Relationship between soil properties of Mallee soils and parameters of two moisture characteristics models.

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Abstract
Readily available water holding capacity (RAW) is an important soil variable used in the design of irrigation systems and irrigation scheduling. Soil surveyors have routinely estimated RAW from field texture grade only. Fitting of moisture characteristic models to measured moisture retention data and relating the derived parameters to routinely measured soil properties can increase the accuracy of RAW values. The Campbell (1974) and the van Genuchten (1980) models were fitted to moisture retention measurements and the derived parameters were then related to soil bulk density, sand and fine earth carbonate content, hand field texture grade and reaction to 1N HCl. Variance accounted for (r^2), of the two models ranged from 0.83 to 0.999 with the van Genuchten model generally having higher r^2 values. The three Campbell parameters (b, ψ_{air}, and θ_{sat}) were all strongly correlated with sand content. The parameter b had a strong linear relationship with sand content ($r^2 = 0.83$) while a curvilinear relationship existed between percent sand and ψ_{air}. Only the parameter λ (van Genuchten) showed any strong relationship with sand content of the soil. Based on field texture grades, model parameters displayed characteristic ranges. Field texture grade and soil carbonate reaction class improved estimates of b and ψ_{air} Campbell parameters, but θ_{sat} was not depending only on the continuous sand content variable.

Key Words
Sand content, fine earth carbonate, field texture

Introduction
Historical background
Irrigation along the River Murray in South Australia commenced in the 1890's, with more intense development after the Second World War. Horticultural crops were watered on fixed intervals and volumes based on crop water requirements for periods of four to 6 weeks and 75 and 100 mm depths. Investigations in the region during the mid to late 1970s showed that the fixed or rostered irrigations were in excess of the water holding capacity of most of the irrigated soils in the region. In addition, the crops were often under stress from one to 2 weeks prior to the rostered irrigation with soil matric suction below –100 kPa.

In the mid 1980's, the State water licensing authority required that an intensive soil survey be undertaken as a condition of approval of transfers of water allocations. The soil survey categorised the soils in terms of their readily available water holding capacity (RAW)[1], drainage characteristics, presence of lime, and crop type and suitability. The different soil groupings delineated are then used in irrigation system design and irrigation scheduling. Soil properties, such as texture, carbonate (lime) content, and pH was described from sample pit inspections. Field hand texture grade of each soil layer to the crop rooting depth is used to estimate RAW.

An extensive soil sampling program was undertaken in the early to mid 1980s to better define the moisture characteristics of the region's soil. Soils were sampled in the irrigation districts of the River Murray upstream of Morgan in South Australia (261 soils) and Victoria (33 soils). For each texture grade, average RAW values were estimated. These RAW values have been used by soil surveyors when doing surveys in intensive irrigated horticultural areas within South Australia, Victoria, and New South Wales, and for irrigated agriculture elsewhere in Australia. The collected soil moisture characteristic data set was not further analysed to see if improved estimates of RAW could be made by using soil properties that are readily measured in the field.

[1] Readily available water capacity is defined as the amount of water held between -8 and -60 kPa for irrigated horticultural crops and -8 and -40kPa for vegetable crops.

Model Selection

In irrigated horticulture in southern Australia, the RAW value is an important property in the design of irrigation systems and scheduling of irrigations. The determination of soil moisture characteristics is universally accepted as a costly process. If soil properties such as texture and particle size distribution can be related to either specific measured points of the moisture release curve or related to parameters of a functional description of the release curve, then the determination of available water values over whatever range is chosen can then be predicted from inexpensive routinely measured soil properties.

Brooks and Corey (1964) proposed a mathematical function to describe the soil moisture release curve that has been further developed by many soil scientists. Campbell (1974) simplified this model by introducing scaling parameters ψ_{air} *and* θ_{sat}: $\psi / \psi_{air} = (\theta / \theta_{sat})^b$, where θ_{sat} is the moisture content at 0 kPa soil matric suction. Converting the equation to a logarithmic form linearizes the Campbell model: $\ln(\psi) = -\ln(\psi_{air}) + b(\ln(\theta) - \ln(\theta_{sat}))$. A simpler form of this equation is $\ln(\psi) = a + b\ln(\theta)$ where $a = -\ln(\psi_{air}) - b * \ln(\theta_{sat})$ which was used by Williams et al. (1983) for describing the moisture characteristic of some Australian soils. Soil structure, soil particle size composition, soil texture, and soil mineralogy were important in determining the shape of the moisture characteristic curve. Furthermore, Gregson et al (1987) showed that a linear relationship exists between the 'a' and 'b' parameters, as can been seen from the equation immediately above. Gregson et al and Williams et al. (1992) used this model along with a single point measurement of volumetric soil water and matric suction, texture, and bulk density to improve their estimates of soil water content.

