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# Predicting the mobile water content of vineyard soils in New South Wales, Australia

Jonathan E. Holland[a,∗,1], Asim Biswas[b,2]

[a] Wagga Wagga Agricultural Institute, NSW Department of Primary Industries, Wagga Wagga 2650, NSW, Australia
[b] Department of Natural Resource Sciences, McGill University, 21111 Lakeshore Road, Ste-Anne-de-Bellevue, Montréal, QC, Canada H9X 3V9

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ABSTRACT

Better understanding of the relationship between soil properties and soil function is required to minimise nutrient losses from agriculture and protect the environment. There is a need to predict the solute movement through horticultural soils because of the intensive management practices. Thus, the mobile water content ($\theta_m$), the active fraction of soil water content engaged in solute transport, is a suitable soil property to investigate further. Accurate measurement of such solute transport properties in the field are costly, labour intensive and time consuming but there are opportunities to establish predictive relationships. $\theta_m$ was measured together with other basic soil properties to test established predictive relationships (known as pedotransfer functions, PTFs) and to develop new PTFs. The field measurements were taken on a diverse range of vineyard soils across New South Wales (NSW), Australia. Poor predictions were found with available PTFs for $\theta_m$ and the mobile water fraction $f$ ($=\theta_m/\theta_{fm}$; where $\theta_{fm}$ = volumetric water content at which $\theta_m$ was measured). Backward stepwise multiple regression analysis produced better PTF model predictions than the multiple linear regression analysis for new PTFs that were calculated. Differences in the analysis methods showed a trade-off between the prediction capacity and the number of predictor variables in each PTF model. A prediction accuracy of between 80 to 90% was found with 3 predictor variables in the PTFs for $\theta_m$ and $f$. Both the PTFs developed were in strong agreement with the measured properties (minimum $R^2 = 0.82$). For the $\theta_m$ PTF, the % clay content (varied from 11 to 59) was the strongest predictor variable while bulk density (ranged from 1.2 to 1.51 g cm$^{-3}$) contributed the smallest. The PTF for $f$ was similar to $\theta_m$ except it was the % soil organic carbon which had the smallest contribution. These relationships are useful to predict $\theta_m$ and $f$ from easily measured soil physical properties of vineyard soils in NSW, but further testing on a wider range of soils is required.

## 1. Introduction

Understanding the movement of soil nutrients is important for agricultural production and environmental health. Estimating the availability and loss of nutrients is a key task for agronomists in research and commercial fields. This requires a determination of the loss of nutrients in order to make robust fertilizer recommendations (Chen et al., 2008). The loss of nutrients from agricultural land, especially nitrogen and phosphorus e.g. nitrate leaching from pastures (Ridley et al., 2001), remains an issue of concern for fresh water quality globally (Drewry et al., 2006). This can be more acute in countries like Australia due to its climatic conditions. The rate at which nutrients move from the soil surface through the profile to ground water is governed by the inherent soil properties, especially those related to soil structure. Where land is used for agricultural crops the soil structure formation and stability is largely controlled by the management practices. Less intensive management practices such as reduced cultivation in perennial crops allows the formation of soil structure. Additionally, the irrigation of perennial crops is more common in Australia than for annual crops (Bryan et al., 2009). Because of the importance of irrigation for viticulture in Australia (Stevens et al., 2011) and internationally (López-Urrea et al., 2012; Williams, 2012), this study was undertaken on vineyard soils to investigate the relationship between basic soil properties (such as texture, bulk density) and the mobile water content ($\theta_m$). The relationship can help us better understand and predict the movement of solutes through perennial crop growing soils. More broadly, there is a lack of relationships across the world for the

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∗ Corresponding author. Tel.: +61 2 6938 1948; fax: +61 2 6938 1809.
*E-mail addresses:* jonathan.holland@dpi.nsw.gov.au (J.E. Holland), asim.biswas@mcgill.ca (A. Biswas).

[1] Formerly: National Wine and Grape Industry Centre, Charles Sturt University, Wagga Wagga 2678, NSW, Australia.

[2] Formerly: PO Box 1666, CSIRO Land and Water, Canberra 2601, ACT, Australia.

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prediction of solute transport parameters in perennial crops that are applicable at the field-scale. Further research is required in understanding the relationship between basic soil physical and key soil hydraulic properties for soils with this land use type. This type of information has major implications on irrigation and surface water management in agricultural systems and subsurface water quality management.

The movement of water and dissolved nutrients in soil has been described in simplified terms as the flow through 2 regions of pore space i.e. connected pores and isolated micropores (Philip, 1968). The connected pores allow convective transport of water and nutrients and are defined as the mobile region ($\theta_m$); while the isolated micropores are poorly connected or stagnant and are known as the immobile region ($\theta_{im}$) (van Genuchten and Weirenga, 1976). The $\theta_m$ is the active fraction of soil water content engaged in solute transport and has been described as the rapid-mobile porosity (Legout et al., 2009) or the water-conducting macroporosity (van Tol et al., 2012). Various field (in-situ) and laboratory (columns) experiments have been conducted to estimate the mobile and immobile regions. For example, Clothier et al. (1992) estimated $\theta_m$ by measuring the tracer concentration during a controlled unsaturated flow while White et al. (1986) estimated the $\theta_m$ from solute breakthrough data. Lee and Casey (2005) used shallow measurements of $\theta_m$ to predict field-scale solute transport of an irrigated soil; under the conditions observed the $\theta_m$ compared well with a more complex and data intensive method with the transfer function model. For a given soil $\theta_m/\theta$ was reported nearly constant over a range of unsaturated potential heads (−20 mm to −150 mm) measured at the initial soil water content of $\sim$0.3 cm$^3$ cm$^{-3}$ (Clothier et al., 1995). However, $\theta_m$ and the soil properties controlling $\theta_m$ are known to vary across different soil types (Clothier et al., 1995; Okom et al., 2000; Oliver and Smettem, 2003; Vogeler et al., 2006). Because of the potential efficiency in saving time and reducing the number of experimental measurements needed, this study has focused on better understanding the $\theta_m$ variable and the most important soil properties which influence $\theta_m$.

