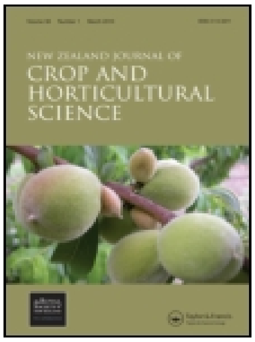

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Estimation of field capacity and wilting point of some New Zealand soils from their saturation percentages

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Abstract The purpose of this study was to investigate the applicability of the readily measured saturation percentage (SP) as a possible index for estimating field capacity (FC) and wilting point (WP) water contents of some New Zealand soils. Saturation percentages of 39 soil samples from different depths in five different texturally layered soils were determined by the saturation paste method. Undisturbed soil cores from the field were used to determine laboratory-based measurements of the field capacity and wilting point of these samples. The results indicated a strong linear relationship between the mass percentage water contents at field capacity and wilting point, and the saturation percentage. High correlation coefficients suggested that easy and quick estimates of FC and WP of these soils can be obtained from their saturation percentages. However, the lack of correlation between the saturation percentage and available water capacity (AWC) in these soils clearly showed the inability of the SP method to provide good estimates of AWC. The paper also debates the relative value of field and laboratory measurements of "field capacity", supporting the latter as a useful practical guide for the grower.

Keywords field capacity; wilting point; soils; water content; saturation percentage; available water capacity

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INTRODUCTION

Plant growth is largely governed by the available water capacity (AWC) of the soil, which is the difference between the soil moisture held at field capacity (FC) and wilting point (WP). A knowledge of the soil water content at field capacity and wilting point is also very important for assessing plant water requirements, irrigation scheduling, predicting crop responses to irrigation, modelling solute transport, and assessing soil suitability for different land uses. The laboratory determination of these moisture constants (i.e. FC and WP) involves field sampling followed by measurements using tension tables and pressure plate apparatus. The whole process is very laborious and time-consuming (Salter 1967). In view of the time and labour involved, a great deal of attention has been placed in the past on prediction of soil water retention values from soil survey data, or from other soil physical and structural properties, especially composition properties, including texture, organic matter content, density and clay mineralogy (Husz 1967; Gupta & Larson 1979; Oosterveld & Chang 1980; Rawls & Brakensiek 1982; Rawls et al. 1982; Saxton et al. 1986). However, the methods for determining particle-size distribution, organic matter content, and mineralogical composition of soils are themselves time-consuming. Another approach, for estimating water retention, has been through the modelling of the soil moisture characteristic with simple parameterised functions (Brooks & Corey 1964; Visser 1966; Gardner et al. 1970; Rogowski 1971; Campbell 1974; Ghosh 1976; Clapp & Hornberger 1978; van Genuchten 1980). This however, also involves prior paired measurements of soil water content and potential.

More recently Karkanis (1983) and Dahiya et al. (1988) have explored an alternative and simpler approach for estimating field capacity and wilting point, using the *saturation percentage* (SP) of a soil. Here SP refers to the amount of water required to achieve saturation (indicated by initial expression of free water) in a remoulded paste of a 100 g oven-dry soil sample. The above two studies, however, revealed different results. Karkanis (1983) determined soil saturation percentages by a capillary rise method and suggested a linear relationship between FC (i.e., moisture retained by the sample at 33 kPa suction) and SP, and also between WP (i.e., moisture retained at 1500 kPa suction) and SP. In contrast, the study by Dahiya et al. (1988) suggested a log-linear relationship between SP and FC, and SP and WP. Dahiya et al. (1988) used for the field capacity limit, the moisture retained by the sample at 10 kPa suction for sandy soils and 33 kPa for other soils, and for the wilting point the soil water content at 1500 kPa suction. Further, in both studies the FC and WP water contents were determined on a mass basis using disturbed soil samples (< 2mm).

The present study was conducted using 39 soil samples from different depths including A and B horizons from eight soil profiles of five different texturally layered soils from Canterbury, New Zealand. The aims were (a) to test the applicability of the method, and (b) to determine the type of relationship between field capacity and wilting point and the saturation percentage. Moreover, in this study undisturbed field samples were used to determine FC and WP.