In 1980, van Genuchten proposed a model that scaled the hydraulic potential and took account of the 'residual water' remaining at –1500 kPa.

$$\theta = \theta_{res} + \frac{\left(\theta_{sat} - \theta_{res}\right)}{\left(1 + \left(\alpha \cdot \psi\right)^{\lambda}\right)^{\mu}}$$

where θ_{res} is the residual volumetric water ($m^3\ m^{-3}$), α is a scaling parameter, and λ and μ are fitting parameters. Vereecken et al explored 5 versions of the van Genuchten model using 33 moisture characteristics of Belgian soils. All the versions of the model performed adequately in modelling the moisture curves. Particle size distribution, bulk density, and carbon content were significant soil properties in estimating the parameters of the van Genuchten equation.

The estimation of model parameters has become known as parametric *pedotransfer functions (PTFs)* after Bouma (1989). Two main approaches have been common: (*1*) relating estimates of the individual points to soil properties and (*2*) relating the model parameters to soil properties (Minasny et al. (1999), Minasny and McBratney. (2002), and Tomasella et al. (2003)). Tomasella et al reported that estimating water contents at specific soil water potentials gave a mean root squared error of 0.036 $m^3\ m^{-3}$ compared to a mean root squared error of 0.098 036 $m^3\ m^{-3}$ for estimating water contents from direct estimation of the van Genuchten parameters. Minasny and McBratney (2002) used an objective function that was trained to fit measured water content using artificial neural network (ANN) procedures. Bulk density and particle size distribution was used as input to train the ANN that improved the accuracy of soil water content estimation at soil matric potential values.

While these techniques are useful in estimating either the parameters or the measured moisture content values, the soil surveyor in the field is constrained to deliver their product at least cost to the client. If model parameters can be related to easily measured soil properties, then instead of the costly determination of soil moisture characteristics, or even a single determination, on typical soils in field survey, the moisture retention characteristics can be derived from easily measured field properties. This paper reports on the fitting of two parametric models of Campbell (1974) and van Genuchten (1980) describing the functional relationship between volumetric soil water and the matric potential to measured soil properties of the 294 soil samples. This paper also describes the analysis undertaken on the relationships between routinely measured soil properties of Mallee soils and the derived parameters of two models describing soil moisture

Materials and Methods

During the early to mid 1980s soil sampling sites were selected from landscapes above the River Murray floodplain in the Riverland and the Sunraysia regions of South Australia and Victoria respectively by officers of the South Australian Department of Agriculture (Wetherby pers. comm). Six undisturbed samples were taken from each discernable soil layer that was present to a maximum depth of 1.5m as described by Cock (1985). Initially, 291 soil samples were taken from the Riverland and 36 soils in the Sunraysia district of Victoria. The sampled soils were hand textured in the laboratory and assigned to a soil texture grade and reaction of the soil sample to 1N HCl (McDonald et al. 1984) were recorded. The soil moisture characteristics were measured at –2, -5, -10, -20, -67, and –1500 kPa according to the method described by Cock (1985). The measured points were then plotted on log-linear graph paper and the points joined by linear interpolation. The moisture content data at 0 to –20 kPa in 0.5 kPa intervals, -20 to –70 kPa in 10 kPa intervals and finally at –1500 kPa were entered into a computer spreadsheet. In addition, clay (< 2μm), silt (<20 - 2μm), and sand (20 – 2000μm) content was measured by mechanical analysis (McIntyre in Loveday, 1974), bulk density (as described by Cock (1985), and fine earth carbonate (FEC) content (Piper, 1947) were also measured.

In 1996/97, the author selected 294 of the 327 Mallee soils (Riverland (261) and Sunraysia (33)), as some of the soils did not have a full complement of soil properties measured. The original data from the measured points were not able to be found, so a subset of points were selected at -1, -2.5, -5, -7.5, -10, -15, -20, -30, -40, -50, -60, -70, and –1500 kPa for non-linear regression analysis. . The data was analysed with the NLIN procedure of the SAS © program (1993) using the *Levenberg-Marquardt* algorithm to derive the model parameters. The parameters and the degree of model fit, r^2, were saved in a database and related to the measured soil parameters for the sample. The analyses of the parameters and soil properties were undertaken using S-Plus v6 (® Insightful Corporation).

