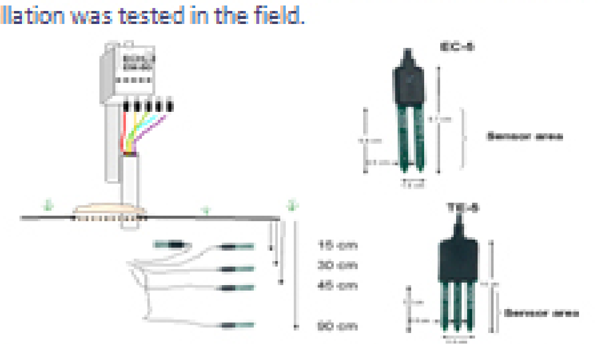
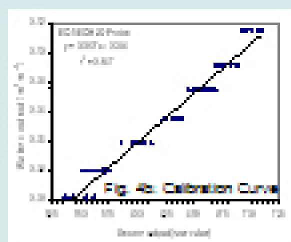


Fig. 3: EC-5 & TE-5 probes and datalogger setup in the field

Objective 1: Probe to probe signal variability



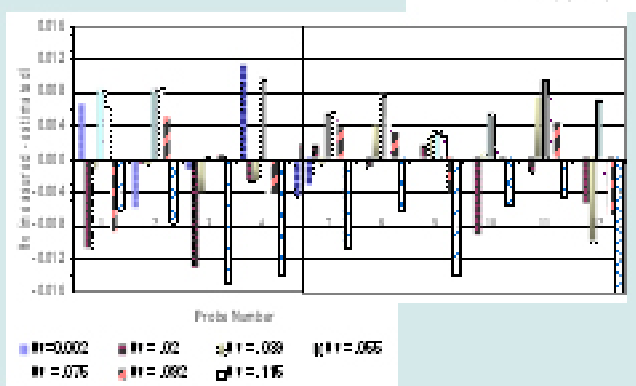


Fig. 4a: Differences in estimated θv as compared to actual θv by each individual probe

- Output variations from individual sensors can significantly affect the estimated θv when these sensors are used to operate within a narrow soil water range (0.02 and 0.08 m³ m⁻³ θv)
- Fig. 4a indicates measured minus estimated θvfor each individual probe using the calibration equation presented in Fig. 4b
- The maximum θv variation from different probes over the range of different θv values tested is ±0.016 m³ m⁻³. This is about 26% of the available water in this sandy soil
- Further, Fig. 5a indicates clearly that the variation displayed by each probe does not indicate a pattern (trend) but varied randomly over different θv points
- Probe to probe variation is more influenced by external factors than inherent manufacturing differences

Objective 2: Response to fertilizer induced salinity

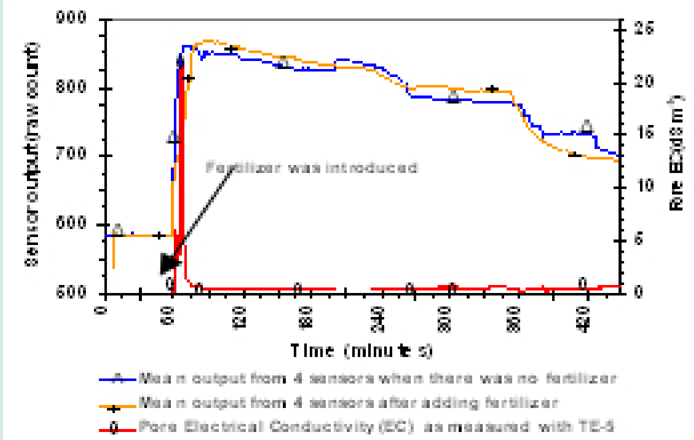


Fig. 5: Sensor output over time when irrigated with and without fertilizer and the change in electrical conductivity due to fertilizer

