Field calibration of the capacitance soil moisture probes for Brown Sodosol

Belyaeva O[1], Ward G[1], Chen D[1], Suter H[1].

[1] University of Melbourne, Vet and Agri Science, Bld. 184, 30 Flemington Road, Parkville, Victoria, 3052, https://www.unimelb.edu.au, oxana.belyaeva@unimelb.edu.au

Abstract

Knowledge of soil moisture is needed to understand crop water use and improve water-use efficiency: capacitance probes can be used for this. However, often generic calibrations supplied by the manufacturer the probes are used and this can lead to errors. The aim of this study was to estimate the accuracy of using generic calibration relationships for capacitance probes to monitor soil water. A set of 4 probes (0-120 cm depth) were installed at irrigated and non-irrigated pasture sites and calibrated using the traditional core-sampling technique. For the sandy top soil (up to 30 cm), the factory generic calibration overestimated soil moisture with a significant error of 0.05-0.28 m^3/m^3. For deeper clay horizons the error between the generic calibration and actual moisture tended to be larger. This increased error in sub-soils can be associated with changing bulk density and porosity down a profile and, on this soil, also presence of voids and cracks. Using the generic calibration would lead to a significant overestimation of volumetric soil water at the high water content (>0.45 m^3/m^3) and understating at the dry end (<0.17 m^3/m^3). The findings show that a soil specific calibration of the capacitance probes is required for accurate soil moisture measurements.

Key Words

Soil moisture monitoring, capacitance probes, calibration capacitance probes

Introduction

Throughout Australia, management of irrigation is directed to increasing water-use efficiency. For precision irrigation it is important to measure continuously soil water content to determine the need for irrigation. Such management can reduce the cost of production, prevent leaching of fertilizers and limit ground water pollution. Several moisture sensors have become available in the market, providing the opportunity to monitor soil moisture continuously. One popular method is use of capacitance probes. These probes can be used with factory calibration settings, but there are reports that the accuracy of capacitance probe measurements can be improved by developing a calibration equation relevant for each soil type (Fares and Polyakov 2006; Saito 2009). Nemali *et al*. (2007) and Topp *et al*. (1980) showed that soil salinity and electrical conductivity significantly affect performance of capacitance sensors. Malicki *et al*. (1996) showed that soil specific calibration is needed for mineral and organic soils. This paper reports a study to assess the difference in the accuracy of capacitance probes with factory calibration compared with site specific calibration by: (1) performing a field calibration of the capacitance probes at two field sites (irrigated and rainfed dryland); (2) comparing the results from the field and factory calibration.

Methods

Site location, climatic and soil properties

Two research sites (irrigated and dryland) were located at a commercial dairy farm near Warrnambool in south west Victoria. The climate is characterised by hot dry summers and wet mild winters. The experiment was located at a site under long-term (>50 years) pasture dominated by perennial ryegrass (*Lolium perenne*). The soil was a Melanic-Mottled, Subnatric, Brown Sodosol (Australian soil classification). The organic carbon concentration was up to 4.6 % in the top soil layer. Exchangeable sodium percentages and electrical conductivity increased from 2 % to 10.6 % and 0.12 dS/m to 0.18 dS/m respectively down the profile. Soil samples were analysed as described by Ryment and Higginston (1992). *Soil analysis and capacitance probes calibration*

Soil moisture content was monitored continuously with four (two at each site) EnviroPro® capacitance probes (EnviroPro, Australia) connected to MAIT industries dataloggers. The sensors monitored moisture and temperature at 10 cm increments for 80 (two probes) to 120 (two probes) cm depth. Soil samples were obtained using a 1 m corer at four times (April 2017, August 2017, November 2017 and December 2018), to provide a range of water contents for calibration and assessment. On each occasion, two soil samples were taken at each sensor depth close to each probe. Both samples were bulked and analysed in a laboratory for gravimetric water content. In total, 224 samples were collected from both sites. In addition to these samples, soil texture (Table

1) and bulk density were measured using standard protocols (Rayment and Higginson 1992) at 10 cm intervals in the beginning of the experiment.

Table 1. Soil particle size and bulk density for the two investigated sites

Soil depth, cm	EC, dS/m^{-1}	ESP, %	Silt, %	Clay, %	Sand, %	Bulk density, g/cm3	EC dS/m	ESP, %	Silt, %	Clay, %	Sand, %	Bulk density, g/cm3
	Irrigated site						Dry land site					
0-10	0.12	3.5	11.4	4.4	84.2	1.21	0.12	2.0	12.3	6.7	81.0	1.33
10-20	0.09	4.2	12.3	5.5	82.2	1.48	0.10	2.9	10.1	13.2	76.7	1.48
20-30	0.08	3.7	12.6	13.3	74.1	1.77	0.07	5.3	8.8	15.7	75.5	1.54
30-40	0.09	6.3	7.4	30.4	62.2	1.52	0.07	7.1	10.1	27.2	62.7	1.56
40-50	0.13	9.1	6.2	45.2	48.6	1.36	0.08	7.5	5.0	39.3	55.7	1.49
50-60	0.17	10.9	5.0	51.9	43.1	1.31	0.12	8.0	7.6	52.4	40.0	1.52
60-70	0.17	10.6	5.1	62.7	32.2	1.34	0.15	8.1	2.5	57.5	40.0	1.68
70-80	0.18	10.6	0.0	61.8	38.2	1.47	0.17	9.2	6.2	43.9	49.9	1.64

