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Evaluating Traditional and Modern Laboratory Techniques for Determining Permanent Wilting Point

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Evaluating Traditional and Modern Laboratory Techniques for Determining Permanent Wilting Point

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Summary

The permanent wilting point is often considered the lower limit for plant available water and can be measured in the laboratory using a pressure plate apparatus (traditional method) or a dewpoint water potential meter (modern method). However, recent evidence suggests substantial discrepancy between the soil moisture at the permanent wilting points derived from these two laboratory techniques. This preliminary study investigated the magnitude of the discrepancy between permanent wilting points derived from traditional and modern laboratory techniques and the concomitant effects on plant available water estimations. For the analysis, a total of 21 undisturbed soil samples were collected from the top 20 inches of the soil profile at 18 locations of the Kansas Mesonet. The soil moisture content at the permanent wilting point measured using the pressure plate apparatus was 22% higher in clay loam soils and 25% higher in the clay soils than the soil moisture values obtained using a dewpoint water potential meter. When using the pressure plate apparatus, the resulting plant available water capacity (PAWC) was 33% lower in clay loam soils and 57% lower in clay soils compared to the PAWC estimated using the dewpoint water potential meter. Only minor discrepancies of about 8 to 9% were observed in both the resulting permanent wilting point and the estimated PAWC in the silt loam and sandy loam soils.

Introduction

The concept of plant available water capacity describes the maximum amount of soil water that is available for root water uptake and is an important variable for making timely irrigation decisions. Plant available water capacity is computed as the difference between an upper limit commonly known as the "field capacity" and a lower limit known as the "permanent wilting point" (Figure 1). Field capacity refers to the soil water content retained after gravitational water has drained (Veihmeyer and Hendrickson, 1931). Permanent wilting point refers to the point at which plants cannot longer recover from soil water stress, and represents the point at which plant roots cannot longer extract water for the transpiration process (Briggs and Shantz, 1912). Field capacity and permanent wilting point are not considered soil physical properties, but are two concepts that have proven useful to farmers, water managers, and researchers. Field capacity and permanent wilting point can be measured either in the field or in laboratory conditions. Field observations tend to be more accurate, but can be laborious and usually require the span of an entire growing season. On the other hand, laboratory determination relies on small soil samples, but it allows researchers to process batches of soil samples from different fields and can substantially speed up the process. In laboratory conditions, field capacity and permanent wilting point are often measured by equilibrating soil samples at predetermined pressures of -1.5 psi (-10 kPa) and -217.6 psi (-1500 kPa), which represent specific levels of work expressed in units of energy per unit volume. Traditional methods for measuring field capacity and permanent wilting point in the laboratory typically rely on multiple pieces of apparatus that use porous ceramic plates (e.g. tempe cells and pressure plates) (Richards and Fireman, 1943). These traditional methods have been used in research for almost a century and remain popular due to their ability to process large batches of soil samples in a single operation. However, recent evidence suggests that the traditional porous ceramic plate apparatus may be prone to measurement errors at pressures approaching the permanent wilting point in fine-textured soils (Solone et al., 2012). This study investigated the discrepancy between the permanent wilting point measured using pressure plate (traditional) and a dewpoint water potential meter (modern) techniques and the concomitant effects on plant available water capacity estimates.