Developing predictive relationships (i.e. pedotransfer functions, PTFs) between soil properties has proven successful for soil hydraulic properties e.g. hydraulic conductivity (Minasny and McBratney, 2000; Paydar and Ringrose-Voase, 2003) and the soil water characteristic (Vervoort et al., 2006). Much less attention has been given to solute transport parameters. Nevertheless, interest in $\theta_m$ and other solute transport parameters has led to studies that investigate relationships with basic soil properties such as soil texture or soil organic carbon. This involves collecting quantitative data on these soil properties to explore relationships that can be used for predictive purposes. For this study the application is to aid the understanding on movement of nutrients in vineyard soils. PTFs have been developed for solute transport parameters such as the diffusion function ($D_m$) using easily measured soil properties (Goncalves et al., 2001; Shaw et al., 2000). The mobile water fraction $f$ (=$\theta_m/\theta$; $\theta$ is equivalent to $\theta_{fm}$ in this study, therefore $\theta = \theta_{fm} = \theta_m + \theta_{im}$ which is the measured water content at the applied potential) was found to vary with soil texture across a range of different soils in Victoria, Australia (Okom et al., 2000). The authors of this study also suggested a predictive relationship between $f$ and other soil properties which was developed from $\theta_m$ PTFs provided earlier by Okom (1998). A review of solute transport parameters by Minasny and Perfect (2004) found that the data is limited and the methods used to generate data is not consistent. Despite this Minasny and Perfect (2004) were able to develop a PTF to predict $\theta_m$ using data from several studies. The authors used 28 different soils with clay content between 10 and 40%. These PTFs (Minasny and Perfect, 2004; Okom, 1998) have not yet been independently tested and it is not known how widely they can be applied or how they perform. In addition to robust testing, this study will investigate opportunities to improve accuracy for PTFs of $\theta_m$.

This study aims to improve understanding of basic soil properties that control and influence the movement of soil nutrients and solutes. This will be achieved by focusing on the $\theta_m$ and exploring relationships between basic soil properties and solute transport and/or soil hydraulic properties. Consequently the specific objectives of the present study were to (i) measure the mobile water content ($\theta_m$), mobile fraction ($f$) and unsaturated hydraulic conductivity ($K$) together with a range of basic soil properties; (ii) test established PTFs and; (iii) develop new PTFs for $\theta_m$ and $f$ for perennial crop growing soils. The new PTFs were developed from field measurements on a selection of vineyard soils across New South Wales (NSW), Australia. Vineyard soils and the management practices adopted in growing grapes can be considered similar to soils for some other perennial crops.

## 2. Materials and methods

### 2.1. Study sites and field measurements

Measurements were completed on soils of 10 different vineyards located across NSW, Australia (Fig. 1). These soils covered a wide range of soil textural classes from sandy loam through to heavy clay and are classified as Chromosols to Dermosols (according to Australian Soil Classification) (Isbell, 2002) which is equivalent to Lixisols and Luvisol, respectively (IUSS Working Group WRB, 2006); representing the most important wine growing regions in NSW. A tension infiltrometer (Soil Measurement Systems, Tucson, AZ, USA) was used to supply a tracer solution (0.01 $M$ KBr) to the soil surface following the method of Okom et al. (2000). This enabled the determination of the $K$ and $\theta_m$ at the same point (Fig. 1). The soil was sampled for a selection of key properties (including soil texture, soil water content, soil organic carbon content and bulk density) both close by and beneath the position of the tension infiltrometer disc (Fig. 1). These measurements were taken during the period from February to May 2010. Between 4 and 8 tension infiltrometer measurements were taken along the vine row at each location (within 10 m linear distance), while other soil properties were measured on samples taken close by (<0.15 m from the disc edge) (Fig. 1). The sampling and measurements were taken in the area where fertilizers and irrigation water is commonly applied. Each vineyard chosen was drip irrigated and managed commercially.

### 2.2. Hydraulic conductivity

A tension infiltrometer (200 mm diameter) was used to measure the in-situ $K$. The measurement sites selected were level and free from surface protruding stones or signs of recent disturbance. Wherever necessary, the grass or other vegetation covers were removed with care without disturbing the soil surface. A 0.01 $M$ KBr solution was used in the infiltrometer to determine the $\theta_m$ from the same measurements as the $K$. The measurements were performed at a single potential (−20 mm) because for a particular soil the $f$ is independent of the potential applied, but vary across soils (Okom et al., 2000). Following White *et al.* (1992) the early-time infiltration data was used to determine the sorptivity ($S$), while the steady state infiltration data enabled the calculation of $K$. The slope of first 300 s of infiltration data ($I$ v. $t^{1/2}$) was used to determine $S$ with:

$$I = St^{1/2} \tag{1}$$