Gravimetric water was converted to volumetric water content actual (VWC_A) using bulk density to create the soil-specific calibration. At the time of soil sampling, water content reading were obtained from the probe (VWC_P). Then VWC_A was plotted against VWC_P values. Actual VWC_A and probe VWC_P readings were plotted and a trendline equation created for each sensor. This equation was applied to the probes VWC_P reading to obtain absolute values for this specific soil type. Each sensor behaved differently and therefore, was assessed individually.

Results and Discussion

VWC_A of all collected samples ranged from 0.22 m^3/m^3 to 0.62 m^3/m^3 at the irrigated site and from 0.88 m^3/m^3 to 0.70 m^3/m^3 at the dry land site. VWC_P varied from 0.20 $m^3/\ m^3$ to 0.77 m^3/m^3 and 0.08 m^3/m^3 to 0.64 m^3/m^3 at the irrigated and dry land sites respectively.

At both sites, the responses of the top three sensors located in the soil layer from 0 to 30 cm was similar. The slope of the regression curve between VWC_A and VWC_P was not significant different from unity (R^2 ranged from 0.79 to 0.99), but it shifted with an intercept different from zero. An example of one regression is shown in Figure 1a.

However, for these depths (0 cm to 30 cm), volumetric water content estimated by the probes (default calibration) were generally higher than the soil moisture content estimated by the core-sampling method (Figure 1b).

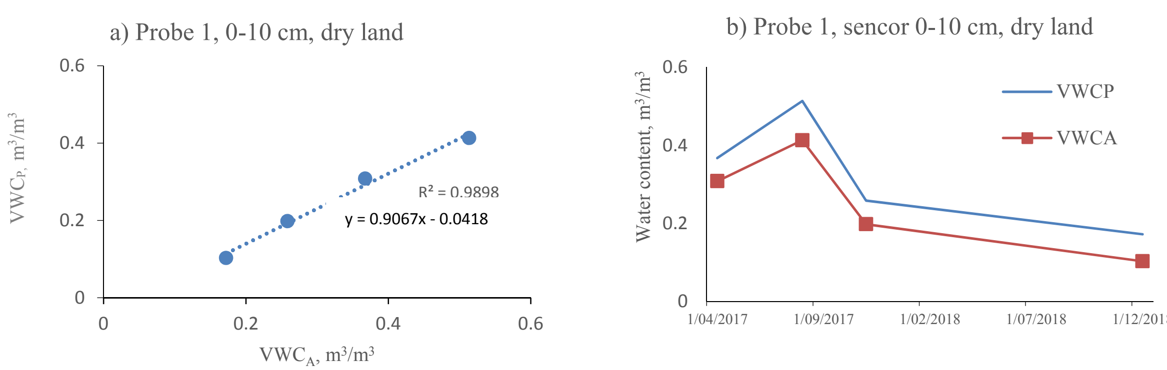

Figure 1. (a) The example of the soil specific calibration and (b) soil water content estimated by the default (VWC_P) and the soil core (VWC_A) calibration (sensor 0-10 cm, the probe 1, the dry land site)

On average, the overestimation error was 0.21 $m^3/\ m^3$ for the depth 0-30 cm for both irrigated and dry land sites. This finding is in agreement with data obtained by Hanson and Peters (2000) on a silt-loamy soil. Robinson et al. (2008) described overestimations of water content by generic calibrated probes.

At depth the relationship between VWC_A and VWC_P exhibit higher variability. A regression analysis of actual water content versus capacitance probe output returned an R^2 of <67 at depths below 30 cm. The lower accuracy compared with surface soils is most likely due to changing soil texture from loamy sand (0 cm-30 cm) to clay (30 cm-80 cm). In clay soils a greater potential exists for air gaps occurring around the probes due to the natural process of swelling and shrinking in response to changing soil moisture during a year. Exposing probes to air would contribute to the higher moisture reading variability estimated by probes.

Because of the significant amount of scatter between VWC_A and VWC_P below 30 cm, combined data from both sites from 0 cm to 30 cm were used for comparison between the factory calibrated moisture and the soil sampling moisture (four probes over 4 sample times at 31 sample points). The slope of this linear regression was substantially different from the regression obtained with the factory equation (Figure 2).