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Table 1 Mean water contents (mass basis) at field capacity (FC) and wilting point (WP), mean saturation percentages (SP), and the mean available water capacity (AWC) values of soils under study. Bulk density (BD) and organic carbon (OC) data given for reference. Figures in parentheses are standard deviations for the triplicate measurements.

Soil	Depth (cm)	Horizon & field texture	BD (g/cm^3)	OC (%)	FC (%)	WP (%)	AWC (%)	SP (%)
Templeton	0–5	Ap1 SL	1.28 (0.03)	3.05	31.7 (0.7)	24.4 (0.8)	7.3 (0.5)	45.1 (0.2)
	5–10	Ap1 ZL	1.27 (0.04)	3.16	30.8 (0.6)	21.9 (2.3)	8.8 (1.6)	42.2 (0.3)
	10–15	Ap2 ZL	1.21 (0.06)	2.81	33.0 (0.4)	23.7 (0.8)	9.3 (0.5)	45.5 (0.5)
	15–20	Ap2 ZL	1.15 (0.05)	2.77	27.9 (1.1)	19.0 (1.3)	8.9 (0.5)	39.6 (0.5)
	20–25	Ap2 ZL	1.35 (0.04)	2.78	24.2 (0.3)	16.6 (0.8)	7.7 (1.0)	40.0 (0.0)
Temuka	3–15	Ap1 ZL	1.22 (0.02)	3.14	31.9 (2.4)	21.7 (3.3)	10.2 (1.0)	46.5 (0.6)
	40–55	B1 CL	1.58 (0.03)	0.29	20.0 (0.2)	11.5 (0.4)	8.4 (0.5)	32.9 (0.1)
	40–55	B1 CL	1.30 (0.04)	0.31	27.0 (0.5)	15.5 (2.5)	11.5 (2.9)	46.9 (0.2)
	131–136	C CL	1.50 (0.02)	0.21	27.6 (0.9)	16.2 (3.3)	11.5 (3.9)	41.7 (0.1)
Wakanui (minimum tilled)	0–5	Ap1 ZL	1.17 (0.06)	3.42	32.7 (0.4)	20.8 (1.7)	11.8 (1.8)	49.0 (0.2)
	5–10	Ap1 ZL	1.28 (0.03)	3.29	27.6 (0.1)	17.1 (1.5)	10.5 (1.4)	43.7 (0.2)
	10–15	Ap2 ZL	1.21 (0.02)	3.01	26.6 (0.2)	17.0 (1.5)	9.7 (1.6)	41.2 (0.2)
	15–20	Ap2 ZL	1.27 (0.07)	2.80	25.6 (0.3)	16.3 (2.4)	9.3 (2.6)	41.4 (0.1)
	20–25	AB ZL	1.30 (0.03)	2.34	25.0 (0.4)	15.6 (2.1)	9.4 (1.8)	40.2 (0.2)
Wakanui (highly cultivated)	0–5	Ap1 ZL	1.27 (0.03)	2.54	28.6 (1.4)	14.7 (2.2)	13.8 (1.2)	47.1 (0.1)
	5–10	Ap1 ZL	1.21 (0.07)	2.52	28.0 (0.3)	15.3 (1.8)	12.7 (1.6)	47.1 (0.1)