The model functions used to describe the relationship between the volumetric soil moisture content θ (m^3 m^{-3}) and the matric suction ψ (kPa) were the Campbell (1974) and the van Genuchten (1980) models. The Campbell model using the volumetric soil moisture content θ as the dependent variable is defined as:

$$\theta = \theta_{sat} \qquad ,\psi \geq \psi_{air} \qquad (1)$$

$$\theta = \theta_{sat}\left(\frac{\psi}{\psi_{air}}\right)^{-1/b}, \qquad \psi < \psi_{air}$$

where

θ = volumetric soil moisture content (m^3 m^{-3})

θ_{sat} = saturated volumetric soil moisture content (m^3 m^{-3})

ψ = soil matric potential (kPa)

ψ_{air} = air entry potential (kPa)

b is a fitting parameter representing the slope of the water retention curve.

The parameter ψ_{air} was constrained to be > 0; otherwise the model would not converge satisfactorily and for physical interpretation of the derived parameters. A specific form of the van Genuchten equation was selected (Model 2 in Vereecken et al,. 1989):

$$\theta = \theta_r + \frac{(\theta_s - \theta_r)}{\left(1 + (\alpha\psi)^{\lambda}\right)^{(\lambda+1)/\lambda}} \qquad (2)$$

where

θ = volumetric moisture content (m^3 m^{-3})

θ_r = residual volumetric water content (m^3 m^{-3})

θ_s = saturated volumetric water content (m^3 m^{-3})

ψ = soil matric potential (kPa)

α and λ are fitting parameters

Constraints were placed on the parameters θ_r, θ_s, and α to be greater than 0 for model stability and physical interpretation of the parameters.

Results

Physical description of soils in Mallee landscape

The soils of the Mallee region above the floodplain of the river have been developed on several Aeolian systems that is characterized by predominantly east-west trending dune-swale topography. The soils on the crest of dunes are characterised by sand to sandy loam soils in the top 0.3m gradually increasing in texture grade at depth to sandy clay loam to depths of 1m or more. The subsoils are highly calcareous, mainly $CaCO_3$, varying in composition from fine particles to large stones and boulders. The soils in the swales are shallower (0.3 – 1.0m) and of heavier texture (loamy sands) with the calcareous subsoils of similar composition. Soil pH varies from 7.0 – 7.5 in the surface to 8.5 – 9.0 at depth. Often underlying the soil at a depth from 1m and deeper is a layer of light medium clay to medium clay texture, referred to as "Blanchetown Clay[2]" that inhibits drainage. The soils above the "Blanchetown Clay" are generally apedal and single grained; the calcareous subsoil tends to be massive especially when moist to wet. Cock (1984, 1985) reported on the moisture characteristics of the typical range of soil profiles found above the river valley

The numbers of samples represented in each field texture grade varied from 40 to 58 samples for loamy sand through to clay loam and 16 and 27 samples in the sand and clay texture grades respectively (Table 1). The sand content ranged from 38 to 97.5% with the corresponding range in clay content ranged from a minimum of 2% to a maximum of 46.5% while silt content ranged from 0.5% to 18%. The top 0.1 m of surface soils had the highest sand content and varied in field texture from sand to sandy loam. The highest average clay content occurred in the 0.50 – 0.75m depth interval with field texture predominantly clay loam. The FEC content increased down the profile and ranged from zero to a maximum of 38% with an average of 8.5%. Average bulk density varied in a narrow range (1.57 to 1.61 Mg m^{-3}) in the sand to clay loam texture grade with the average bulk density of clay the lowest at 1.54 Mg m^{-3}. Bulk density increased with depth (Table 2). Because of the close correlation between sand and clay content (r = 0.975) of the 294 soils and with sand content having better correlations with derived parameters, clay content will not be discussed further in the paper.

