Estimation of readily available waterholding capacity using field hand texture

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Abstract

The determination of readily available waterholding capacity (RAW) in the field provides essential information when conducting soil survey's for irrigation design and scheduling. This paper outlines a method for estimation of RAW in the field based on the accepted descriptive method of "field hand textures" as outlined in the "yellow book", McDonald *et al.* (1990). Relationships of field texture to soil carbonate and bulk density were also investigated. Intact core samples (triplicate samples of 329 discernable soil layers from 94 profiles) from the Riverland, Barossa and Adelaide Hills regions in South Australia and Sunraysia district in Victoria were equilibrated on ceramic plates in a pressure chamber to determine the water retention characteristics and readily available waterholding capacity deficit ranges from field capacity (-8 kPa) to -40, -60 and –1500 kPa. A significant linear relationship (r^2 values of 0.91, 0.95, 0.95 and 0.92 respectively) exists between volumetric water content and average clay percent from field texture at matric potentials in the plant available range. Soil carbonate significantly increases readily available waterholding capacity in the deficit ranges of field capacity to -40 kPa, -60 kPa and -1500 kPa for light sandy clay loam and sandy clay loam field textures. A bulk density greater than 1.6 g/cm^3 decreases readily available waterholding capacity for sandy loam (SL) and light sandy clay loam (LSCL) field textures.

Keywords

Field texture, soil water retention characteristic, waterholding capacity

Introduction

Soil survey for irrigation requires an estimate of readily available waterholding capacity of each soil layer within the rootzone at each soil pit. Irrigation management units and scheduling programs can then be varied according to the data collected. The waterholding capacity of a soil sample can be estimated from the water retention curve (Childs 1940) derived from the relationship between water content and matric potential. This relationship is dependant on soil texture and structure (Hillel 1982). Laboratory determinations of water retention curves for each layer of a soil pit in a soil survey would be time consuming and costly as triplicate samples would be required from each layer. Alternatively, empirically derived regression equations for prediction of water retention curves (pedotransfer functions) can be produced from soil physical properties, but reliability of these predictions depends on the soil data collected.

Estimation of available waterholding capacity based on field texture has been shown by Salter and Williams (1967) in some soils to give a better estimate than that derived from the textural class determined by laboratory particle size analysis. They also state that provided the textural assessment is only one class out, then the error in estimating available waterholding capacity is small. The observer can also make judgments in the field regards the nature of the soil layer that assists them in selecting the correct textural class (Salter and Williams 1967). Collection of a large data set, based on samples from a representative range of soil textures can be used to produce water retention curves suitable for estimation of readily available waterholding capacity deficit ranges (RAW). This data can be used in the field, inconjunction with the coarse fragment content of each layer, to estimate the RAW value for the rootzone. This paper outlines such a system.

Methods

Sample collection

Intact core samples from 329 discernable soil layers (94 soil profiles) sampled in triplicate and measuring 6cm in length and 7.2cm in diameter were collected in the Riverland, Barossa and Adelaide Hills districts of South Australia and the Sunraysia district of Victoria. The samples were collected from each layer at a moisture content near field capacity.

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Water retention measurements and bulk density determination

The water retention characteristics of collected samples were determined as per the method of Cock (1985). Cores were saturated in a Haines apparatus with porosity 3 plates and with 53 µm silica flour for contact. From saturation soils were equilibrated at matric potentials of -8 kPa, -40 kPa and -60 kPa after transfer to 1-bar ceramic plates connected to a bubble tower apparatus. After each stage of equilibrium the gravimetric moisture content (*w*) was found by weight and the bulk density at -70 kPa was determined after drying at 105ºC for 24 hours. The cores were then bulked, ground and sieved (<2 mm) and equilibrated at -1500 kPa in a pressure chamber to determine permanent wilting point.

