Laboratory calibration of different soil moisture sensors in various soil types

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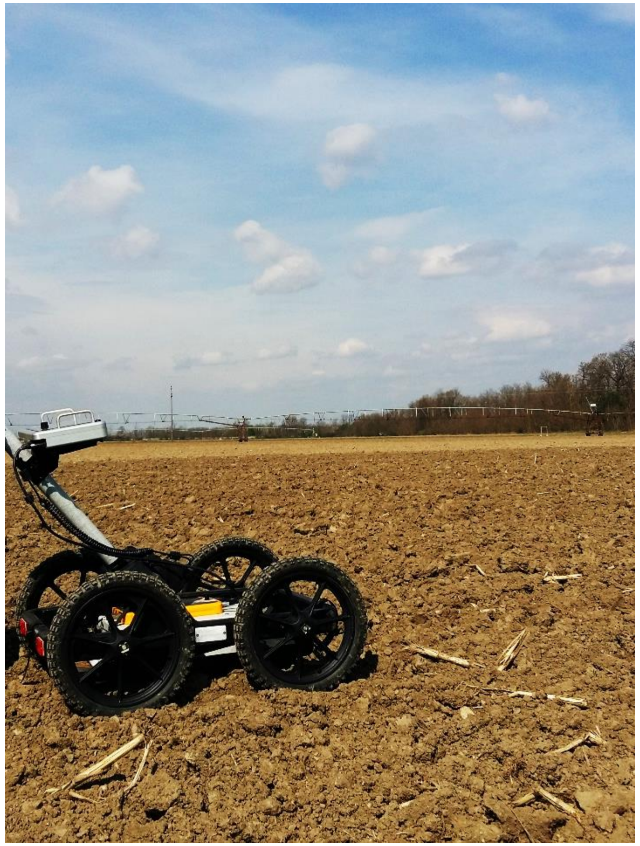
Introduction

- technological innovations enable more sustainable agricultural management
- agricultural practices based on measurements of different soil and plant parameters can decrease the amount of used inputs
- irrigation management based on measurements of soil water content is increasingly used in agriculture



Soil water content measurements

- measurements of soil water content (θ) are most commonly conducted with dielectric sensors
- indirect method which measures relative permittivity ($\mathcal{E}_r$)

  $\mathcal{E}$(water) = 80, $\mathcal{E}$(soil matrix) = 2-5, $\mathcal{E}$(air) = 1

- manufacturer supplied calibration function (converts raw outputs of sensor → θ)

- variable soil characteristics, such as

  <u>soil texture and mineralogy, organic matter content, soil bulk density, EC</u>

  influence measurements with dielectric sensors

- therefore manufacturer's calibration function might not work well in various soil types

Aim of the study

The aim of our study was to evaluate whether there is a need for a soil-specific calibration of dielectric sensors when used in various soil types

We evaluated the performance of three dielectric soil moisture sensors in nine different soil types:

- SM150T (Delta-T Devices Ltd, UK), FD; capacitance: <u>left</u>
- MVZ 100 (Eltratec trade, production and services d.o.o. , SI), supposedly TDR: <u>middle</u>
- TRIME-Pico 32 (IMKO micromodultechnik GmbH, DE), TRIME (Time Domain Reflectometry with Intelligent Micromodule Elements): <u>right</u>

picture source: Delta-T Devices, 2016

picture source: IMKO Micromodultechnik, 2009

Materials and methods

- we conducted a laboratory calibration for an undisturbed soil samples, proposed by (Holzman et al., 2017):

- instead of obtaining an undisturbed soil sample with a cylinder of a known and sensor type suitable volume, due to possible soil variability, we used disturbed and homogenized soil samples, packed to their original bulk density in PVC cylinders
- we saturated soil samples with water
- inserted a sensor in each sample and left it in laboratory to dry on the air
- at certain time intervals we simultaneously obtained sensor's raw output and weighted the whole sample, together with the sensor, for the latter gravimetric determination of θ

- we used 9 soils with variable soil properties:

Table 1: properties of selected soil types

Soil	Sand (%)	Silt (%)	Clay (%)	Texture	ρ_b (g cm^{-3})	Organic matter (%)	EC (dS m^{-1})	CEC (mmolc 100g^{-1})	pH ($CaCl_2$)
TER	5.8	22.4	**71.8**	**clay**	1.22	0.5	0.014	44.44	**4.4**
BFN	21.9	46.7	31.4	clay loam	1.31	4.1	0.092	23.97	7.0
PAN	29.3	40.2	30.5	clay loam	1.32	3.1	0.188	17.91	6.1
DRA	8.1	49.6	**42.3**	silty clay	**1.00**	4.3	0.147	38.49	7.1
EVR	**68.8**	20.3	10.9	sandy loam	1.42	1.9	0.067	6.36	7.5
KAR	37.0	44.3	18.7	loam	**1.70**	0.7	0.093	9.56	7.5
TUR	15.5	51.4	33.1	silt clay loam	1.54	0.7	0.077	19.96	7.0
TUN	43.3	30.2	26.5	loam - clay loam	**1.59**	2.3	0.196	14.67	6.9
SOT				**organic**	**0.45**	**45.9**	0.488	**128.08**	6.3

Experimental design

- 3 dielectric sensor types
- 9 soil types
- 3 repetitions for each soil and sensor type

Results

regression analysis → developed calibration function → for each sensor and soil type → → calculated measurement error (ME)→ → between sensor θ and gravimetric θ