	10–15	Ap2 ZL	1.15 (0.04)	2.64	28.9 (0.8)	14.7 (0.2)	14.2 (0.7)	45.8 (0.2)
	15–20	Ap2 ZL	1.19 (0.02)	2.59	27.8 (0.5)	14.0 (0.7)	13.8 (0.3)	43.9 (0.1)
	20–25	Bt1 ZL	1.51 (0.08)	0.75	21.0 (0.3)	10.7 (0.0)	10.3 (0.3)	29.8 (1.0)
Wakanui (short-term grass)	0–5	Ap1 ZL	1.33 (0.06)	2.47	26.8 (0.5)	13.1 (0.8)	13.6 (1.0)	38.0 (0.1)
	5–10	Ap1 ZL	1.37 (0.02)	2.33	28.2 (0.4)	14.0 (1.1)	14.1 (1.2)	39.5 (0.2)
	10–15	Ap1 ZL	1.41 (0.02)	2.27	25.6 (0.5)	12.2 (0.9)	13.4 (0.5)	37.8 (0.3)
	15–20	Ap2 ZL	1.38 (0.04)	2.02	25.7 (0.7)	12.3 (0.9)	13.3 (1.2)	34.5 (0.2)
	20–25	Ap2 ZL	1.45 (0.05)	1.09	22.5 (1.5)	9.6 (0.8)	12.9 (1.8)	30.4 (0.2)
Wakanui (permanent grassland)	0–5	Ah1 ZL	1.15 (0.02)	4.40	33.6 (2.4)	21.3 (1.8)	12.3 (1.4)	55.4 (0.2)
	5–10	Ah1 ZL	1.21 (0.03)	3.61	31.4 (1.2)	18.9 (1.3)	12.5 (0.8)	48.4 (0.3)
	10–15	Ah2 ZL	1.31 (0.02)	2.71	26.0 (0.8)	17.1 (0.3)	8.9 (0.8)	41.5 (0.0)
	15–20	Ah2 ZL	1.30 (0.01)	2.57	24.2 (0.5)	16.3 (0.4)	7.9 (0.9)	39.9 (0.4)
	20–25	Ah2 ZL	1.37 (0.05)	2.21	23.3 (2.0)	15.7 (1.0)	7.6 (1.0)	36.4 (0.2)
Cookson	5–10	Ah2 CL	0.83 (0.01)	6.33	57.4 (0.5)	40.2 (1.3)	17.2 (1.6)	89.3 (0.4)
	17–22	AB C	0.90 (0.10)	3.12	53.0 (1.1)	39.3 (0.7)	13.7 (0.6)	76.2 (1.1)
	35–40	Bt C	1.02 (0.01)	1.61	53.1 (1.2)	41.6 (0.6)	11.5 (0.8)	81.3 (0.9)
	55–60	Bw/C CL	1.00 (0.03)	0.40	53.8 (0.5)	41.8 (0.6)	11.9 (1.0)	84.1 (0.1)
	70–75	Bw/C CL	1.03 (0.02)	0.30	51.5 (1.4)	40.8 (1.0)	10.7 (0.5)	77.7 (0.6)
Timpendean	5–10	Ap ZL	1.07 (0.04)	3.78	43.0 (1.7)	36.5 (0.1)	6.5 (1.8)	63.2 (0.5)
	12–17	Ap ZL	1.08 (0.06)	3.65	44.0 (2.2)	37.4 (2.3)	6.6 (1.0)	63.9 (0.5)
	35–40	Bt C	1.21 (0.07)	1.27	41.5 (1.1)	35.7 (1.9)	5.8 (1.0)	72.6 (0.3)
	55–60	Bt C	1.20 (0.05)	1.03	44.7 (2.3)	38.6 (2.4)	6.1 (2.5)	80.4 (0.3)
	90–95	B/C C	1.26 (0.09)	0.77	45.4 (2.5)	35.7 (1.7)	9.6 (1.0)	80.1 (0.5)