Statistical analyses of fitted parameters of models

The goodness of fit statistic, r^2 varied from 0.90 to 0.999 with a median value of 0.99 for the van Genuchten model and for the Campbell model from 0.83 to 0.999 with a median value of 0.971.. The mean $\boldsymbol{b}$ parameters values increased strongly with increasing sand content in the soil, as did its standard deviation (sd) (Table 3). The van Genuchten parameter $\boldsymbol{\lambda}$ decreased in a curvilinear fashion (Figure 1) and its sd decreased as field texture grade went from sand to clay (Table 3). A similar trend was also evident for $\boldsymbol{\lambda}$ as FEC increased (Table 4). The higher the FEC content the less variable the fit of the model parameters were for both the Campbell and van Genuchten models, except for θ_{sat} which became less variable (Table 4). Air entry potential (ψ_{air}) increased as clay content and FEC increased (Table 3, Table 4,). The residual volumetric moisture parameters θ_r had a very low value ($< 1*10^{-5}$ kPa and hence effectively a zero value), in 10% of cases.

The relationship between sand and FEC content and the fitted parameters of the van Genuchten and Campbell models are shown in Figures 1 and 2 respectively. Only the λ parameter (van Genuchten) showed a significant relationship with sand content. The α parameter showed an increasing trend with sand content and a decreasing trend with FEC content (Figure 1). There was no correlation between the parameters α and λ. However, the parameters of the Campbell model showed a much stronger relationship with sand content (Figure 2); as percent sand increased the value of $\boldsymbol{b}$ decreased. As the content of FEC increased in the profile the fitted $\boldsymbol{b}$ parameter was more widely dispersed but had an increasing trend. The θ_{sat} parameter has a negative trend with increasing sand content. Bulk density was correlated with the estimated saturated volumetric moisture contents of both models.

[2] 'Blanchetown Clay' is a fluvio-lacustrine deposit over much of the western Murray-Darling Basin that is dissected close to the river valley. It varies in depth and texture but is mostly 4- 6m in depth and of medium clay to clay texture.

Table 1 The number of samples for field texture grades, and the minimum, mean, and maximum values of sand, clay, and fine earth carbonate content for each grade.

		Field Texture Grade						
		Sand	Loamy Sand	Sandy Loam	Light Sandy Clay Loam	Sandy Clay Loam	Clay Loam	Clay
Parameter	No. of Samples	16	40	53	58	46	54	27
Percent sand	Minimum	92.0	81.0	75.0	56.0	58.0	49.0	38.0
	Mean	95.6	90.7	85.8	77.9	70.6	64.0	55.1
	Maximum	97.5	95.5	94.0	88.0	86.0	77.0	68.0
Percent Clay	Minimum	2.0	2.0	4.5	6.0	9.0	15.0	22.5
	Mean	3.2	6.3	10.1	15.0	20.3	25.7	33.8
	Maximum	4.5	10.5	17.0	25.5	31.0	34.5	46.5
Percent Fine earth carbonate	Minimum	0.0	0.0	0.3	0.3	0.8	0.0	1.3
	Mean	0.6	1.4	3.0	9.4	12.0	15.8	13.0
	Maximum	2.8	4.3	23.3	32.3	33.3	37.8	28.3
Bulk Density (Mg m^{-3})	Minimum	1.54	1.34	1.34	1.25	1.31	1.33	1.36
	Mean	1.61	1.61	1.60	1.57	1.59	1.61	1.54
	Maximum	1.71	1.75	1.75	1.77	1.80	1.78	1.72

Table 2 Average sand, clay, and fine earth carbonate content at depth intervals of the 294 soil samples.

Depth Interval	Sand (%)	Clay (%)	Carbonate (%)	Bulk Density (Mg m^{-3})
0 - 0.1 m	86	10	2.0	1.57
0.1 - 0.2 m	71	22	4.8	1.53
0.2 - 0.5 m	74	18	10.5	1.57
0.5 - 0.75 m	68	23	14.7	1.61
0.75-1.0 m	75	18	12.7	1.65
>1.0 m	74	19	14.8	1.70

Three outlier values of derived parameters were excluded from the regression of model parameters against soil properties. While the fitting of a regression model for α against sand, FEC, BD, and field texture grade was very significant (*Pr (F) < 0.005*), the residual variation accounted for was 43%. The regression relationship between λ and sand and field texture was very significant (*Pr (F) < 0.005*) with the addition of

Table 3 Mean ± sd for the van Genuchten and Campbell model parameters for each field texture grade.

