Comparing Field Measurement Methods of Soil pH and Moisture for Use in an Urban Site Assessment

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Introduction

- Field determination of site conditions is crucial to maximize urban tree performance (Scharenbroch et al. 2017).
- Soil pH and moisture are highly variable requiring frequent evaluation (Wuest 2015).
- Soil pH impacts tree nutrient availability (Wastson et al. 2014).
- Soil moisture directly relates to plant available water (Romano and Santini 2002).
- This study tested low-cost sensors for determining soil pH and volumetric moisture content (VMC).

Methods

- Four soils (Table 1) were sieved (6 mm) at field moisture, homogenized, and air dried.
- Soils were then wetted to three VMC's (0-30%).
- PVC containers were packed in 5 cm increments to field bulk densities (1.2-1.4 gcm^{-3}).
- Each container was replicated seven times.
- Twenty-one sensors (Figure 2) of varying measurement methods were evaluated.
- Standard pH values were determined using a pH glass electrode sensor (Thomas, 1996).
- Standard moisture values were determined using the oven-dry method converted to VMC (Topp and Ferre, 2002).
- Pearson's and Spearman's correlation and Lin's concordance coefficients were determined with SAS JMP 7.0 software (SAS Inc., Cary, NC USA).

Table 1. Descriptions and properties of investigated soils.

Soil Series	Subgroup	Texture	Sand (%)	Silt (%)	Clay (%)	SOM (%)	EC ($\mu S\ cm^{-1}$)
Kewaunee silt loam	Typic Hapludalf	Clay	10	32	58	3.64	236
		Clay Loam	33	32	35	4.56	205
Rosholt sandy loam	Haplic Glossudalf	Sandy Loam	67	24	9	2.67	124
		Loamy Sand	83	8	9	0.51	55

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pH Results

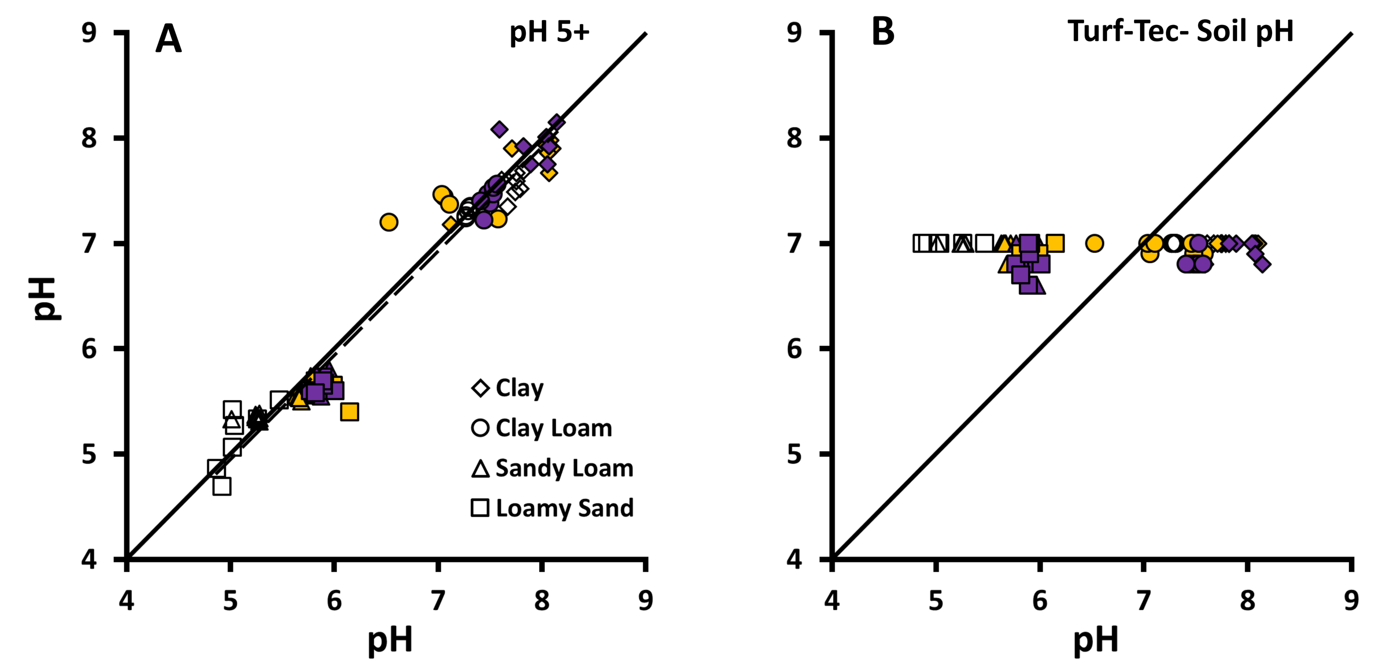


Figure 1. Sensor pH readings by soil texture and moisture content (white= air dry, yellow= ≈0.5 field capacity, purple= ≈field capacity) compared to the standard.

