Plant available water capacity of dryland cropping soils in the south-eastern Australia

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Abstract
Field capacity (FC) and permanent wilting point (PWP) are two critical input parameters required in the APSIM model (Keating *et al*. 2003) which is currently being used nationally for predicting crop yield and fertiliser requirements at the paddock and landscape unit. FC and PWP were measured for three major soils which are used for dryland cropping in the Mallee and Wimmera regions. Plant available water capacity (PAWC) was determined as the difference FC and PWP. Data were grouped according to the three major soil suborders (Hypercalcic Calcarosols, HYC; Red Sodosols, RS; and Grey Vertosols, GV) and nine soil texture classes (ranging from sand to clay). FC, PWP and PAWC were found to be significantly higher for GV followed by HYC and RS. Overall, FC, PWP and PAWC varied from 0.063 to 0.495 and 0.018 to 0.378 m^3/m^3 respectively. PAWC ranged from 0.053 m^3/m^3 (sandy soils) to 0.147 m^3/m^3 (clay soils).

Key Words
Soil type, soil texture, soil hydraulic properties, paddock variability.

Introduction
Numerical models like APSIM (Keating *et al.* 2003) are currently being used nationally for crop yield and efficient allocation of resources (e.g. fertiliser input requirements) in farming systems at the paddock and landscape unit. FC and PWP are two critical input parameters required in most numerical models. The Mallee and Wimmera regions in Victoria produce about 90% of Victoria's grains. There is a lack of data on FC, PWP and PAWC for major soil types across these regions (see Cock 1985; Rab *et al*. 2009). The objectives of this study was to compare PAWC for three major soil suborders within the northern Wimmera and southern Mallee regions of north west Victoria.

Methods
The study area is located approximately 450 km north-west of Melbourne, in the southern Mallee and northern Wimmera regions of Victoria, SE Australia (Figure 1). The southern Mallee region is characterised by calcareous dunefields and plains (5.1.5 geomorphological unit), whilst the Wimmera region is typified by clay plains with intervening subdued ridges (5.4 geomorphological unit).

Two paddocks within each geomorphic unit were selected to capture the variability in PAWC across these significant cropping landscapes of north-west Victoria. Three sampling locations were established strategically to capture the inherent variability within each paddock. These sampling locations were chosen using paddock information including variability in (i) grain yield, (ii) electromagnetic induction (EM38), and (iii) elevation. Coordinates of the sample locations were recorded using a differential GPS with a horizontal accuracy of 10-20 cm. At each of the three sampling locations (within each paddock) three sampling points were randomly selected. At each sampling point undisturbed samples were taken from 0-10 cm and 20-30 cm soil depths.

Soil-water contents of the undisturbed samples were determined at −10 kPa (FC) using bubble tower ceramic suction plate apparatus. Soil-water content at –1500 kPa matric water potential (PWP) was determined using disturbed samples which were placed on a 15-bar ceramic plate in the pressure plate apparatus. Plant

available water capacity (PAWC) was determined as the difference FC and PWP. Soils were classified according to the Australian Soil Classification - ASC (Isbell 2002).
Each soil property was modelled using residual maximum likelihood (ReML) based on a two-factor linear mixed model. The two factors were soil type (S, three levels) and soil depth (D, two levels). Wald tests were used to assess the significance of differences in soil properties between soil types, soil depths, as well as their interactions. All statistical analyses were conducted using GenStat 10.2 (Payne *et al*. 2007). The residuals reasonably satisfied the ReML assumptions of normality and constant residual variance. To study the effect of soil texture group on PAWC, data was analysed using one-way analysis of variance (ANOVA).

