

The *matric flux potential* as a measure of plant-available water in soils restricted by hydraulic properties alone

Cameron D Grant^A, Pieter H Groenevelt^B, Neville I Robinson^C and Sukhpal Singh Chahal^A

^ASchool of Agriculture Food & Wine, University of Adelaide, Urrbrae, SA, Australia, Email cameron.grant@adelaide.edu.au

^BUniversity of Guelph, Guelph, Ontario, Canada, Email pgroenev@lrs.uoguelph.ca

^CSchool of Chemistry, Physics & Earth Sci, Flinders University, Bedford Pk, SA, Australia, Email neville.robinson@flinders.edu.au

Abstract

In a soil for which the plant available water is restricted solely by its hydraulic properties (i.e. not by high soil strength, nor poor aeration and salinity) the amount of plant available water as defined by the integral water capacity which is shown to be equal to the differential matric flux potential.

Key Words

Integral water capacity, plant available water, hydraulic conductivity, matric flux potential.

Introduction

Groenevelt *et al.* (2001, 2004) introduced the theoretical framework to calculate how much soil water might be available to plants. There, the differential water capacity, $C(h)$, was obtained from the water retention curve, $\theta(h)$, and then weighted for various soil physical limitations (e.g. excessively rapid or slow drainage or aeration, high soil strength, salinity, and low hydraulic conductivity). The method allowed any number of physical limitations to be incorporated to obtain a net amount of plant available water. In the present study we are primarily interested in evaluating the sole contribution of low unsaturated hydraulic conductivity common in most coarse-textured soils. This paper describes the theory required to allow such an analysis.

Theory

The *integral water capacity*, IWC, was defined by Groenevelt *et al.* (2001) in terms of the matric head, h :

$$\text{IWC} \equiv \int_{h_f}^{h_i} \left(\prod_{j=1}^n \omega_j(h) \right) \frac{d\theta}{dh} dh \quad [1]$$

in which h_i and h_f are the initial and final matric heads, $h_f > h_i$, and the $\omega_j(h)$ are weighting functions designed to reduce the *differential water capacity*, $C(h) \equiv d\theta/dh$, based upon a number of limiting soil physical properties, $j = 1$ to n . In this context we focus here solely on soil hydraulic limitations, which arise partly from the inability of the soil matrix to release water and partly from its inability to transport water from one point to another. The limiting 'water release' component is found in the differential water capacity, $d\theta/dh$, and the limiting 'transport' component is found in the unsaturated hydraulic conductivity function, $K(\theta)$, both of which can be combined to formulate the so-called 'diffusivity' function, $D(\theta) \equiv K(\theta)/C(h)$.

If as a first approximation we define a weighting function, $\omega(h) \equiv D(\theta)$, its substitution into Eqn [1] gives:

$$\text{IWC} = \int_{h_f}^{h_i} \left(\frac{K(\theta)}{\frac{d\theta}{dh}} \right) \frac{d\theta}{dh} dh \quad [2]$$

It can be seen that equation [2] reduces to:

$$\text{IWC} = \int_{h_f}^{h_i} K(\theta) dh = \Phi(h_i) - \Phi(h_f) \quad [3]$$

which is simply a difference in the *matric flux potential* (or the Kirchhoff potential) as outlined for example by Klute (1952) and Raats (1970). An important consequence is that for soils in which nothing but hydraulic properties restrict water uptake by plants, the *integral water capacity* is identical to the *differential matric flux potential*.

It is common to express h and $K(h)$ as functions of the water content, which allows the integral in Equation [3] to be written as:

$$IWC \equiv \int_{\theta_f(h_f)}^{\theta_i(h_i)} K(\theta) \frac{dh}{d\theta} d\theta \quad [4]$$

To evaluate this integral, we note that $dK(\theta)/d\theta$ is often available, derived from $K(\theta)$ in integral form, which allows Equation [4] to be integrated by parts:

$$\int_{\theta_f(h_f)}^{\theta_i(h_i)} \frac{d[K(\theta)h]}{d\theta} d\theta = \int_{\theta_f(h_f)}^{\theta_i(h_i)} \left[K(\theta) \frac{dh}{d\theta} \right] d\theta + \int_{\theta_f(h_f)}^{\theta_i(h_i)} \left[h \frac{dK(\theta)}{d\theta} \right] d\theta \quad [5]$$

Rearrangement gives a more amenable integral:

$$\int_{\theta_f(h_f)}^{\theta_i(h_i)} \left[K(\theta) \frac{dh}{d\theta} \right] d\theta = \int_{\theta_f(h_f)}^{\theta_i(h_i)} \frac{d[K(\theta)h]}{d\theta} d\theta - \int_{\theta_f(h_f)}^{\theta_i(h_i)} \left[h \frac{dK(\theta)}{d\theta} \right] d\theta \quad [6]$$

Now the first part of the integral in Equation [6] is relatively simple:

$$\int_{\theta_f(h_f)}^{\theta_i(h_i)} \frac{d[K(\theta)h]}{d\theta} d\theta = h_i(\theta_i) K_i(\theta_i) - h_f(\theta_f) K_f(\theta_f) \quad [7]$$

The second part, however, is somewhat more difficult to evaluate and requires assumptions about the form of the θ - h relationship and the nature of its integration. In this work we assume a version of the θ - h relationship proposed by Groenevelt and Grant (2004) and offer a solution to the second part of the integral using incomplete gamma functions. As the work is currently under review for publication, the results will be presented at the Congress or can be obtained from the authors directly.

Conclusion

In the limited circumstances where growth and water-uptake by an ‘average’ plant are restricted by the hydraulic properties of the soil and nothing else, it is possible to calculate the amount of water that plants can remove from the soil (the integral water capacity) by computing the matric flux potential. An evaluation of this approach is currently underway using different types of plants grown at different planting densities under different environmental conditions.

References

- Groenevelt PH, Grant CD (2004) A new model for the soil-water retention curve that solves the problem of residual water contents. *European Journal of Soil Science* **55**, 479-485.
- Groenevelt PH, Grant CD, Murray RS (2004) On water availability in saline soils. *Australian Journal of Soil Research* **42**, 833-840.
- Groenevelt PH, Grant CD, Semetsa S (2001) A new procedure to determine soil water availability. *Australian Journal of Soil Research* **39**, 577-598.
- Klute A (1952) A numerical method for solving the flow equation for water in unsaturated materials. *Soil Science* **73**, 105-117.
- Raats PAC (1970) Steady infiltration from line sources and furrows. *Soil Science Society of America Proceedings* **34**, 709-714.