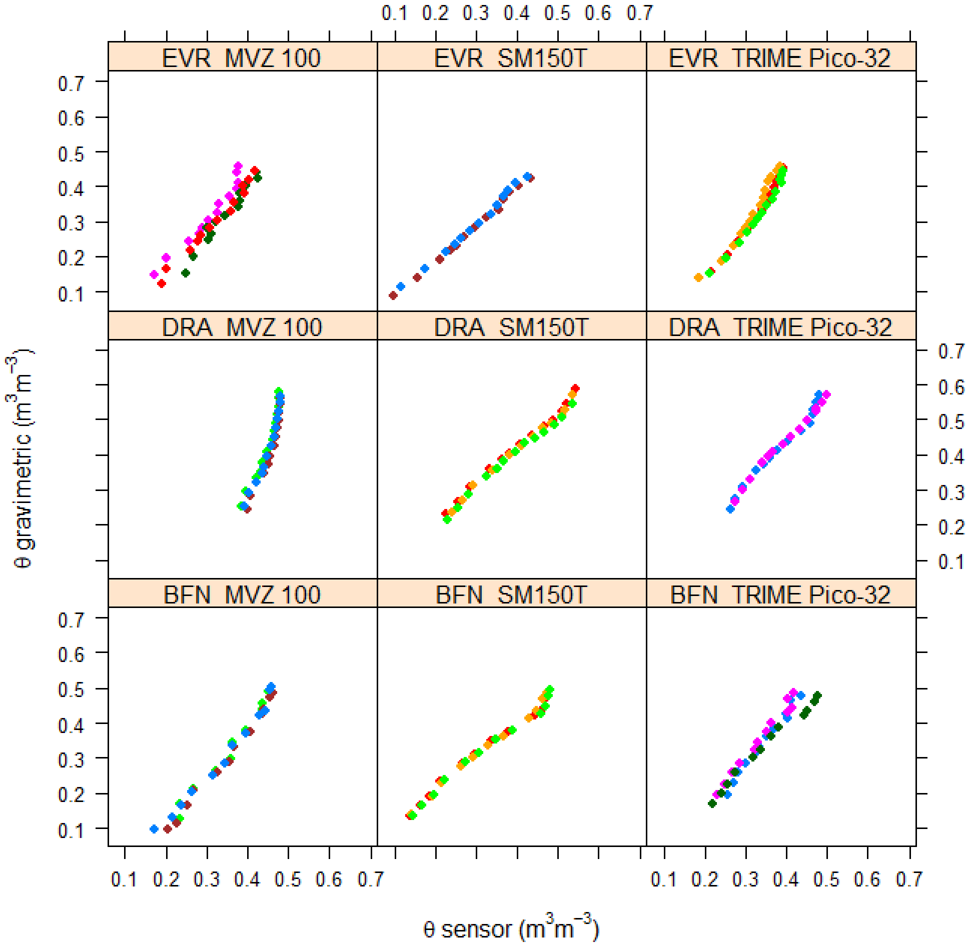


Figure 1: Comparison of soil water content obtained with manufacturer supplied calibration function and gravimetrically determined water content, for soil types EVR, DRA and BFN and sensor types: MVZ 100, Eltratec (left column), SM150T, Delta-T (middle column) and TRIME Pico-32, IMKO (right column)

Table 2: Soil properties

Soil	Clay (%)	Texture	ρ_b (g cm^{-3})	Organic matter (%)	EC (µS cm^{-1})	θ at tension 33 kPa (m^3 m^{-3})
EVR	10.9	sandy loam	1.42	1.9	67	
DRA	42.3	silty clay	1.00	4.3	147	0.44
BFN	31.4	clay loam	1.31	4.1	92	0.40