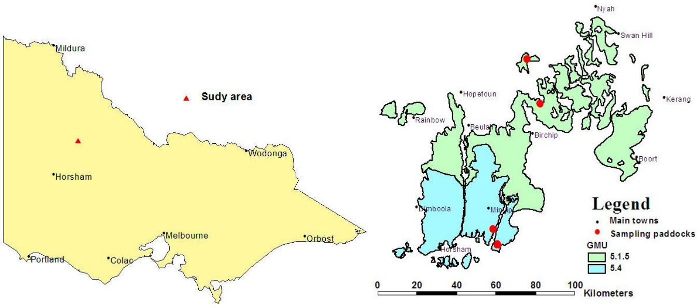

Figure 1 Location of study sites in the southern Mallee and Wimmera regions, SE Australia

Results
Three major ASC soil suborders: Red Sodosols (RS), Hypercalcic Calcarosols (HYC) and Grey Vertosols (GV) were identified in this study area with nine soil texture classes were represented amongst these. There was a wide variation in soil texture across the three suborders; the RS dominated by coarse textures in the 0-10 cm and both coarse and medium textures in the 20-30 cm depth range; the HYC dominated by medium and fine textured soil in the 0-10 cm and 20-30 cm depth ranges respectively, and the GV dominated by fine textures.

Mean values of FC and PWP for three soil types are presented in Table 1. The effect of interaction (soil x depth) and soil suborder on FC and PWP was significant ($p<0.001$) but the effect of depth was non-significant ($P>0.05$). However, a plot of mean values shows that the nature of interaction was of a non-crossover type (data not shown) and at both depths, mean values for RS were consistently low compared to both HYC and GV. The LSD test showed that at 0-10 cm depth, differences in FC and PWP between soil types were significant while at 20-30 cm depth the difference in FC and PWP between HYC and RS was not significant. The LSD test also showed that for GV the FC and PWP was not significantly different between two soil depths while for HYC and RS the differences between depths were significant.

Table 1. FC, PWP and PAWC of three soil suborders at two depths in the Mallee and Wimmera regions of north-west Victoria, SE Australia.

Volumetric soil-water [A]	Soil types (S)[B]	Depth (D, cm)		Mean	Model term	F Prob	SEd
		0-10	20-30				
FC (% vol)	HYC	34	42	38	S	<0.001	2
	GV	46	42	44	D	0.369	1
	RS	17	23	20	S x D	<0.001	3
	Mean	32	36				
PWP (% vol)	HYC	19	28	23	S	<0.001	1
	GV	31	27	29	D	0.146	1
	RS	6	12	9	S x D	<0.001	2
	Mean	19	23				
PAWC (% vol)	HYC	17	14	15	S	0.001	1
	GV	15	14	14	D	0.314	1
	RS	11	11	11	S x D	0.552	2
	Mean	14	13				

[A] FC and PWP are water content at 10 and 1500 kPa matric potentials; PAWC is the difference between FC and PWP
[B] HYC, Hypercalcic Calcarosol; GV, Grey Vertosol; RS, Red Sodosol.

Both FC and PWP were significantly influenced by soil texture class. There were no significant difference in either FC or PWP found between loamy sand and sandy loam; between loam, sandy clay loam and clay loam; and between silty clay loam, silty clay and clay soils (Table 2). This suggests for practical purposes, these nine texture classes can be grouped in to four major texture classes, sandy soils, loamy sand, loams and clayey soils. The relationship between routinely measured soil properties and FC and PWP are presented in Table 3.

Table 2. FC, PWP and PAWC classified by soil texture groups in the Mallee and Wimmera regions of northwest Victoria, SE Australia.

	Volumetric soil water content (%)[A]					
	FC		PWP		PAWC	
Texture groups	Mean	Range	Mean	Range	Mean	Range
Sand	8	6-8	2	2-3	5	4-6
Loamy sand	20	17-23	7	7-8	13	11-15
Sandy loam	21	18-23	8	7-9	13	11-16
Loam	29	26-32	16	13-18	14	13-14
Sandy clay loam	33	31-34	19	18-22	14	12-15
Clay loam	35	30-39	21	15-25	14	11-17
Silty clay loam	44	32-49	29	19-35	15	12-17
Silty clay*	44		29		15	
Clay	45	40-50	30	25-38	15	10-17

* only one observation

[A] FC, Field capacity; PWP, permanent wilting point; and PAWC, plant available water capacity, is the difference between FC and PWP