- In the soil column, fertilizer did not affect probe output
- The maximum sensor output when irrigated with non-saline tap water was 860
- After injecting fertilizer, the maximum output from sensors was 861 (Fig. 5)
- Fig. 5 indicates that the salinity level from fertilizer increased from <1 to an equivalent electrical conductivity of 21 dS m⁻¹
- This is equivalent to ~14,000 ppm of salt concentration (1 dS m⁻¹ is equivalent to approximately 700 ppm salt concentration; Hanlon et al., 1993)
- Test results showed that the EC-5 sensors are not affected by salt over the range of salinity tested

Objective 3: Soil volume sampled by the probe

- EC-5 probes started to detect water when the wet soil was ~1.0 cm away from the probe surface
- Therefore, the sampling soil volume amounts to about 15 cm³ and is smaller compared to the volume sampled by EC-20 probes (~128 cm³; Bandaranayake et al., 2007)

Objective 4: Sensitivity to pockets of air or dry soil

- There was no sensor response to 0.06 m³ m⁻³ θv soil for 35 minutes when a 0.3 cm air-dry soil layer was present between the wet soil and the sensor surface
- This is evidence that a thin very dry soil lens (~0.01 θv) can disrupt the sensor sensitivity to wetting soil
- Such air-dry soil lens can develop close to the sensor surface in this sandy soil

Table 1: EC-5 ECH$_2$O probe performance laboratory tests: The effect of size and number of large pores (macropores) on sensor response.

Core Diameter cm	Number of cores	Core Volume	†Core Volume Ratio(%)	Mean sensor Output	Estimated θv	θv Difference ‡ Before-After
0.71	2	3.64	17	625	0.055	0.000
0.95	2	6.46	30	640	0.065	-0.010
0.71	4	7.29	34	622	0.053	+0.002
0.95	4	12.91	60	631	0.059	-.004

†Percentage of sampling volume; ‡ estimated θv before introducing cores minus after

- Larger pores (<0.95-cm diameter) close to the sensor surface with a total core volume of 60% of sampling volume did not change the probe reading in amounts to affect θv estimation

Objective 5: Sensor response to compaction

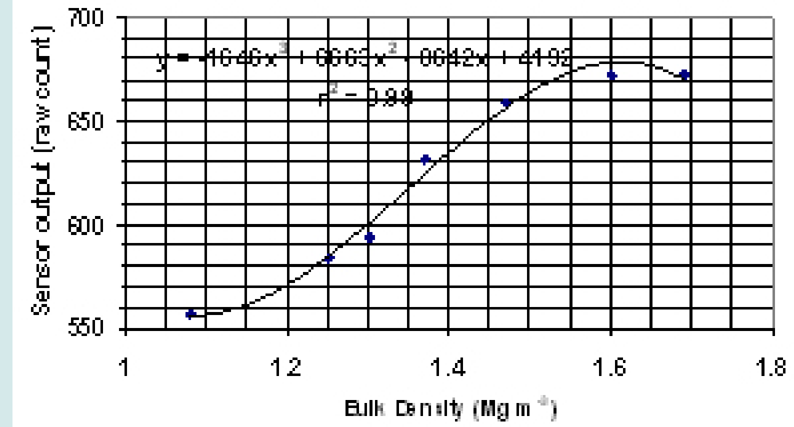


Fig. 6: Sensor response to varying compaction (Bulk Density)

- Probe output increases with increasing bulk density (compaction) until it reaches a maximum (Fig. 6)
- The response rate is very high when bulk density is between 1.2 & 1.6 Mg m⁻³ and less when soil is very loose or very compacted
- Therefore, it is important to pack the soil to the correct bulk density during probe installation

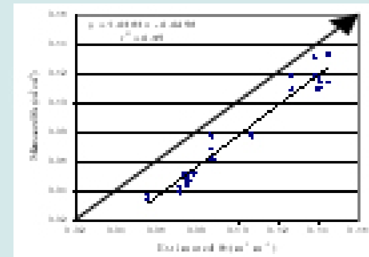


Fig. 7: Measured θv in field vs estimated θv using laboratory calibration

- When gravimetrically measured field θv was compared with laboratory calibrated θv (Fig. 4b), a positive shift occurred i.e. estimated θv was higher than the actual field θv (Fig. 7)
- If bulk density during calibration is different from that of field, θv can be over- or under- estimated
- The average bulk density in the field was measured at 1.65 and the average bulk density during laboratory calibration was 1.58
- Probe output is higher when the field bulk density is higher. When output is higher, the estimated θv is also higher (overestimation).