		Field Texture Grade						
Model	**Parameter**	**Sand**	**Loamy Sand**	**Sandy Loam**	**Light Sandy Clay Loam**	**Sandy Clay Loam**	**Clay Loam**	**Clay**
van Genuchten	α	0.36± 0.09	0.33± 0.07	0.37 ±0.09	0.37± 0.09	0.35± 0.14	0.37± 0.45	0.25± 0.12
	λ	2.94± 0.70	2.51± 0.47	1.87± 0.41	1.57± 0.30	1.36± 0.10	1.22± 0.10	1.18± 0.07
	θ_r	0.05± 0.01	0.07± 0.01	0.09± 0.02	0.10± 0.02	0.10± 0.02	0.06± 0.05	0.06± 0.07
	θ_s	0.39± 0.02	0.37± 0.03	0.37± 0.04	0.38± 0.03	0.37± 0.04	0.37± 0.04	0.41± 0.04
Campbell	b	1.98± 0.25	2.25± 0.36	3.95± 1.07	5.18± 1.02	6.96± 1.21	9.14± 1.98	11.50± 2.15
	ψ_{air}	1.02 ±0.05	1.04± 0.09	1.02± 0.05	1.05± 0.06	1.14± 0.16	1.28± 0.21	1.44± 0.25
	θ_{sat}	0.33± 0.06	0.34± 0.04	0.35± 0.03	0.37± 0.04	0.37± 0.03	0.37± 0.03	0.40± 0.03

BD only marginally improving the predictability of the parameter λ (from 75% to 76%). The estimated saturated volumetric moisture content for the van Genuchten model was closely correlated with both BD and sand content (Pr (F) < 0.005%, $100r^2 = 63\%$). The addition of FEC to the fitting of the parameter ***b*** in the Campbell model did not improve the predictability of the parameter (90% for sand + field texture grade + BD). The ψ_{air} parameter was also significantly correlated with sand and field texture (51%), with the addition of FEC and BD significantly improving the relationship (71%). The regression of the Campbell parameter θ_{sat} was related to BD and sand content (Pr (F) < 0.005, $100r^2$=63%), the same as for the corresponding van Genuchten parameter.

There was no relationship between the 4 van Genuchten parameters however, α values were most variable at both low and high values of λ but α became less variable as θ_r increased (Figure 3). In contrast, there was a strong correlation between the Campbell parameters ***b*** and ψ_{air}. As can be seen from Figure 3, the van Genuchten parameter α was strongly correlated with ψ_{air}, the Campbell parameter. Similarly, there were correlations between λ and ***b***, and θ_{sat} and θ_s.

Table 4 Mean model parameters values for five fine earth carbonate content ranges.

Model	Mean Parameter	<1% (Nil)[3]	>=1 - <5% (Slight)	>=5 - <10% (Medium)	>=10 - <20% (High)	>=20% (Very High)
		Fine Earth Carbonate Category				
van Genuchten	α	0.36±0.09	0.39±0.10	0.35±0.39	0.33±0.12	0.25±0.11
	λ	2.37±0.76	1.85±0.52	1.45±0.15	1.30±0.13	1.28±0.26
	θ_r	0.08±.0.02	0.09±0.03	0.09±0.05	0.07±0.05	0.07±0.04
	θ_s	0.38±0.03	0.37±0.09	0.38±0.04	0.38±0.03	0.38±0.04
Campbell	b	3.32±1.91	4.65±2.29	6.80±2.61	8.31±2.65	8.34±3.02
	ψ_{air}	1.04±0.08	1.03±0.07	1.14±0.23	1.26±0.22	1.29±0.18
	θ_{sat}	0.35±0.04	0.35±0.04	0.37±0.03	0.38±0.03	0.39±0.04