Table 3. Regression models for predicting FC and PWP

	FC		PWP	
Variables[A]	**Models**	**R^2 (%)**	**Models[B]**	**R^2 (%)**
c	Y = 14.64 + 0.665(c)	82	Y=4.5+0.557(c)	82
z+c	Y = 12.90 + 0.473(z+c)	87	Y=3.11+0.395(z+c)	85
c, x	Y = 9.86+0.600(c)+7.67(x)	85	NS	
c, c^2	$Y=6.17+1.50(c)-0.014(c^2)$	93	$Y=-1.32+1.13(c)-0.009(c)^2$	89
c, c^2, x	Y=2.68+1.416(c)-0.0135(c2)+6.12(x)	95	NS	
z+c, $(z+c)^2$	$Y=4.78+1.051(z+c)-0.007(z+c)^2$	93	$Y=-1.74+0.734(z+c)-0.005(z+c)^2$	89
z+c, $(z+c)^2$, b	$Y=2.15+1.023(z+c)-0.007(z+c)^2+4.5(x)$	94	NS	

A z, silt (%); c, clay (%); x, organic carbon (%); b, and bulk density (Mg/m^3).
B NS, regression coefficient for the input variable, x is not significant.

Discussion

Knowledge of FC and PWP is essential for many plant and soil-water studies, especially those related to plant growth and deep drainage. The mean FC observed for HYC and GV in this study were lower than those reported by Murphy and Lodge (2001) for a Brown Vertosol (46 % vol) but higher than for a Red Chromosol (35 % vol). The PWP of the both HYC and GV found in this study were higher than by Murphy and Lodge (2001) for the Red Chromosol (11 % vol). However, the PAWC found in this study for all three soil suborders (11 – 15 % vol) were lower than those reported by Murphy and Lodge (2001) for a Brown Vertosol (23 % vol) and Red Chromosol (24 % vol).

The mean FC and PWP found for each of the soil texture class was higher than those reported by Jensen *et al.* (1990) for US soils except for sandy soils. For sandy soils, both the FC and PWP were lower than Jensen *et al.* (1990). However, PAWC (12 - 15 % vol) compared favourably with Jensen *et al.* (1990) (13 - 15% vol) except for sandy soils which were lower. The FC, PWP and PAWC found in this study also compare favourable with those found for other Australian soils based on field textures, FC (6 - 45 vol%), PWP (2-25 % vol) and PAWC (4 - 20 %vol), (Better Soils 2005). Hochman *et al.* (2001) found increase in field measured PAWC with increase in clay content with depth for both Black and Grey Vertosols while Ratliff *et al.* (1983) reported no significant increase in PAWC with increase in clay content from silt loam to clay. In our study, the FC and PWP for the HYC and RS increased with depth. However, it did not result in any significant increase in PAWC with depth. This was due to an increase in both FC and PWP with increasing clay content.

The relationships between clay content and FC and PWP found in this study are consistent with those reported for other soils (e.g. King and Stark 2005; Minasny *et al.* 1999; Iqbal *et al.* 2005). For example, Iqbal *et al.* (2005) found greater values of volumetric water content at paddock locations where the percentage clay content was high; an indication of the greater water holding capacity of soil micropores between clay-sized particles. Minasny *et al.* (1999) found a positive non-linear relationship between clay content and FC and PWP. The equations developed in this study can be used to predict FC and PWP for similar soil types. These samples used in this study (N=72) cover a wide range in soil textural composition but limited range in organic carbon content. Therefore, further research, covering wide range of landuse systems, soil types and climatic conditions, is required to improve these predictive equations.

Conclusions

FC, PWP and PAWC were found to be significantly higher for GV followed by HYC and RS. FC was affected by both clay content and organic carbon (OC) content but PWP was only affected by clay content but not by OC. The developed equations can be used to predict FC and PWP for similar soils elsewhere. However, further research is needed to validate/improve the predictive models for a wider range of organic carbon content, soil types, soil texture and climatic conditions.

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