SL = sandy loam, ZL = silt loam, CL = clay loam, C = clay.

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MATERIALS AND METHODS

Five soils, Wakanui, Templeton, Temuka, Timpendean, and Cookson, were selected for this study. The first three soils, Wakanui, Templeton, and Temuka, were chosen as both local soils and as representative of dominant texture types in the Canterbury plains. The Cookson and Timpendean soils were chosen from the North Canterbury hill country area to widen the range of textures, to include soils higher in clay. Also, to investigate the possible effects on soil-water properties of cultivation history, which affects both structure and organic matter level, four Wakanui soil sites were selected, representing four different management treatments. The field textures and horizonation of these soils are presented in Table 1. The total organic carbon content in these soils ranged from 0.21 to 6.33%, the highest being in surface horizons (Grewal et al. unpubl. data).

Undisturbed soil cores from these soils were taken using a bulk density corer tool, with internal brass ring (54 mm i.d., 49 mm height) at different depths ranging from 0–5 cm to 131–136 cm. The inner surface of the ring was coated lightly with petroleum jelly to reduce disturbance during sampling by friction and adhesion, and to minimise edge effects in subsequent measurements. Three replicate samples were taken at each depth. Soil immediately adjacent to the core was collected separately in a polythene bag for SP measurements. The ends of each core were carefully trimmed flush using a sharp knife, and after covering the cores with lids and polythene bags, they were transported to the laboratory in a carrying box. In the laboratory, a fine-mesh nylon cloth was attached to the base of each core with a rubber band. Smearing of a core surface caused by trimming can cause artificial "necking" (i.e., local reduction in pore diameter) of those (especially larger) pores intersected by the surface (Greenwood 1989). This will cause such pores to drain at suctions higher than those applicable in situ in the field, thus shifting the apparent distribution of pores toward smaller sizes. Thus the upper surface of each core was first prepared using a resin-peeling technique. Peeling of the lower surface of the core was not performed because (i) it would result in poor contact between the core and tension table, and (ii) for those larger, predominantly vertical pores which are continuous between the trimmed surfaces, peeling of the upper surface should suffice to enable their drainage, although at a slower rate. A viscous solution of cellulose acetate (13 g cellulose acetate + 75 cm^3 acetone) was applied to the upper surface of each core with a spatula. After hardening (4–5 h), the layer of cellulose acetate was peeled from the soil surface. A thin (c. 1 mm) layer of soil adhered to the lower surface of the cellulose acetate peel. The resultant soil surface appeared unsmeared, revealing pores that were not previously apparent. The cores were first saturated and then the water content of each sample at field capacity (10 kPa suction) was determined using tension tables. After FC measurement, a small subsample was collected from the individual core by gently pressing a plastic ring (33 mm i.d., 10 mm height) and the wilting point water content at 1500 kPa suction was measured on the subsample using pressure plate apparatus. The remainder of the core was used for bulk density (BD) measurement.

The samples taken for saturation percentage measurement were air-dried and passed through a 2 mm sieve. Saturation percentage of the sieved soil samples was then determined in triplicate by the saturation paste method (Richards 1954). The saturated soil paste was prepared by adding distilled water from a burette to a 250 g air-dry sample of soil while stirring with a spatula. The soil-water mixture was consolidated from time to time during the stirring process by tapping the beaker. At saturation, the soil paste glistened as it reflected light, flowed slightly when the beaker was tipped, and the paste slid freely and cleanly off the spatula. After mixing the sample was covered with a polythene sheet to check evaporation and allowed to stand for an hour or more, and then the criteria for saturation were rechecked. If the paste stiffened or stopped glistening, it was remixed with more water. SP was calculated as follows:

$$\text{Mass of oven-dry soil} = \frac{\text{Mass of air-dry soil} \times 100}{100 + \text{air-dry moisture percentage}} \quad (1)$$

$$\begin{aligned}\text{Total mass of water} &= (\text{water added}) + (\text{water in air-dry soil}) \\ &= [(\text{mass of water added}) + (\text{mass of air-dry soil}) \\ &\quad - (\text{mass of oven-dry soil})]\end{aligned} \quad (2)$$

$$SP = \frac{\text{Total mass of water}}{\text{Mass of oven-dry soil}} \times 100 \quad (3)$$

RESULTS AND DISCUSSION

The mean soil water contents at field capacity and wilting point, and the mean saturation percentages of all 39 samples are presented in Table 1. The figures in parentheses indicate standard deviations.

Before proceeding with further analysis of the results, it is worth considering the value of our chosen

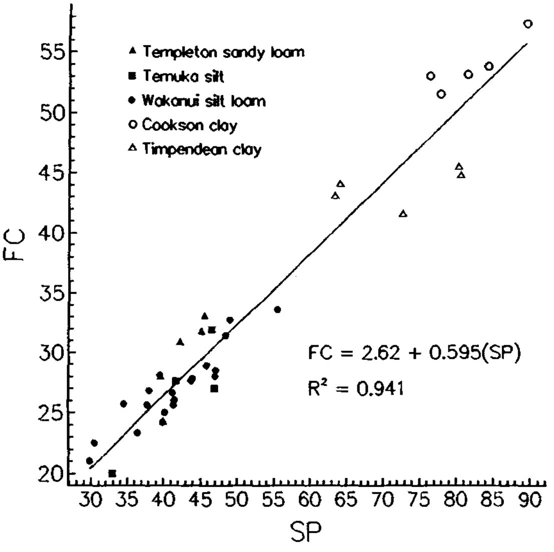

Fig. 1 Regression analysis between field capacity (FC, mass basis) and saturation percentage (SP) for all soils.