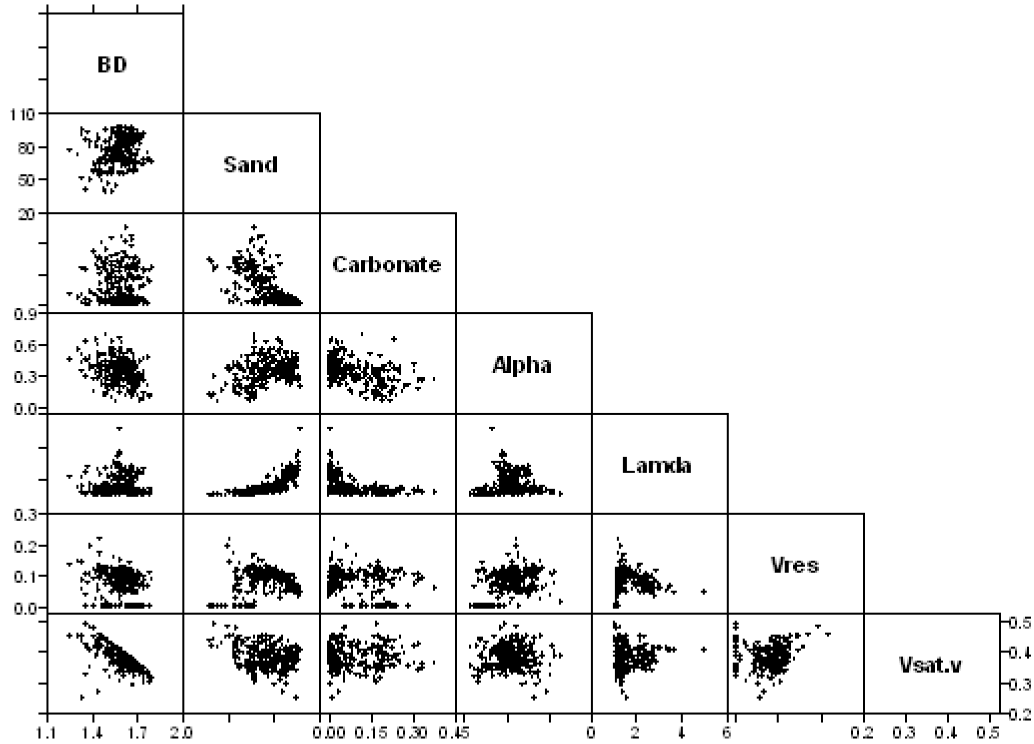

Figure 1 Trellis graphic of the relationship between bulk density, percent sand and fine earth carbonate and the derived van Genuchten parameters, α (Alpha), λ (Lambda), θ_r (Vres) and θ_s (Vsat.v).

Analysis of variance of the categorical variables of field texture (6 categories) and FEC reaction (5 categories) was also carried out against the model parameters. While the analysis in most cases was significant, only the parameters ***λ***, ***b***, and ψ_{air} were comparable to the regression of field texture with percent FEC and sand content(75%, 84%, and 59% respectively). Coefficients for these parameters are given in Table 5.

[3] Reaction categories of soil to 1N HCl

Discussion

The derived soil moisture retention characteristics for the 294 Mallee soils in this study can be adequately modelled with the van Genuchten model or the simpler Campbell model; the van Genuchten model being slightly better model fit over all soils. Vereecken et al (1989) for Belgium soils, and Williams et al (1983) for Australian soils also showed similar model fits for the van Genuchten and Campbell models respectively. The mean derived parameters for air entry potential **(ψ_{air})**, θ_s, and θ_{sat} were within the range of values quoted by Ahuja and Williams (1991) but ψ_{air} in this study was higher than the pooled Australian and British soils

quoted in the same article but lower than θ_s for this study. This study and those of Vereecken et al, Williams et al., and others have shown that the power models were adequate in modelling individual characteristics for use in modelling soil water movement and describing water available to plants. Regression equations predicting model parameters were strong for λ and θ_s for the van Genuchten model and b, θ_{sat}, and ψ_{air} for the Campbell model, but the weak relationship for the other parameters of the van Genuchten model limits its usefulness as a predictor of volumetric moisture content at soil matric suctions of –8 and –60kPa that are used to calculate RAW. Hence, the Campbell model maybe better for estimating RAW for Mallee soils and for use in modelling soil hydraulic behaviour. Further analysis is still be done to compare predicted soil moisture content against the measured points for example at –10, -67, and –1500 kPa. Minasny et al (1999), Minasny and McBratney, (2002), and Tomasella (2003) have used artificial neural networks to derive parameters for the van Genuchten model or estimate moisture content at measured matric potentials with success. This approach may be worthwhile to pursue for the Mallee data especially for the van Genuchten model parameters.