Field texture determination

Field texture was determined on duplicate samples split off prior to determination of the water retention characteristics. Field texture was assessed by four pedologists working independently using the method outlined in the Australian Soil and Land Survey Field Handbook (McDonald *et a.l* 1990), which has been adapted from (Northcote 1974). The procedure (McDonald *et al.* 1990) involves taking a sample of soil, moistened with water and kneading into a ball in the palm of the hand. Enough water is applied so that the ball just fails to stick to the fingers. This quantity of water approximates field capacity. The soil ball or bolus is then pressed out between thumb and forefinger and the length of ribbon determined. Ribbon length inconjunction with the “feel” of the bolus during the wetting up procedure is used to determine soil texture class and clay content. Particle size analysis was determined by the method of McIntyre and Loveday (1974) with soil carbonate not removed. This result was used as the 5th pedologist. The “accepted” soil field texture was selected based on the following guidelines: Category 1, where 3 pedologists agreed on the field texture of the sample; Category 2, where 2 pedologists agreed on the field texture of the sample.

The differences between pedologists seldom exceeded one texture class. For example 3 pedologists may have classed a sample as light sandy clay loam (LSCL), 1 pedologist classed the sample as SL+ and another classed the sample as sandy clay loam (SCL-). The procedure is considered a valid method with 58% of samples falling into category 1 and 41% into category 2. Only 1% of samples had no agreement between pedologists, but the disagreement may have been within one texture class.

Fine earth carbonate determination

The presence of fine earth carbonates was measured on each of the 329 layers by 4 pedologists using the method of (Northcote 1974) with adaptation of the categories observed. Duplicate portions of each sample were placed in porcelain drop plates, leveled with a spatula and 2 drops of 1 molar hydrochloric acid (1N HCL) applied to the surface. The strength of the reaction was noted and the effervescence of CO_2 recorded as follows: N (Nil) No effervescence; S (Slight) Effervescence audible and or visible; M (Moderate) Effervescence easily visible; H (High) Strong effervescence; V (Very High) Thick effervescence (bubbling). A solution of 1N HCL can be made by adding 100ml of pure HCL (Commercial Spirits of Salts, 35.5% w/w) to 1000ml of distilled water or rain water.

The fine earth carbonate (free lime) content was also determined in the laboratory on each of the 329 samples using the titration method of (Piper 1947).

Results

Field texture and readily available waterholding capacity

A relationship exists between waterholding capacity and “field texture” for soils from the River land, Barossa Valley, Adelaide Hills regions of South Australia and Sunrays district of Victoria. The relationship between volumetric water content (m^3/m^3) and matric potential (kPa) for soils with increasing clay content as determined by “field texture” is shown in figure 1. Linear regression of volumetric water content and average clay percentage from field texture class (McDonald *et al.* 1990) at 4 matric potentials (-8, -40, -60, -1500 kPa) was significant (r^2 values of 0.91, 0.95, 0.95 and 0.92 respectively at 0.05 probability level), figure 2. Analysis of variance (two-way ANOVA) for the interaction between field texture class and matric potential was significant ($P < 0.000$ at 0.05 significance level). That is, the fraction of variation in volumetric waterholding capacity over a range of matric potentials from field capacity (-8 kPa) to permanent wilting point (-1500 kPa) is explained by the proportions of sand, silt and clay in the sample, as determined by the field texture method. A study (Forrest *et al.* 1985) of the wheat growing districts of southern Australia presented water retention curves for soils from 60 sites. This data was based on field texture, however the relationship of volumetric water content and clay percentage for field texture class at similar matric potentials was lower (r^2 equals 0.49, 0.45, 0.69 and 0.87 at 5, 10, 100 and 1500 kPa respectively at 0.05 probability level). The average clay percentage for each field texture class used in regression analysis is based on (McDonald *et al* 1990) as follows: KS, 2.5%; LS, 5%; SL, 15%; LSCL, 20%; ZL, 25%; SCL, 25%; CL, 32.5%; CLS, 32.5%; ZCL, 32.5%; SC, 35%; LC, 37.5%; ZC, 40%; LMC, 42.5%; MC, 47.5; HC, 55%. The significance of the results obtained for soils from South Australia and Victoria, highlights the usefulness of water retention curves produced from this data set for use in estimating readily available waterholding capacity in the field based on field texture.