Table 2. Pearson's correlation (*r*), Spearman's correlation (P) and Lin's correlation (*Pc*) values between tested pH sensors and a reference sensor (Hach Sension+ PH3).

Sensor (Fig. 2 label)	Cost ($)	*r*	P	*Pc*†	Sensor (Fig. 2 label)	Cost ($)	*r*	P	*Pc*†
PCTestr 35 (P)	135	0.96*	0.92*	0.95	Luster Leaf1847 (U)	21	-0.07ˇ	-0.12ˇ	0.01
pH 5+ (O)	225	0.97*	0.95*	0.98	MoonCity 3-in-1 (B)	13	0.06ˇ	0.00ˇ	0.02
Turf-Tec PH1-N (R)	299	0.01ˇ	0.00ˇ	0.01	Dr.Meter®4-in-1 (C)	13	-0.28ʹ	-0.60ˇ	0.19
Luster Leaf 1835 (T)	26	-0.10ˇ	-0.04ˇ	-0.01	Control Wizard (D)	60	-0.25ˇ	-0.10ˇ	-0.02
Luster Leaf 1840 (S)	14	-0.07ˇ	-0.04ˇ	0.03	Kelway® Tester (A)	120	0.15ʹ	0.08ˇ	0.22
Luster Leaf 1845 (Q)	11	0.11ˇ	0.07ˇ	0.06	† No p-value is calculated for *Pc*, * Denotes *P* <0.0001, ʹ denotes *P* <0.05, and ˇ denotes *P* > 0.1				