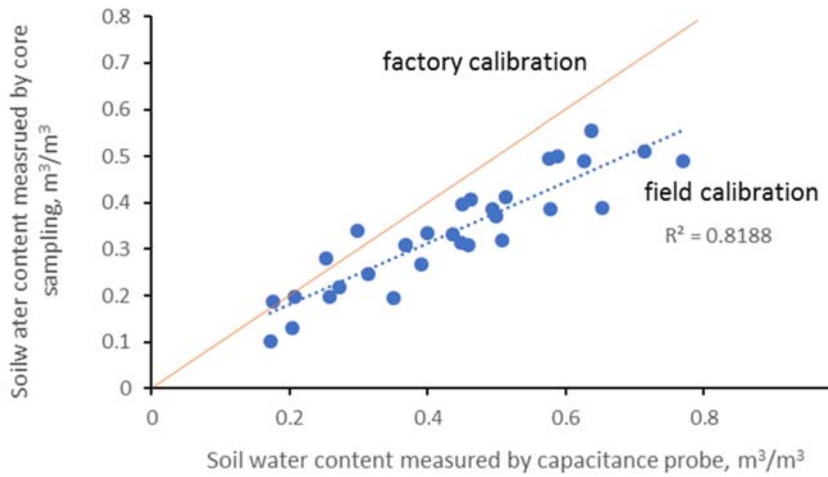

Figure 2. The factory calibration compared with the site-specific calibration obtained from all measurements collected from 0-30 cm depths for the four probes over four sample dates (Apr 2017, Aug 2017, Nov 2017 and Dec 2018)

Based on this, the generic calibration is expected to provide a low level of accuracy at low water contents (<0.17 m^3/m^3) underestimating VWC_A, and overestimating VWC_A in wet soils (>0.45 m^3/m^3). Similar errors have been observed in other studies. For instance, Kelner *et al.* (2001) showed that at low water contents (<0.35 m^3/m^3), probes underestimated VWC_A, while at high water content (>0.35 m^3/m^3), SWC_A was overestimated by as much as 80%.

The factory calibration poor performance might originate from the generic sensor calibration procedures offered by manufacture.

A factory calibration directly relates the sensor frequency to the soil water content. The generic calibration equation that comes with the EnviroPro probes is:

$$VWC_P = a*\ln(F)-b, \qquad [1]$$

where F is the sensor frequency, the constants a = 12.9 and b = 13.6. However, the sensor reacts to the capacitance of the soil, which in turn is related to the permittivity of the soil, as a function of the soil water content (Kelleners *et al*. 2004). The relationship between volumetric water content and permittivity (ε) can be expressed as:

$$\varepsilon=[3.47-6.22\Theta+.382\Theta^2+\Theta(7.01+6.89\Theta-7.83\Theta^2)], \qquad [2]$$

where Θ is soil porosity, which in turn is linked to a soil bulk density as:

$$\Theta=1 - \text{bulk density/particle density} \qquad [3]$$

However, as seen from equation 1, there is no mechanism to consider the differences in porosity between sampling depths in the first equation as used by the manufacture. Thus, large systematic errors tend to appear in actual soils as the generic calibration did not accommodate changes in the soil texture, and hence in the bulk density.

Conclusion

It was found that the generic calibration tends to under- and over-estimate the soil water content substantially. Soil specific calibration is needed to obtain accurate estimates of volumetric soil moisture for the EnviroPro probes used in this study.

The site-specific calibration developed for this study on the pooled data from 0 cm to 30 cm at both sites provided a reasonable calibration equation for EnviroPro capacitance probes.

This calibration is soil specific and depends on soil bulk density.

References

Fares A, Polyakov V (2006) Advances in crop water management using capacitive water sensors. Advances in agronomy 90, 43–77

Hanson RB, Orloff S, Peters D (2000). Monitoring soil moisture helps refine irrigation management. California Agriculture Journal 54, 38-42

Kelleners TJ, Soppe WO, Aysrs JE, Skaggs TH (2004) Calibration of capacitance probe sensors in a saline silty clay soil. Soil Science Society of America Journal 68, 770-778

Kellner E, Lundin LC (2001) Calibration of time domain reflectometry for water content in peat soil. Nord. Hydrol 32, 315–332

Malicki MA, Plagge R, Roth CN (1996) Improving the calibration of dielectric TDR soil moisture determination taking into account the solid soil. European Journal of Soil Science 47, 3, 357-366

Nemali K, Montesano F, Dove KS, Marc van I (2007) Calibration and performance of moisture sensors in soilless substrates: ECH_2O and Theta probes. Scientia Horticulture 112, 227-234

Rayment GE, Higginson FR (1992) Australian laboratory handbook of soil and water chemical methods. Inkata Press: Melbourne

Robinson DA, Hopmans JW, Campbell CS, Hornbuckle BK (2008) Soil Moisture Measurement for Ecological and Hydrological Watershed-Scale Observatories: A Review. Vadose Zone Journal 7, 1, 358-369

Saito T (2009) Empirical Temperature Calibration of Capacitance Probes to Measure Soil Water. Soil Science Society of America Journal 73, 6,1931-1937