Objective 6: Response to soil temperature changes

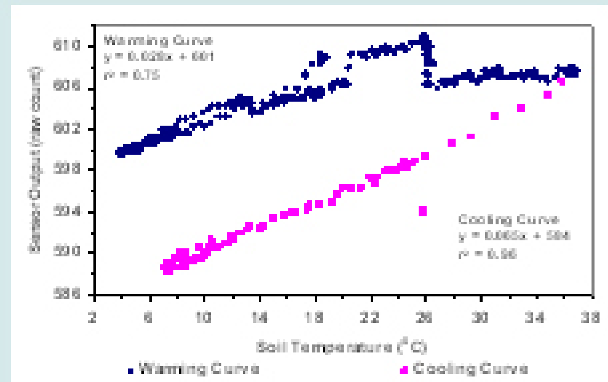


Fig. 8: Sensor response to changing temperature

- Response of EC-5 probes to soil temperature changes is negligible compared to that of EC- 20 probes. When temperature was changed gradually from 3 to ~38°C, probe output increased from 600 to about 606 (Fig. 8)

Objective 7: Sensor performance in the field

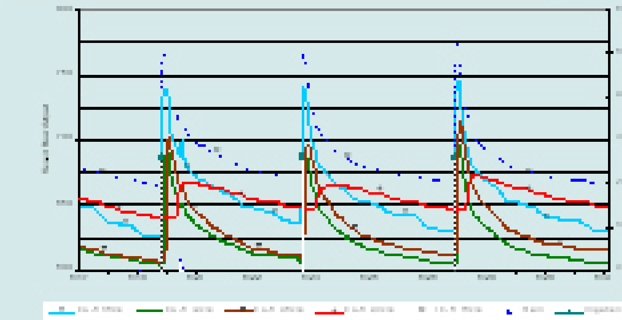


Fig. 9: Response pattern of probes in the field to 3 consecutive irrigation events and a light rainfall event on 6/19

- EC-5 compared to EC-20 probes are more stable in the field over time
- The output fluctuations from EC-5 and TE-5 at 15–cm depth are higher than at other depths. θv is depleted from soil by evaporation and root uptake *(The TE-5 probe is similar to EC-5 with the exception that it produces a higher output to θv changes, and estimates soil temperature and salinity simultaneously)*
- EC-5 probes at 30 and 45–cm depths fluctuate less intensely compared to that at 15-cm depth. θv is depleted from soil by root uptake only
- Output fluctuations from EC-5 at 90-cm depth is very low indicating that θv does not fluctuate sharply at that depth
- This suggests that a minimal amount of irrigation water reaches the 90-cm depth

Summary

- Probe to probe output variance can be a problem in this sandy soil when the θv range monitored is very narrow
- Laboratory calibration also indicated that the bulk density to which the soil is packed can greatly influence calibration results
- Variance in probe output is probably related to differences in bulk density and other unknown factors
- The EC-5 probes did not indicate sensitivity to changing salinity or temperature within the range tested
- They also did not respond to large (≤ 1.0 cm) pore channels that could develop from dead roots or burrowing soil fauna (e.g. earth worms).
- EC-5 compared to EC-20 was more stable in the field and continued to perform well during one year of testing
- Output from this EC-5 probe did not fluctuate noticeably in the field and was not disrupted by electrical interference
- Despite the smaller sampling volume compared to EC-20 the response to soil water changes due to irrigation or rainfall was clear

Reference

Bandaranayake, W.M., L.R. Parsons, M.S. Borhan, and J.D. Holeton. 2007. Performance of a capacitance-type soil water probe in a well-drained sandy soil. SSSAJ 71(3):993-1002

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