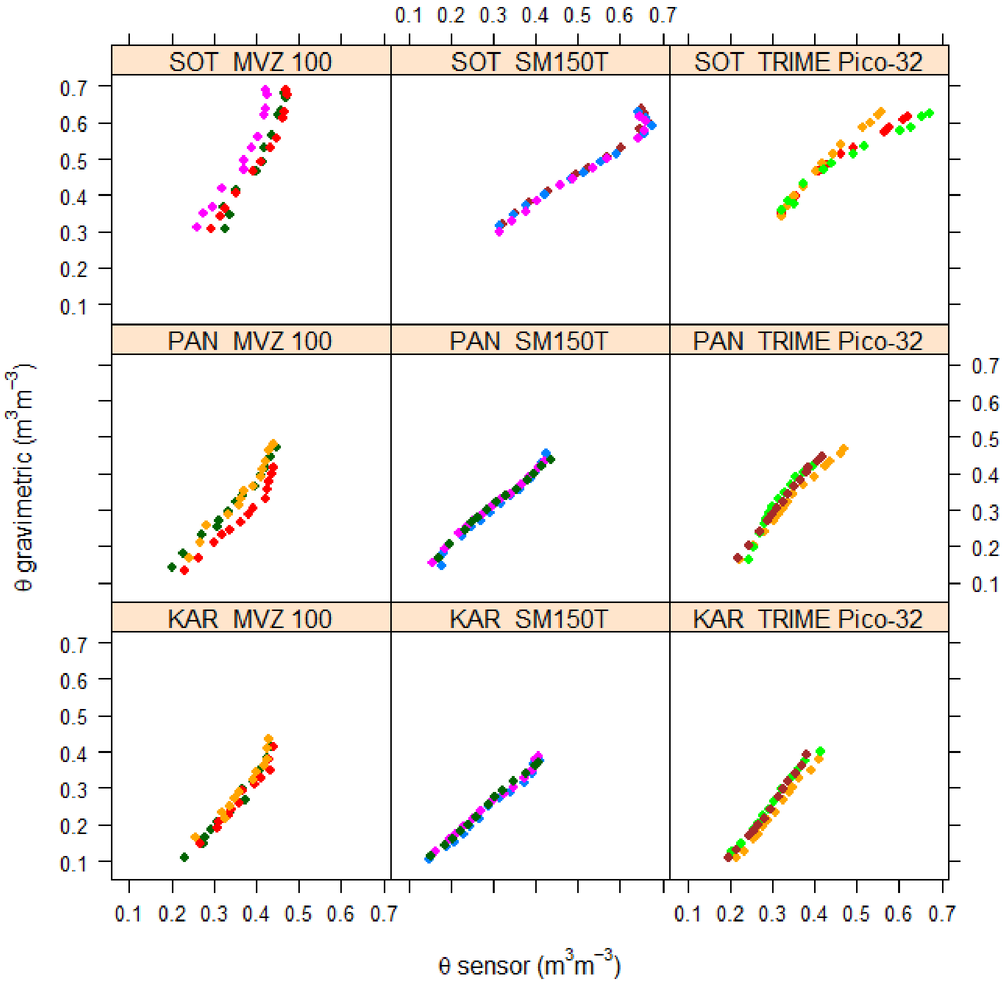


Table 3: Soil properties

Soil	Clay (%)	Texture	ρ_b (g cm^{-3})	Organic matter (%)	EC (µS cm^{-1})	θ at tension 33 kPa (m^3 m^{-3})
SOT		organic	0.45	45.9	488	
PAN	30.5	clay loam	1.32	3.1	188	0.35
KAR	18.7	loam	1.70	0.7	93	0.34

Figure 2: Comparison of soil water content obtained with manufacturer supplied calibration function and gravimetrically determined water content, for soil types SOT, PAN and KAR and sensor types: MVZ 100, Eltratec (left column), SM150T, Delta-T (middle column) and TRIME Pico-32, IMKO (right column)

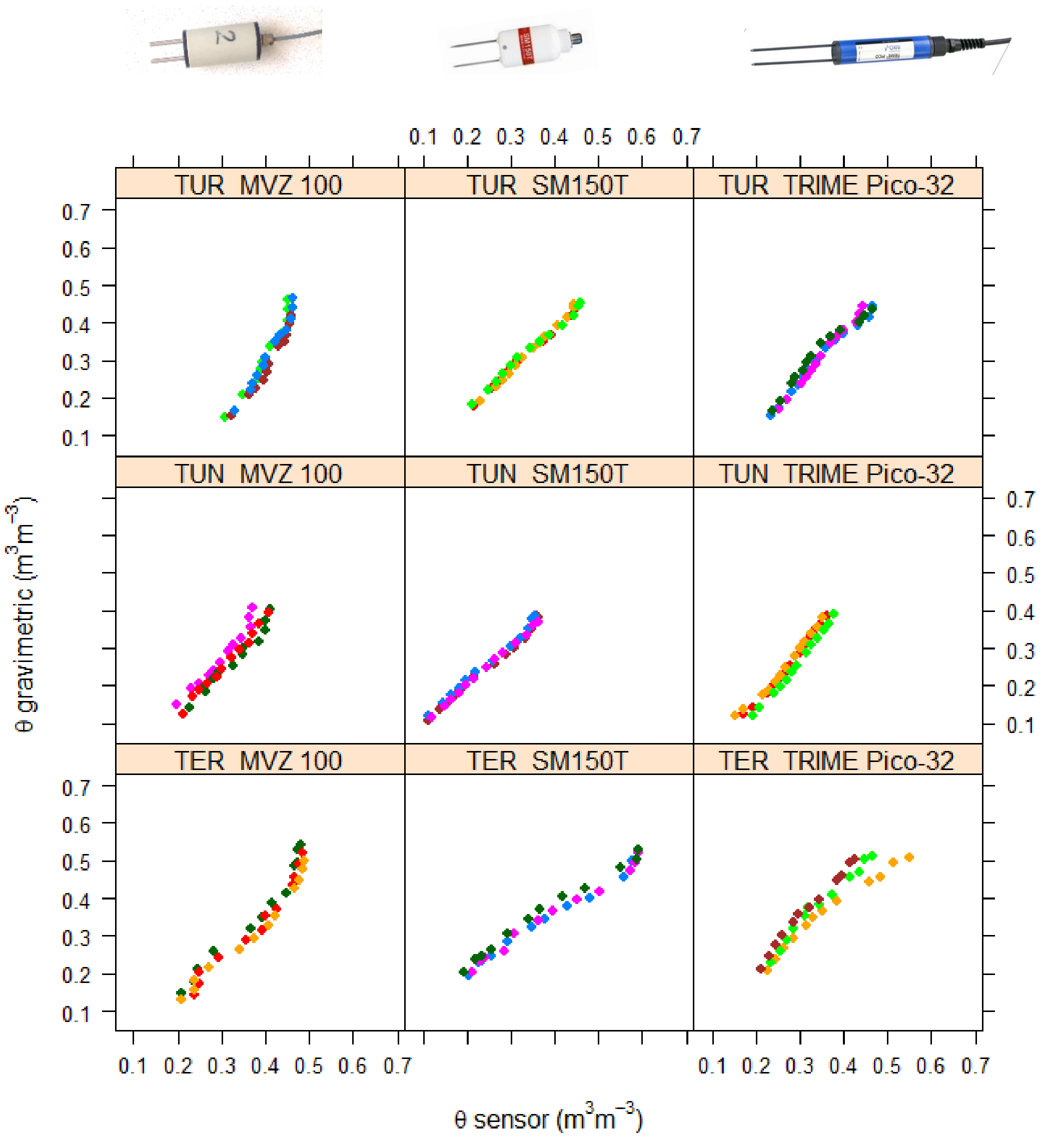
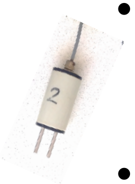