Procedures

A total of 21 undisturbed soil samples with a volume of 3.3 fluid ounces (98 cm^3) were collected at 2, 4, 8, and 20 inch depths at 18 stations of the Kansas Mesonet (Patrignani et al., 2020) using a hand-held soil sampling kit (Eijkelkamp, The Netherlands). Soil samples were saturated in 5 mmol L^{-1} $CaCl_2$ solution and then field capacity was determined at -1.5 psi (-10 kPa) tension using a sandbox (Eijkelkamp, The Netherlands) (Figure 2A), and permanent wilting point was determined at -217.6 psi (-1500 kPa) tension using the traditional pressure plate apparatus (Soilmoisture Equipment Corp. Santa Barbara, CA) (Figure 2B). The water potential of the equilibrated samples from the pressure plate were verified with a modern dewpoint water potential meter (WP4C, Meter Group, Inc., Pullman, WA) (Figure 2C). After measuring the permanent wilting point, the soil samples were oven-dried at 221°F (105°C) for 48 hours, ground, and sifted through a 0.08 inch (2 mm) sieve, and then particle size analysis was determined using the hydrometer method (Gavlak et al., 2005). Plant available water capacity was computed as the difference between the volumetric water content at field capacity (-1.5 psi) and the permanent wilting point (-217.6 psi). The derived plant available water capacity was multiplied by the soil profile thickness to convert it to units of equivalent depth of soil water storage. The soil water storage measurements expressed in terms of inches of available water can be easier to compare to other components of the soil water balance such as evapotranspiration and precipitation, which are also measured in inches (or millimeters). In this study, we assumed a soil profile thickness of 4 feet to compute the equivalent depth of soil water storage in inches.

Results

The soils analyzed in this study had 3 to 70% sand, 17 to 61% silt, and 12 to 63% clay particle sizes (Table 1). Our soils captured seven out of the twelve U. S. Department of Agriculture soil textural classes, with silt loam soils making up 10 of the 21 total samples analyzed. The bulk density ranged from 1.33 to 1.83 g cm^{-3} with a corresponding porosity range of 31 to 50%. The soil moisture at the permanent wilting point registered higher when measured with the pressure plate apparatus than when measured with the dewpoint potential meter in all the soil textures except in the sandy loam, in which both techniques yielded the same water content at permanent wilting point (Table 2).

Assuming a soil profile that is 4 ft., the equivalent difference in water content at permanent wilting point between the pressure plate and dewpoint water potential ranges from 1 inch in the silt loam and silty clay loam to 4 inches in the clay soil. This measurement corresponds to 10 to 25% higher water content at permanent wilting point by the pressure plate technique compared to the dewpoint water potential meter.

In the fine-textured soils, measuring the permanent wilting point using pressure plate apparatus resulted in average plant available water capacity values that are 33% lower in clay loam and 57% lower in clay soils than the permanent wilting point measured using dewpoint water potential meter (Table 2). The silty clay and silty clay loam soils had almost the same plant available water capacity regardless of the method used.

In the coarse soil, the estimated plant available water capacity was almost the same for the pressure plate apparatus and the dewpoint potential meter in the sandy loam (9%) and silt loam (8%) soils, suggesting that both pressure plate and dewpoint water potential meter yield similar results in coarse-textured soils.

Our preliminary results indicate that measuring the permanent wilting point in the laboratory using traditional pressure plates could result in 22% higher water content at permanent wilting point in clay loam and 25% higher water content in clay soils than using modern dewpoint water potential meter techniques. This could lead to a difference of 33% plant available water capacity in clay loam and 57% difference in clay, depending on the laboratory method. Future research by the Kansas State University Soil Water Process laboratory will include detailed determination of field capacity and permanent wilting point using different methods covering a wider range of soils in Kansas.

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Table 1. Number of samples in each textural class and textural class mean of bulk density, total porosity, percent sand, percent clay, and verified matric potential from dewpoint water potential meter for pressure plate-equilibrated samples at -1500 kPa

Textural class	Number	Bulk density	Porosity	Sand	Clay
		g cm^{-3}	-------------------------	%	-------------------------
Clay	1	1.33	50	3	63
Clay loam	2	1.45	46	26	34
Sandy clay loam	1	1.83	31	48	25
Sandy loam	2	1.70	36	70	12
Silt loam	10	1.43	46	15	23
Silty clay	3	1.34	49	7	46
Silty clay loam	2	1.50	44	15	31

Table 2. Textural class mean of field capacity (FC), permanent wilting point (PWP), derived from pressure plate (traditional), dewpoint water potential meter (modern) techniques, and the resulting plant available water capacity (PAWC) computed for a 4-feet soil profile

