Evaluation/pilot-test of a low-cost monitoring methodology to represent plot-scale soil moisture for wheat cropping in India

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The Problem

- Lack of data-based agricultural/irrigation management in smallholdings in developing countries with high dependence on agriculture.
- High cost of monitoring instruments and realtime transmission, difficulty in safe outdoor field monitoring.

Objectives

- To compare the performance of medium, low and very low-cost soil moisture instruments in measuring plot scale representative conditions: Wheat season January – April 2018, Kanpur (India).
- To suggest a cost-effective methodology for plot-scale soil moisture representation for irrigation scheduling.

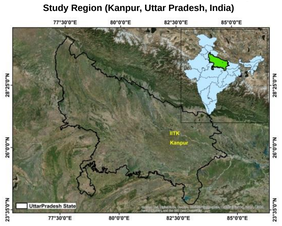
Experiments

1. Continuous plot-scale monitoring of soil moisture: spatially less dense, temporally fine (15 minutes' frequency), varied costs – medium, low and very-low cost soil moisture instruments.
   ⇒To understand development of soil moisture through the cropping season.
2. Grid-based, manual, time discreet ('snapshot') measurement: spatially dense (grid size 0.5m x 0.5m, 750 points), high cost accurate soil moisture instrument.
   ⇒ To compare maps combining dense point measurement data and continuous data.
3. Simultaneous spatially dense (grid size: 1m x 1m) point measurement of high-cost and low-cost soil moisture sensors.
   ⇒ To check the usage of low cost instead of high cost soil moisture instruments to generate interpolation data, to further reduce cost.

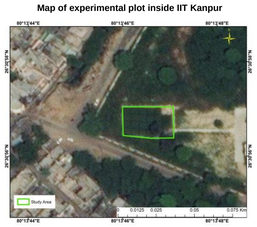
Study Area

- Experimental plot in IIT Kanpur (Kanpur, India)
- Plot description: size = 20m x 30m (~0.06ha) similar/smaller than typical smallholdings.
- Agricultural description: Wheat variety - K 7903 Halna (late sown variety), flood irrigation in check basins, fertilizer application (DAP, urea) as per local practices.

Study Region (Kanpur, Uttar Pradesh, India)



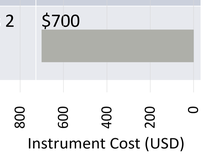
Map of experimental plot inside IIT Kanpur



Date: 24.01.2018 (Day 20 after sowing)

Date: 18.03.2018 (Day 80 after sowing)

Term used	Instrument description	Relevance in Study	Cost per instrument (USD)
Medium cost	***UGT* SMT100 (German make)** Combination of TDR and FDR	Experiments 1 and 2	$175
Low cost	***Spectrum* SM100 (US Make)** Capacitance based	Experiments 1, 2 and 3	$90
Very-low cost	**Generic Soil moisture sensor (Chinese make)** Resistive	Experiments 1 and 2	$2
High cost	***Delta-T* ThetaProbe (UK Make)** TDR based	Experiments 2 and 3	$700



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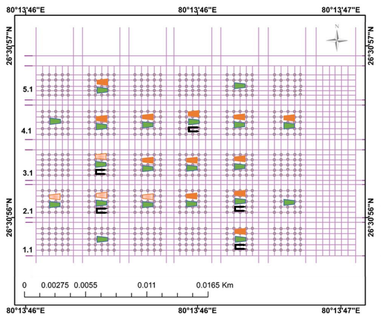
Methodology



Medium-cost SM instruments:
UGT SMT 100 (German made)
FDR-TDR combination
Data logger (non-realtime)

Low-cost instruments:
Spectrum SM100 (US Made)
Capacitance type
Data logger (non-realtime)

Interpolation grid (high cost):
Delta-T ThetaProbe (UK Made)
TDR type
Data reader

Low-cost instruments:
Spectrum SM100 (US Made)
Capacitance type
Realtime data transmission
(Kritsnam Technologies)

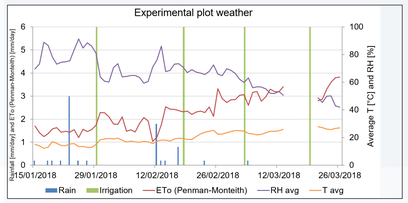
Very low-cost instruments:
Generic Soil Moisture Sensors
(Chinese make)
Resistive
Data logger (non-realtime)

Results

Experiment 1: Univariate Description (continuous measurements)

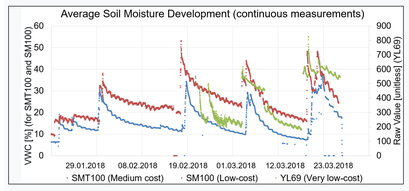
Summary statistics of continuous measurements

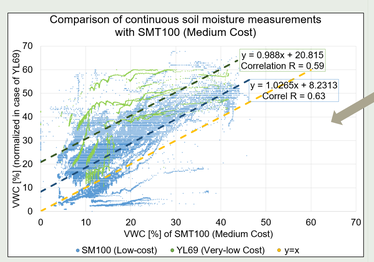
Sensor	Mean [% VWC]	Median [% VWC]	Range (min, max) [% VWC, %VWC]	SD [% VWC]
SMT100 (Med cost) n = 121596	15.39	14.01	(0.00, 48.89)	7.55
SM100 (Low cost) n = 74086	24.20	24.00	(0.00, 67.80)	12.33
YL69 (Very-low cost) n = 29974	31.45 Raw=472	35.52 Raw=534	(10.57, 60.00) Raw=(159, 902)	13.50 Raw=203
Delta-T ThetaProbe (High cost) or SMEC300 (n = 2124)	21.94	21.20	(5.40, 59.90)	6.67