Table 1 shows the means and standard deviations of clay, silt and sand percentages as determined by particle size analysis and grouped according to texture. Texture was grouped by field hand texturing method (FT) or texture triangle (McDonald *et al.* 1990). A loam texture contains 13 to 14% silt compared to 7 to 9% for light sandy clay loam (LSCL) and sandy clay loam (SCL) textures. The ribbon length and description given in (McDonald *et al.* 1990) for a loam texture as determined by hand texturing is similar to that of LSCL and SCL textures and the higher silt content can only be detected by the feel of the bolus. The higher volumetric water content of the loam textures is due to siltstone and shale parent material in the area where the samples were collected (Charleston, Woodside and Kenton Valley in the Adelaide Hills, SA).

Table 1 – Percentage clay, silt and sand determined by particle size analysis and grouped by "field texture" (FT) and texture triangle (TT) (McDonald *et al.* 1990).

Texture	method	N	C %		Z %		S %	
			mean	SD	mean	SD	mean	SD
S	FT	16	3	*0.7*	1	*0.9*	96	*1.4*
	TT	61	6	*1.9*	2	*1.0*	92	*2.6*
LS	FT	41	6	*1.8*	3	*2.2*	91	*3.0*
	TT	22	8	*1.2*	7	*3.3*	85	*3.6*
SL	FT	59	10	*3.1*	5	*2.9*	85	*4.7*
	TT	101	14	*2.9*	5	*2.4*	81	*4.7*
LSCL	FT	60	15	*3.8*	7	*3.4*	78	*5.8*
	TT	nd						
L	FT	7	13	*2.8*	13	*3.8*	74	*6.0*
	TT	24	16	*3.2*	14	*2.0*	70	*3.4*
SCL	FT	49	20	*4.3*	9	*3.0*	71	*5.5*
	TT	32	23	*9.1*	7	*2.5*	70	*15.0*
CL	FT	55	26	*4.8*	10	*3.1*	64	*6.4*
	TT	62	28	*3.9*	11	*2.3*	61	*4.8*
C	FT	27	34	*7.1*	11	*3.2*	55	*8.8*
	TT	12	40	4.3	12	4.3	48	8

FT - field texture

TT - McDonald et al (1990) (after Marshall 1947, International Fractions)

nd - no data

%C, Z, S - determined by method of McIntyre and Loveday (1974)