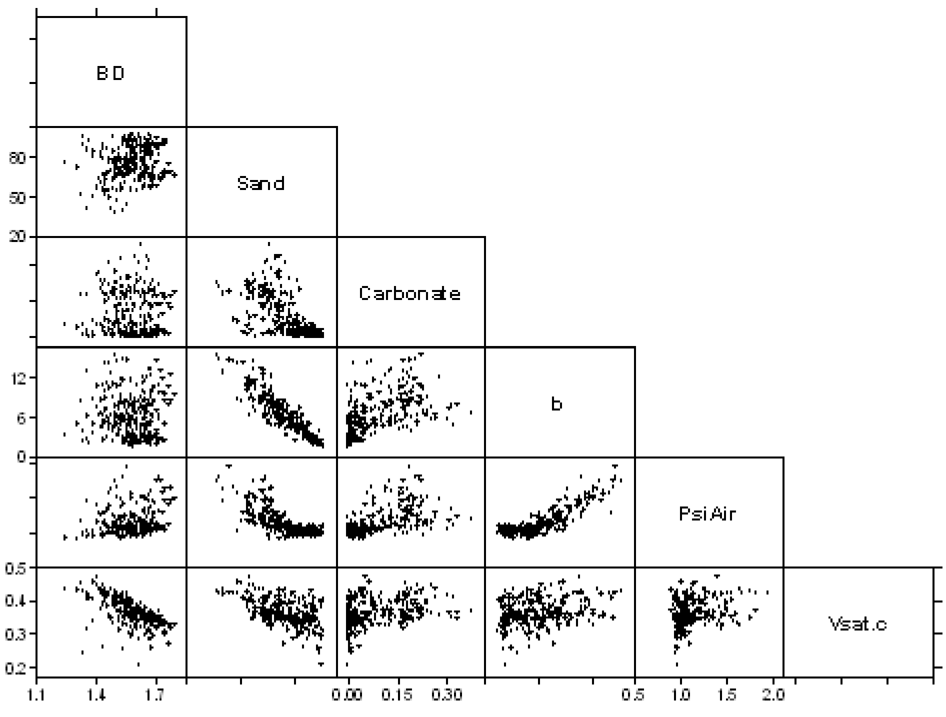

Figure 2 Trellis graphics showing the relationship between bulk density, sand and fine earth carbonate content and the derived Campbell parameters: *b*, ψ_{air} (PsiAir), and θ_s (Vsat.c).

Table 5 Coefficients for λ, *b*, and ψ_{air} parameters for each field texture grade and 1N HCl reaction

Field Texture	Parameter	Reaction N	S	M	H	V
	λ	2.923	3.064	2.900		
Sand	b	1.975	1.596	2.409		
	ψ_{air}	1.015	1.017	1.077		
	λ	2.449	2.590	2.427	2.400	
Loamy Sand	b	2.517	2.138	2.950	2.368	
	ψ_{air}	1.005	1.007	1.067	1.045	
	λ	1.846	1.987	1.823	1.797	1.751
Sandy Loam	b	3.990	3.611	4.423	3.841	4.597
	ψ_{air}	0.996	0.998	1.058	1.036	1.148
	λ	1.607	1.748	1.585	1.558	1.512
Light Sandy Clay Loam	b	4.967	4.588	5.401	4.818	5.575
	ψ_{air}	0.974	0.976	1.036	1.014	1.126
	λ	1.411	1.551	1.388	1.361	1.315
Sandy Clay Loam	b	6.699	6.320	7.133	6.550	7.306
	ψ_{air}	1.057	1.059	1.119	1.097	1.209
	λ	1.298	1.439	1.276	1.249	1.203
Clay Loam	b	8.744	8.364	9.177	8.595	9.351
	ψ_{air}	1.174	1.176	1.236	1.214	1.326
	λ	1.230	1.371	1.207	1.181	1.135
Clay	b	11.255	10.876	11.689	11.106	11.863
	ψ_{air}	1.351	1.353	1.413	1.391	1.504

Field texture as an integration of soil textural properties was important in predicting the values of two Campbell model parameters but only one of the van Genuchten parameters. Soils within the South Australian Mallee region are dominated by free lime (predominantly $CaCO_3$ in various forms). The amount of FEC in the soil modifies the soil moisture characteristic (Meissner, unpublished data) and therefore can be expected to influence the predictability of some of the model parameters, as has been demonstrated (Table 5). However, the lack of a strong predictor of the other model parameters using field measured categorical variables renders the use of these models in the field as not practical. An alterative approach could be explore as outlined by Minasny and McBratney to see if their method gives good predictions of RAW based on field measured soil properties. Soil surveyors may need to consider whether taking a limited numbers of soil samples of the major soil groups for measuring the sand content might be cost effective in improving the accuracy of prediction of RAW. While RAW is important in design of irrigation systems and irrigation scheduling, other soil characteristics are also taken into account such as presence of hard pans, the amount boron and salinity in determining irrigation management units for design of irrigation systems and scheduling of irrigations.