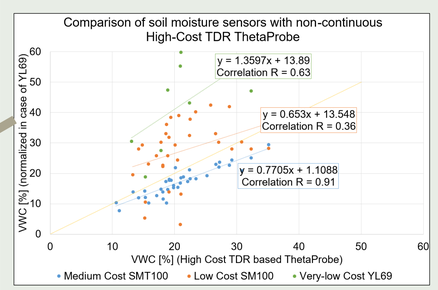


Bivariate Description (continuous and non-continuous measurements)

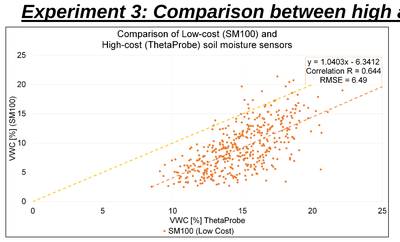
Correlation Coefficient (R) & RMSE	Continuous Measurement			
Continuous Measurement		SMT100 (Medium Cost)	SM100 (Low cost)	YL69 (Very-low cost)
	SMT100 (Medium cost)		**R = 0.63** RMSE=12.87 (n = 69565)	**R = 0.59** RMSE=23.14 (n = 6256)
Non-continuous measurement	ThetaProbe (High-cost)	R = 0.91	R = 0.36	R = 0.63







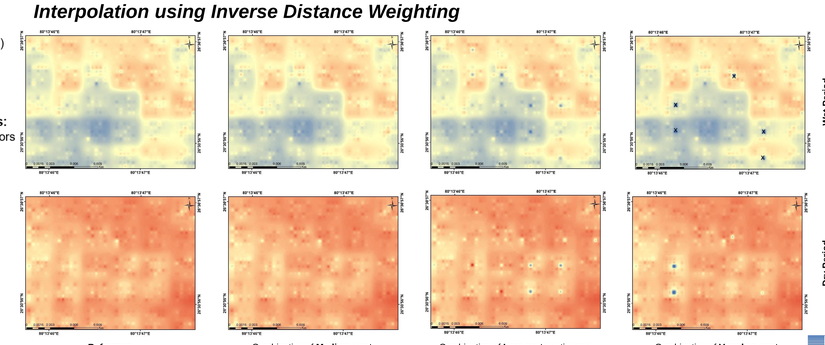
Experiment 3: Comparison between high and low-cost point soil moisture data



Comparing low and high-cost instruments (for interpolation) (n = 871)	Correlation Coefficient (R)	RMSE
	0.64	6.49

Experiment 2: Spatial Description

Interpolation using Inverse Distance Weighting



Reference
Grid-based, manual soil moisture measument (1 High cost ThetaProbe, 0.5x0.5m grid, 750 points)

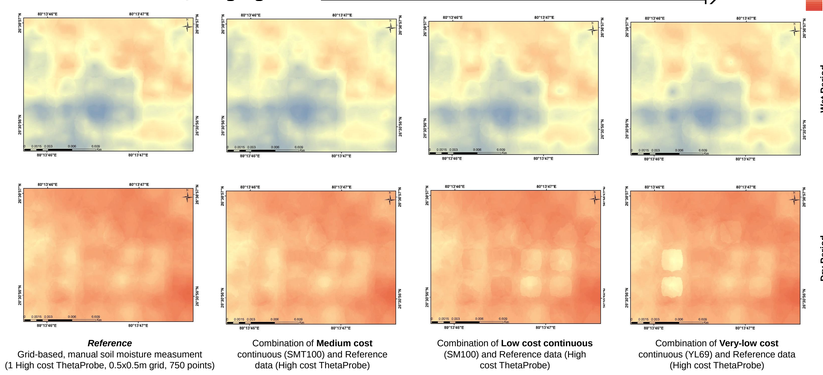
Combination of **Medium cost** continuous (SMT100) and Reference data (High cost ThetaProbe)

Combination of **Low cost** continuous (SM100) and Reference data (High cost ThetaProbe)

Combination of **Very-low cost** continuous (YL69) and Reference data (High cost ThetaProbe)

Interpolation using Kriging

Decreasing cost of continuous measurements



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Combination of **Very-low cost** continuous (YL69) and Reference data (High cost ThetaProbe)

Conclusions

1. Medium, low, and very-low cost instruments are suitable to different extents for continuous measurement to represent plot-scale soil moisture [Expt 1].
2. Medium cost sensors have high agreement with High-cost sensors (R=0.91) thus substantiating their accuracy; very-low cost sensors have similar agreement (R=0.59) to the accurate medium cost sensors as low-cost sensors (R=0.63) [Bivariate Description].
3. There is merit in exploring the combination of calibrated low/very-low cost continuous measurements combined with dense point non-continuous point measurements to represent plot scale soil moisture development [Expt 2].
4. Continuous measurement costs may be reduced by variable frequency of continuous measurement (function of ET, crop water requirement) and reduced spatial density of continuous measurements (future work).
5. Cost of interpolation can be reduced by using a low-cost SM100 instrument instead of the high-cost ThetaProbe after appropriate correction (R = 0.64, RMSE = 6.49) [Expt 3].

Future Work

Extensive calibration and testing (laboratory and field) of low-cost and very low-cost sensors, to increase accuracy and reliability; data collection in different seasons for repeatable results;

References

- Isaaks, E. H., & Srivastava, R. (1989). Applied Geostatistics. New York: Oxford University Press.

Acknowledgements

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