VMC Results

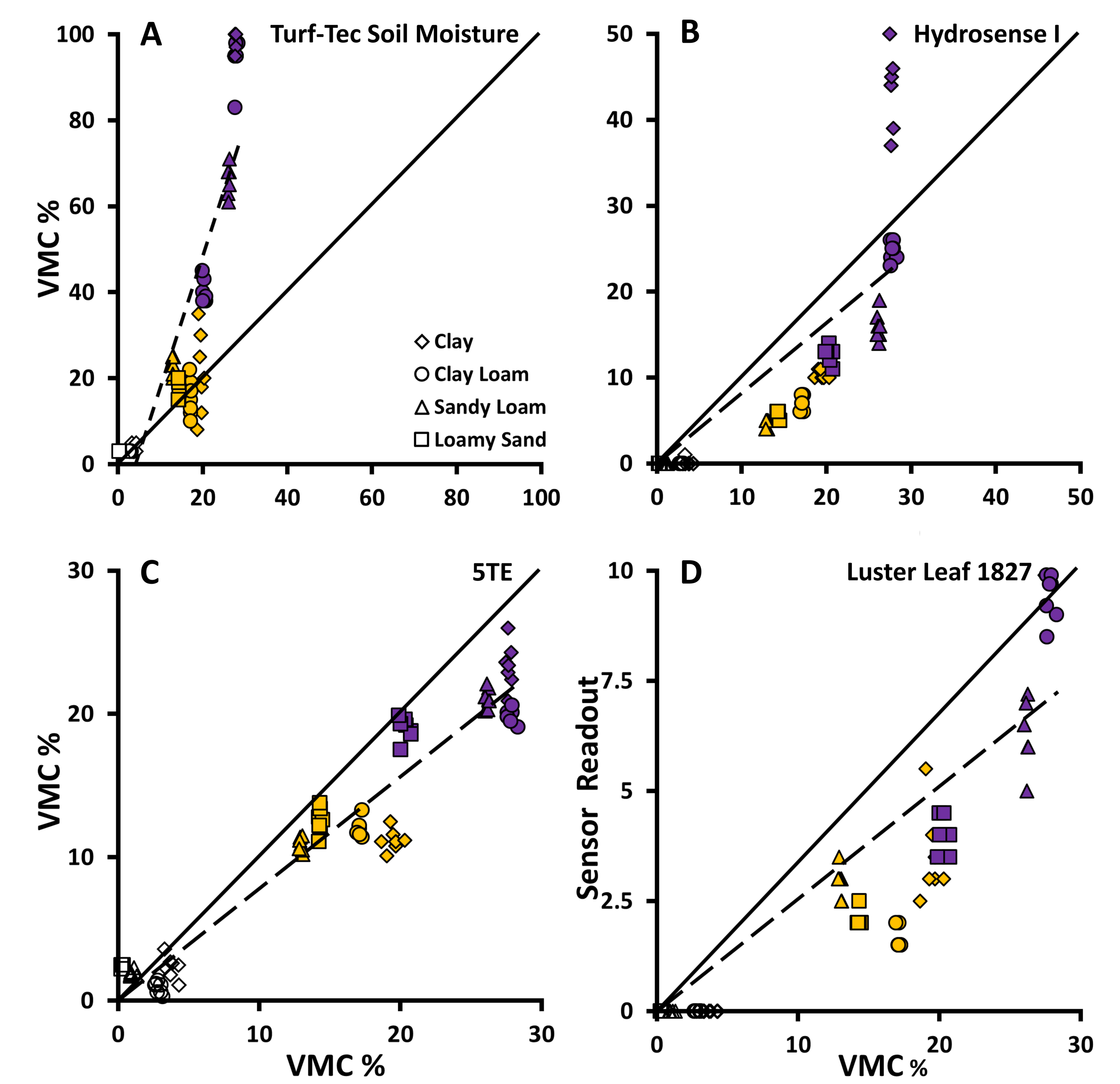


Figure 3. Sensor VMC readings by soil texture and moisture content (white= air dry, yellow= ≈0.5 field capacity, purple= ≈field capacity) compared to the laboratory standard.

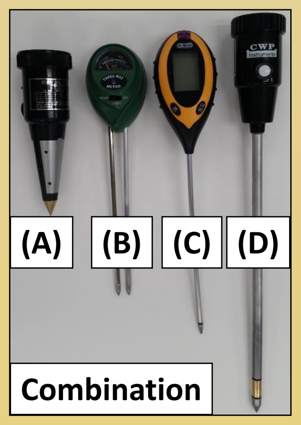
Table 3. Pearson's correlation (*r*), Spearman's correlation (P) and Lin's correlation (*Pc*) values between tested soil (VMC) sensors and a standard VMC.

Sensor (Fig. 2 label)	Cost ($)	*r**	P*	*Pc*†	Sensor (Fig. 2 label)	Cost ($)	*r**	P*	*Pc*†
Lincoln Moisture Meter (L)	93	0.95	0.95	0.30	Luster Leaf 1820 (N)	12	0.75	0.91	0.14
Dr. Meter Moisture (K)	11	0.89	0.95	0.21	Luster Leaf 1825 (J)	10	0.78	0.78	0.15
MoonCity 3-in-1 (B)	13	0.89	0.92	0.21	Luster Leaf 1827 (I)	21	0.90	0.94	0.26
Dr. Meter® 4-in-1 (C)	13	0.93	0.91	0.08	5TE (H)	248ʹ	0.96	0.90	0.89
Kelway® Soil Tester (A)	120	0.90	0.82	0.26	Hydrosense I (G)	545	0.82	0.97	0.76
Control Wizard (D)	60	0.97	0.94	0.28	General® Meter (F)	194	0.77	0.91	0.71
Turf-Tec MS1-W (M)	375	0.87	0.98	0.38	EXTECH® Meter (E)	280	0.77	0.91	0.71

*P < 0.0001, † No p-value is calculated using *Pc*, ʹ Sensor read with ProCheck unit ($506)

Figure 2. Evaluated sensors grouped by variable measured and measurement method.

- VMC sensors using time domain reflectometry (E), frequency domain reflectometry (F), or electrical conductance (G-N)
- Soil pH sensors using a glass electrode (O,P) or a metal electrode (Q-U)
- Combination sensors measure soil pH and VMC using EC (A-D)



Discussion

- Glass electrode sensors (A) showed significant 1:1 correlations to the standard (Table 2).
- Metal electrode sensors (B) failed to show any significant correlation to the standard (Table 2).
- Glass electrode sensors' increase in accuracy is likely due to measurement of hydrogen conductance instead of bulk electrical conductance.
- Dielectric VMC sensors were more accurate than electrical conductance sensors (Table 3).
- This increase in accuracy may be due to the strong relationship between dielectric permittivity and VMC.
- Overestimation of VMC was observed with finer textures near field capacity (Fig.3).
- The two most expensive VMC sensors were also the most accurate.

Conclusion

- Soil pH sensors perform best when measuring a soil solution (soil:deionized water).
- Soil moisture is best determined by measuring dielectric properties.
- Sensor cost is a strong indicator of sensor quality.

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