Textural class	FC	PWP-Trad	PWP-Modern	PAWC-Trad	PAWC-Modern
	--		inches		--
Clay	25	18	14	7	11
Clay loam	18	12	9	6	9
Sandy clay loam	16	9	7	7	9
Sandy loam	15	3	3	12	12
Silt loam	20	8	7	12	13
Silty clay	22	13	11	9	11
Silty clay loam	20	10	9	10	11

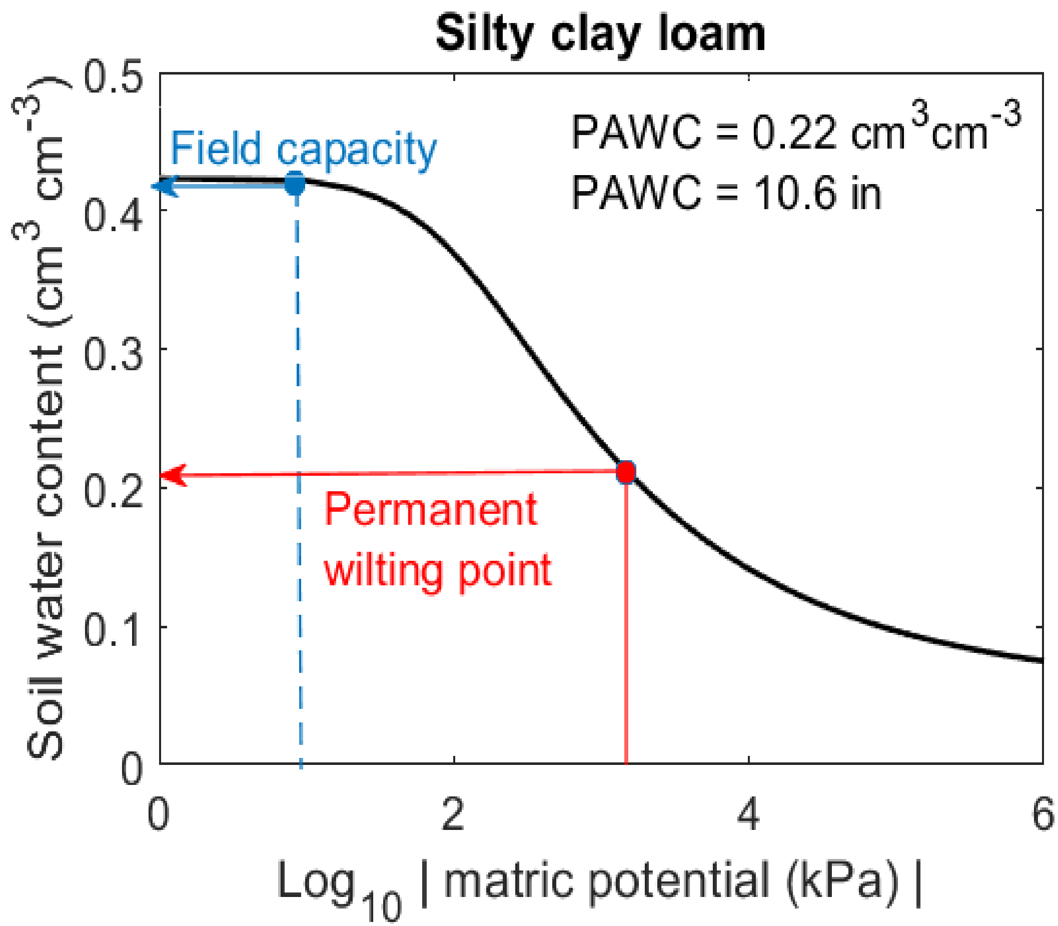

Figure 1. A soil water retention curve showing the field capacity (upper limit) and permanent wilting point (lower limit). Plant available water capacity (PAWC) is computed as the difference between soil water contents at field capacity and permanent wilting point. The PAWC (in volume fraction) is multiplied by the soil profile thickness to convert it to units of equivalent depth of soil profile water storage. Thus, assuming a soil profile thickness of 4 feet (48 in.) in this example, PAWC is 48 in × 0.22 cm^3 cm^{-3} = 10.6 in.