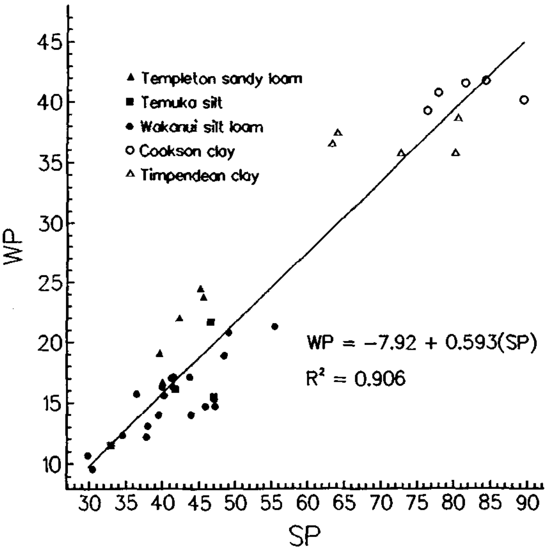

Fig. 2 Regression analysis between wilting point (WP, mass basis) and saturation percentage (SP) for all soils.

index of field capacity. The soil water content at a matric potential of −1500 kPa is widely accepted as an estimate of wilting point. However, recent literature debates the relative ability, to represent true field capacity, under field conditions, of: (i) laboratory measurements on cores at a prescribed matric potential

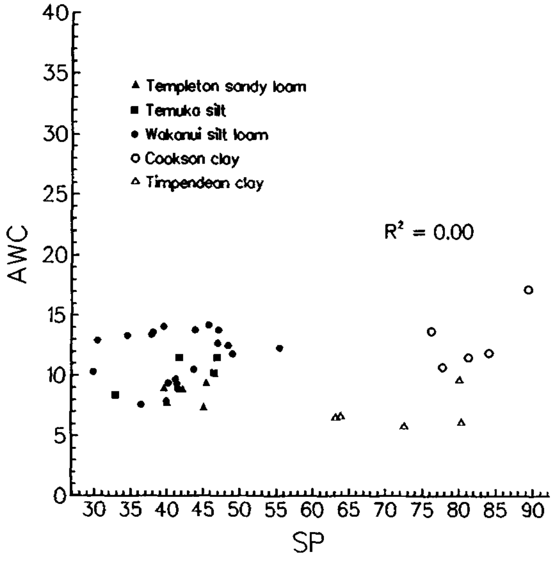

Fig. 3 Regression analysis between available water capacity (AWC, mass basis) and saturation percentage (SP) for all soils.

(here, −10 kPa equivalent to a suction of 0.1 bar); and (ii) the field method of assessing field capacity, i.e. profile water content following internal drainage from near saturation, either after a fixed time (e.g. 2 days, Veihmeyer & Hendrickson 1949), or after profile drainage has declined to a prescribed rate (e.g. 1 mm/day, Thorburn & Gardner 1986). The tendency is to reject the laboratory method, and to encourage use of the field method (Scotter 1976; Ahuja & Nielson 1990; Hillel 1990). Here, we argue that the laboratory method provides a useful version of field capacity for *practical* field use by the grower. First, note that the main difference between methods will usually arise from the holdup of water in the field by poorly permeable layers, or by a textural interface (e.g. fine-textured over sandy layer, Clothier et al. 1977). These conditions will cause the field method to assess FC as wetter than −10 kPa for layers suffering impeded drainage. Second, the practical utility of field capacity for the grower is that it (a) either estimates water retention at the start of the growing season, or (b) serves as a target "full point" for the soil after irrigation. In Situation (a), interannual variations in winter rainfall can make the "field" method of doubtful value. In dry years, the soil will be drier than −10 kPa, whereas the field method would assess FC as *wetter* than −10 kPa for any layers suffering impeded drainage. In Situation

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(b), it is good practice to aim at suctions of around 0.1 bar to minimise crop water stress, and preferably not wetter to avoid aeration problems.

Further, field measurements with tensiometers indicate that the soils in the Canterbury Plains typically drain, within a few days from heavy rain or irrigation, to about 0.1 bar suction in the upper 40 cm of the profile, to which most of our data pertain. In a separate study, Greenwood (1989) determined field capacity of a Wakanui silt loam from field measurements, and reported that results agreed well to a depth of 70 cm with laboratory core measurements of water content at −10 kPa matric potential. Thus the above reasoning supports the use of water content at −10 kPa matric potential as a *practical* version of field capacity.