Figure 3: Comparison of soil water content obtained with manufacturer supplied calibration function and gravimetrically determined water content, for soil types TUR, TUN and TER and sensor types: MVZ 100, Eltratec (left column), SM150T, Delta-T (middle column) and TRIME Pico-32, IMKO (right column)

Table 4: Soil properties

Soil	**Clay (%)**	**Texture**	**ρ_b (g cm^{-3})**	**Organic matter (%)**	**EC (µS cm^{-1})**	**θ at tension 33 kPa (m^3 m^{-3})**
TUR	33.1	silt clay loam	1.54	0.7	77	0.49
TUN	26.5	loam – clay loam	1.59	2.3	196	0.33
TER	71.8	clay	1.22	0.5	14	0.53

Conclusions



- <u>MVZ 100 sensors</u>: consistently overestimated θ in drier conditions. In the case of organic soil SOT, sensors consistently underestimated θ

- <u>TRIME Pico-32 sensors</u>: in general relative ME increased with drying of the soils, with an exception of DRA, TER and SOT soil types. Sensor consistently overestimated θ with KAR and TUR soil types. In the case of mineral soil TER and DRA and organic SOT, sensors underestimated the actual water content

- <u>SM150T sensors</u>: relative ME oscillated around zero (soil types: PAN, BFN, DRA, TUN). In TER soil type, obtained values were higher than actual at more saturated soil conditions. We obtained higher values than actual in KAR and TUR soil type at drier conditions
- from all combinations of sensors and soils, only measurements with SM150T were within the manufacturer specified error ($\pm$ 0.03 m^3 m^{-3}) in three soil types: BFN, TUN and EVR. In all other combinations of sensors and soils, soil-specific calibration is required to obtain relevant soil water content data in the field, since incorrect measurements of θ can have a significant negative impact on irrigation management

remark: TRIME Pico-32, were not recalibrated in the calibration set, after being used in the field for several years, as recommended by the manufacturer – since we lacked the necessary equipment.

Thank you!

Calibration protocol:

- Holzman, M., Rivas, R., Carmona, F., & Niclos, R. (2017). A method for soil moisture probes calibration and validation of satellite estimates. Methodsx, 4, 243–249. https://doi.org/10.1016/j.mex.2017.07.004

Picture source:

- Delta-T Devices. (2016). User manual for the SMT150T soil moisture sensor. Delta-T Devices, Cambrige, UK

  https://www.delta-t.co.uk/wp-content/uploads/2017/01/SM150T-user-manual-version-1.0.pdf

- IMKO Micromodultechnik. (2009). Trime - Pico 64/32 Manual. IMKO Micromodultechnik GmbH, Ettlingen, Germany

  https://www.eijkelkamp.com/files/media/Gebruiksaanwijzingen/EN/m1-146503-06epicosensors.pdf