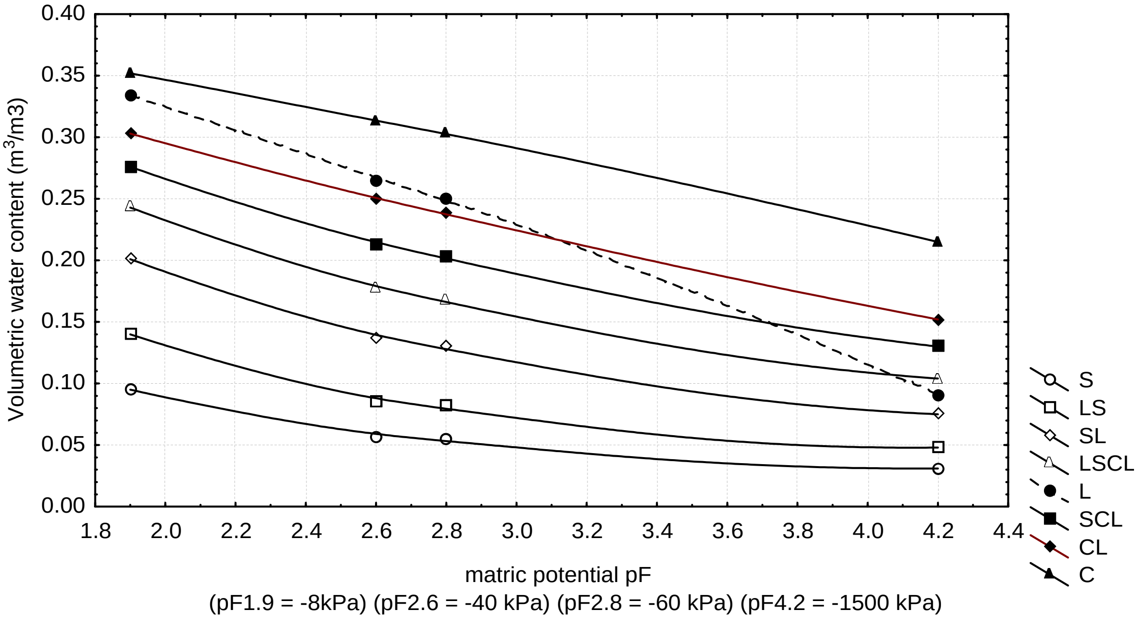


Figure 1 – Volumetric water content versus matric potential, based on field texture class.

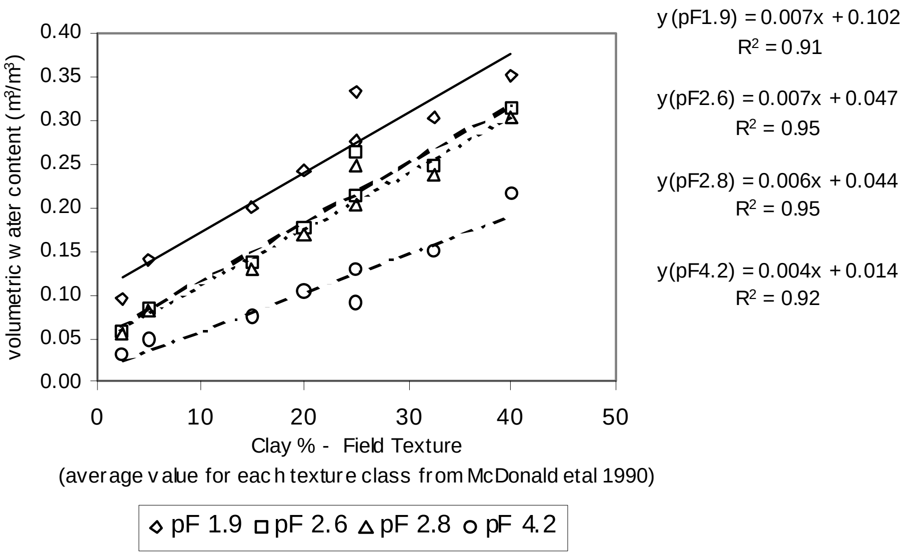


Figure 2 – Linear regression of water content versus average clay percentage per field texture class at 4 matric potentials

The volumetric water content data presented in figure 1 have been used to calculate readily available waterholding capacity deficit ranges (RAW), table 2. Field capacity (FC) has been taken as a matric potential of -8 kPa and permanent wilting point (PWP) as -1500 kPa. This data can be used to calculate irrigation requirements and plan irrigation design and scheduling. The use of volumetric data for determining irrigation requirements has been discussed by a number of authors (Hillel 1982; Salter and Williams 1967; White 1997).