Figures 1 and 2 show the results and regression analyses for field capacity and wilting point versus saturation percentages, respectively, for all soil samples of Table 1. The regression equations obtained are shown in Table 2, which clearly indicates that strong linear relationships exist between the moisture constants FC, WP expressed on a mass basis, and the saturation percentage. These correlations weakened when moisture constants expressed on a volume basis were used.

This can be explained as follows. First, SP is a measure *on a mass basis* of the water-absorption capacity of the soil (under prescribed conditions), and so can be expected to correlate better with FC and WP also expressed on a mass basis. Shifting to water contents on a volume basis, i.e. $\theta_v = \theta_m \times \rho_b$ (where θ_m is water content on a mass basis, and ρ_b is bulk density), multiplies θ_m by bulk density, which is thus implicated as an additional variable, under the control of still further factors (especially organic matter content, structure, and mechanical history of the soil). Then the effect of bulk density is , as expected, to weaken the correlation. We also explored the possibility of relationships between FC and WP, and the logarithm of SP (as reported by Dahiya et al. 1988) and also between logarithms of FC and WP, and the logarithm of SP. However, both these analyses resulted in slightly poorer correlations than with the linear relationship (Table 2).

Table 2 Summary of regressions between field capacity (FC), wilting point (WP), and saturation percentage (SP).

Regression	r^2 (%)	Signif. level
Mass basis		
FC = 2.62 + 0.595(SP)	94.1	***
WP = −7.92 + 0.593(SP)	90.6	***
AWC = 10.5 + 0.0020(SP)	0.0	NS
Volume basis		
FC = 17.9 + 0.422(SP)	84.8	***
WP = 0.11 + 0.512(SP)	78.5	***
AWC = 17.8 - 0.0898(SP)	18.1	***
Logarithmic relations (mass basis)		
FC = −93.8 + 32.6ln(SP)	92.0	***
WP = −105.0 + 32.7ln(SP)	89.6	***
AWC = 10.9 − 0.08ln(SP)	0.0	NS
ln(FC) = −0.094 + 0.913ln(SP)	93.6	***
ln(WP) = −2.30 + 1.37ln(SP)	88.6	***
ln(AWC) = 2.56 − 0.060ln(SP)	0.5	NS

*** = $P < 0.001$; NS = not significant.

Figure 3 illustrates the regression analysis between the available water capacity (i.e. AWC = FC − WP), and the saturation percentage, for all soils. The correlation (r^2=0.0%) indicates that AWC has no relationship with the saturation percentage. Hence we conclude that the SP method fails as a predictor of AWC across the range of textures for the soils studied.

Two possible reasons for this failure of correlation deserve investigation. First, it might be argued that the SP test itself is imprecise and subject to large operator error. However, the very low standard deviation values for triplicate SP measurement (Table 1) show good precision in the determination of SP values. A second, more likely, reason is that SP is a compound index of the ability of a soil to absorb water on *remoulding*, the SP point occuring when the soil's absorption capacity is fulfilled, and free water begins to be expressed from the soil. Thus SP will integrate the effects of factors such as texture, organic matter content, clay mineralogy, and cation balance, and other constituents (e.g., sesquioxides). While these factors also contribute to FC and WP, and hence to AWC, they will probably compound in different ways to determine SP compared to their influence on AWC.

CONCLUSIONS

Soil water property measurements for 39 New Zealand soil samples suggest that a good linear relationship exists between field capacity and wilting point water contents, when expressed on a mass basis, and the saturation percentage of each soil. Hence, saturation percentage can be used to provide a rapid estimate of the field capacity and wilting point water contents of these soils. However, the results also clearly indicate that although SP serves as a good predictor of the overall trend of FC and WP against texture variations, accounting for over 90 % of the variation in these parameters for the soils examined, it does not appear to be useful as a predictor of AWC, which represents the smaller *difference* between FC and WP. This is because of the different ways in which AWC and SP integrate the basic composition and physicochemical properties of soil, and because of the fact that the SP method destroys soil structure.

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