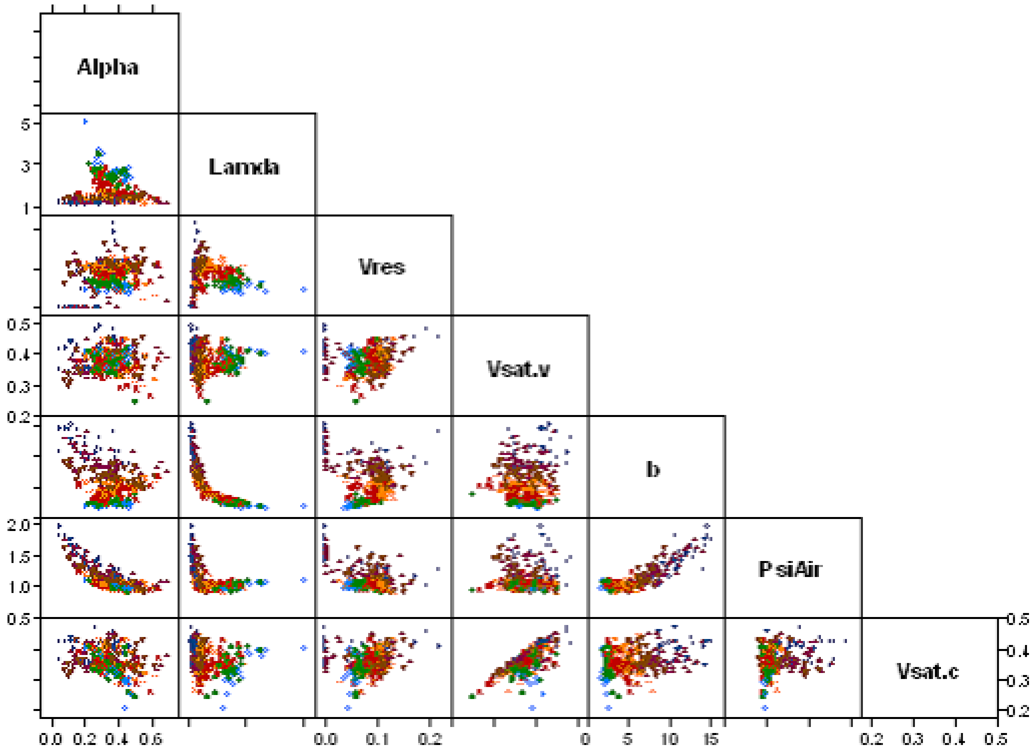

Figure 3 Trellis graphic showing the relationship between the van Genuchten parameters Alpha (α), Lambda (λ), V_r *(θ_r)*, and V_{sat} *(θ_{sat})*, and the Campbell parameters *b*, PSIair (ψ_{air}), and V_s *(θ_s)*.

Cock (1985, 1985) published typical soil moisture release curves for the Mallee region and water content at the derived points of –8, -40, and –60 kPa suction and that have been used to estimated RAW for irrigated crops in the region. Cock's results and that of the RAW of the unpublished 361 soil moisture characteristics have been used to estimate RAW throughout Australia. Hence the use of the Mallee data has extended outside the region from which it was derived. Without an extensive and intensive sampling and moisture characteristic measurement program it is not known how well these relationships hold for more structured soils and soils of contrasting mineralogy.

Conclusion

This study of 294 Mallee soils have shown that both the van Genuchten and the Campbell models are excellent in describing the functional relationship between the soil moisture content and matric suction. The Campbell model is more useful in predicting the soil moisture characteristic of Mallee soils than the van Genuchten model, as its parameters are more closely correlated with easily measured soil parameters of sand and FEC content, soil reaction class, and field texture grade. Hence, the Campbell model is one of more practical use, but its use outside the Mallee soils is one for further study and analysis. Further work needs to be done to compare model predictions of soil moisture content to measured contents at specific matric suction so that confidence can be had by soil surveyors in estimating RAW in the field for Mallee soils.

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