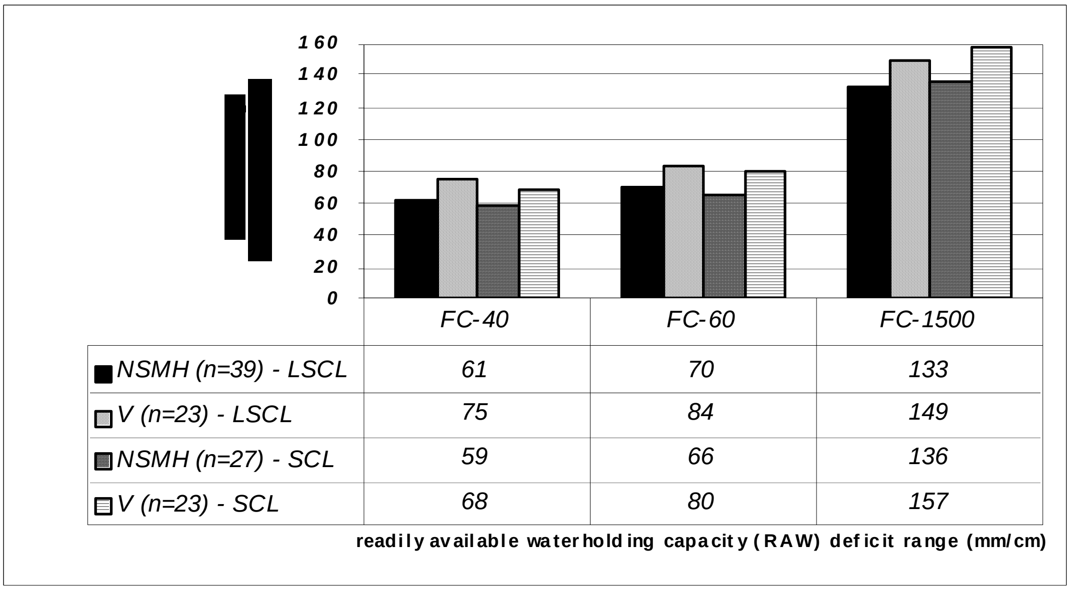
The "Readily Available Waterholding Capacity" (RAW) for a soil profile can be calculated by determining the thickness (cm) and percentage (%) of coarse fragments in each layer of the rootzone. This method allows rapid field estimation of irrigation requirements at a predetermined deficit range without the need for further laboratory measurements of particle size analysis, bulk density and water retention characteristics.

Table 2. Readily available waterholding capacity RAW (mm/cm) at 3 matric potential deficit ranges based on “field textures” (Note: RAW values presented in mm/cm as soil horizons and predicted or observed rootzones are measured in cm).

Field Texture	FC to -40 kPa	FC to -60 kPa	FC to -1500 kPa
S	38	39	63
LS	54	57	90
SL	63	70	125
LSCL	66	74	137
SCL	64	73	146
CL	53	65	149
C	45	56	149

Field texture and fine earth carbonate percentage
A reaction recorded as very high (V) using the field test for presence of fine earth carbonate is associated with soil Carbonate Layers which are visually distinct in the soil profile, (Wetherby and Oades 1975). It is therefore possible to separate out field textures with very high reactions from those with nil (N), slight (S), moderate (M) and high (H) reactions based on visual soil profile characteristics and the fine earth carbonate test. Figure 3 shows a significant increase in readily available waterholding capacity (RAW) at 3 matric potential deficit ranges for LSCL and SCL field textures (P-values, 0.05 level were 0.0004, 0.003, 0.014 for LSCL and 0.019, 0.001, 0.0004 for SCL). A non-significant increase was recorded for other field textures, confirming fine earth carbonate has increased waterholding capacity.

The cementation of fine earth carbonate into microaggregates is hypothesised as the reason for the higher readily available waterholding capacity. The cementation may also be responsible for the higher percentages of fine earth carbonate (greater than 18%) determined in the laboratory for sandy clay loam, clay loam and clay field textures. Thin section analysis and scanning electron microscopy, in conjunction with sieving at ½ phi intervals to determine particle size distribution of unaltered samples is required to verify this hypothesis.



	FC-40	FC-60	FC-1500
■ NSMH (n=39) - LSCL	61	70	133
□ V (n=23) - LSCL	75	84	149
▦ NSMH (n=27) - SCL	59	66	136
▤ V (n=23) - SCL	68	80	157

Figure 3. Increase in readily available waterholding capacity (RAW) at 3 matric potential deficit ranges with increase in soil carbonate content for LSCL and SCL field texture

Comparison of laboratory determination of carbonate as per the method of (Piper 1947) and the field carbonate test shows the latter can be used as an estimate of the percentage of carbonate in a soil sample, table 2. A fine earth carbonate percentage of 12.6% to 18.5% is associated with a very high (V) reaction. The carbonate percentage determined in the laboratory increases with clay content with sandy clay loam, clay loam and clay field textures containing 18.3% to 18.5% fine earth carbonate. The nil (N), slight (S), moderate (M) and high (H) reactions for these same field textures contained 1.7% to 7.5% fine earth carbonate. Samples with a field texture of sand or loamy sand did not give a very high (V) reaction when assessed using the field carbonate test and are usually associated with soil layers above a Carbonate Layer in Mallee soils of South Australia and Victoria. Results show a fine earth carbonate percentage greater than 10% corresponds to a very high (V) reaction; values of 1% to 10% correspond to slight (S), moderate (M) and high (H) reactions and less than 1% to a nil (N) reaction.