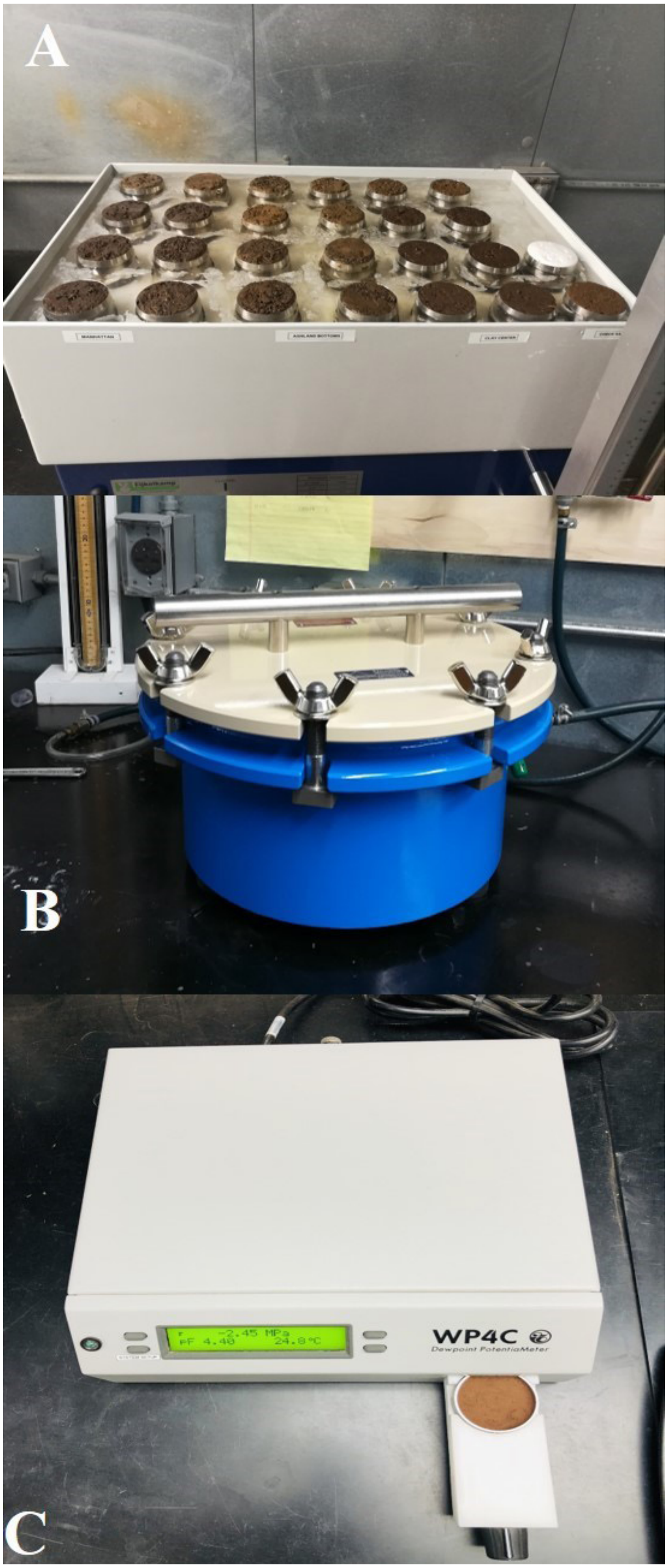

Figure 2. Measurements of field capacity using sandbox (a), and permanent wilting points using pressure plate apparatus (b; traditional technique), and dewpoint water potential meter (c; modern technique).