Field texture, bulk density and waterholding capacity

The expected bulk density range of soils has been stated as 1.0 to 1.4 g/cm^3 for well aggregated loamy soils to 1.2 to 1.8 g/cm^3 for sands and compacted clay soils (White 1997). Similar ranges have been stated by (Hillel 1982) with values as low as 1.1 gm/cm^3 in aggregated loams and clays to 1.6 g/cm^3 in sandy soils. Bulk density was measured on all samples and ranged from 1.25 to 1.8 g/cm^3.

A bulk density of 1.6 g/cm^3 is regarded as high (Hillel 1982). This value has been used to compare readily available waterholding capacity deficit ranges (RAW) for field textures with a bulk density of less than or greater than 1.6 g/cm^3. Field textures of sandy loam (SL) and light sandy clay loam (LSCL) gave significant decreases in RAW when bulk density was greater than 1.6 g/cm^3, table 3. Remaining field textures showed no significant decrease in RAW.

Table 2. Comparison of Field Carbonate Test with laboratory determination of carbonate percentage

Texture	No of Samples	Field Carbonate Test Reaction	Laboratory Carbonate Percentage
S	(n=15)	NS	0.5
	(n=2)	M	1.2
LS	(n=29)	NS	0.8
	(n=13)	MH	2.7
SL	(n=55)	NSMH	1.7
	(n=6)	V	12.6
LSCL	(n=39)	NSMH	4.9
	(n=23)	V	15.9
SCL	(n=27)	NSMH	7.0
	(n=23)	V	18.3
CL	(n=14)	NSMH	5.5
	(n=42)	V	18.5
C	(n=22)	NSMH	7.5
	(n=12)	V	18.5

Table 3.Change in readily available waterholding capacity (RAW) (mm/cm) with bulk density (g/cm^3) at 3 matric potential deficit ranges (P – values (1,57) at 0.05 significance level for SL field textures and P – values (1,58) at 0.05 significance level for LSCL field textures).

Field Texture	Bulk Density	FC to -40 kPa	FC to -60 kPa	FC to -1500 kPa
SL	< 1.6	68	77	138
	> 1.6	59	65	113
	P - value	*0.036*	*0.034*	*0.005*
LSCL	< 1.6	69	79	146
	> 1.6	59	66	122
	P - value	*0.015*	*0.004*	*0.0001*

In summary, field texture as described by (McDonald *et al* 1990) for the average of 329 triplicate core samples from discernable soil layers in South Australia and Victoria, have been shown to be highly significant in the prediction of waterholding capacity at matric potentials in the plant available range from field capacity (-8 kPa) to wilting point (-1500 kPa). This data has been used to calculate readily available waterholding capacity (RAW) of a soil profile where layer thickness, coarse fragment content and predicted or observed rootzone depth of the crop is known. The quantity of irrigation water required to refill a profile for a known matric potential deficit range can then be determined in the field.

The fine earth carbonate in soil layers with a very high (V) reaction to 1N HCL significantly increases readily available waterholding capacity at the deficit ranges of -8 to -40 kPa, -8 to -60 kPa and -8 to -1500 kPa in light sandy clay loam and sandy clay loam field texture classes. Other field texture classes also show a non significant increase in waterholding capacity at these deficit ranges. A high bulk density (greater than 1.6 g/cm3) in sandy loam and light sandy clay loam field textures has been shown to significantly decrease readily available waterholding capacity at the 3 matric potential deficit ranges stated above.

Conclusion

Based on these findings field texture is a reliable, quick and cost effective method for estimation of readily available waterholding capacity (RAW) of soils. The method can be used in routine soil survey where irrigation design and scheduling can be based on the estimates of RAW for individual soil profiles.

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