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THE INFLUENCE OF SOIL WATER POTENTIAL ON MOISTURE UPTAKE BY WHEAT SEED

M. Josiah, I. Yule, J. Favier

Department of Agricultural and Environmental Science, University of Newcastle upon Tyne, NE1 7RU United Kingdom

A b s t r a c t. A limiting factor governing the germination of seeds in soil is the availability of water for seed hydration. Soil water potential is one of the main factors controlling the amount of water moving to the seed surface from the surrounding soil. This potential has been related to the rate of moisture uptake of wheat seed germinated in soil of constant osmotic and different matric potentials. A diffusion model is used to describe the rate of increase in seed moisture. From the moisture uptake model, a wetting constant, which is related to the diffusion coefficient, is defined. An hyperbolic relationship was found between the wetting constant and soil matric potential over the range -5 to -66 kPa.

K e y w o r d s: seed moisture, soil water potential, germination, wheat seed

INTRODUCTION

An adequate supply of water is essential for seed germination and in soil this supply is governed by the conductivity of soil water, the degree of soil-seed surface contact and the soil water potential [4,5,9, 12,17]. The hydraulic conductivity of soil determines the rate of water movement and depends on the degree of saturation [14]. Water in the liquid phase in the absence of a differentially permeable membrane tends to move in response to a gradient in hydraulic potential [18]. Diffusion models have been used to describe water movement to a seed in unsaturated homogeneous soil using soil diffusivity and soil moisture content [5-7]. The assumptions made in these models are that the seed is spherical, equilibrium soil moisture content is achieved instantly at the seed surface and the soil diffusivity is constant. Dasberg [5] showed that the distance from which water is taken up by seeds does not exceed 10 mm. In this area the soil moisture content was found to be important.

The structure and components of a soil will determine its water holding potential. This potential is composed of an osmotic potential which depends on the soil water solution and a matric potential which is a measure of the absorption capacity of the soil [14]. For a given soil composition a relationship exists between the volumetric moisture content and the matric potential [14].

If the rate of water uptake by a seed is considered to be a function of the remaining potential for water absorption, then for the period from the start of imbibition to germination:

$$\frac{dM}{dt} = -k\,(M - M_g) \qquad (1)$$

where M is the moisture content at time t after the start of imbibition, Mg is the moisture content at germination and k is a rate constant. Integrating Eq. (1) from initial to germination moisture content gives:

$$\frac{M - M_g}{M_o - M_g} = e^{-kt} \qquad (2)$$

where M_o is the initial moisture content. The L.H.S. of Eq. (2) is the moisture gradient and is termed the 'moisture ratio'. Equation (2) can be derived from Fick's law of diffusion assuming a spherical shaped

seed, radial diffusion of water into the seed and negligible swelling. A form of this equation has been used to model the uptake of water by wheat seed germinating in free water [11].

When the potential of the water supplying medium is zero, as is the case when seeds are germinated with a free supply of water, the factor limiting water uptake is seed diffusivity. When seeds are germinated in soil, water uptake is also influenced by soil water potential [5,6,12]. The effect of these two resistances to water uptake can be combined in the rate constant such that:

$$\frac{M-M_g}{M_o-M_g} = e^{-k_s t} \qquad (3)$$

where k_s is called the soil wetting constant.

The results reported here are part of a wider investigation into the effect of cultivation methods on seed bed quality and focus on the effect of soil matric potential on the rate of water uptake by wheat seeds.

EXPERIMENTAL METHOD

Soil preparation

The soil used in the experiments is a sandy loam. One important parameter controlling soil structure is aggregate size [2,13,19]. Soil samples with a range of matric potentials were made up of proportions, by weight, of aggregate size ranges between 0.5 and 6.7 mm obtained by sieving the original soil bulk sample, to which water was added in amounts calculated to bring the moisture contents to 25 % and 30 % (wet basis). The soils were then allowed to equilibrate for three days.

To determine the soil matric potentials, the filter paper method was used [8]. Filter paper (Whatman No. 42, 5.5 cm diameter) for which a matric potential calibration is available [8] were placed at the bottom of 5.8 cm diameter plastic containers and 100 g of soil placed on top. The containers were closed and equilibrated at 18 °C for five days. After equilibration the filters papers were removed and quickly weighed. They were then oven dried at 105 °C and the moisture content determined. Using the moisture content of the filter papers the matric potential of the soil samples was read from a calibrated moisture relief curve for Whatman No. 42 filter paper [8].

Maintenance of constant matric potential

Two methods were used to maintain a constant soil matric potential around seeds placed in the soils. In the first setup (Fig. 1a) transparent flexible tubing was connected to a Sinta Glass, grade 4 funnel. The pore size of this grade funnel can support suction up to 200 cm. The funnel was then filled with deaerated distilled water by means of a vacuum pump. A semi-permeable membrane (dialysis tubing) was positioned in contact with the surface of the water in the funnel. Soil equilibrated to the desired moisture content were placed above the membrane in the funnel which was then covered with clingfilm in which a small hole was made to allow for the exchange of gases while minimizing evaporation. The soil was subjected to a constant hydrostatic pressure by maintaining a constant height difference between the surface of the soil and the free water surface in the tube. The soils were then left to equilibrate for 24 h. A check on the matric potential of samples showed that variation from the value obtained from the filter paper test of the original samples was less than 1.5 %.

The second setup (Fig. 1b) was used for suctions greater than 200 cm. The lower chamber of a double-chambered glass container was filled with a PEG solution of concentration corresponding to a soil matric potential [15]. The lower chamber was separated from the upper by means of a semi-permeable membrane (dialysis tubing). The two chambers were clamped together making sure there was no air trapped between the surface of the PEG solution and the membrane. The upper

chamber was then filled with a soil sample of the same matric potential as the PEG solution. The chamber was covered with clingfilm as in the first setup. In order to maintain a constant vapour pressure above the soil, the upper chamber was connected by means of a tube to a flask half filled with PEG at the same concentration as in the lower chamber. The soil was then allowed to equilibrate for 24 h.

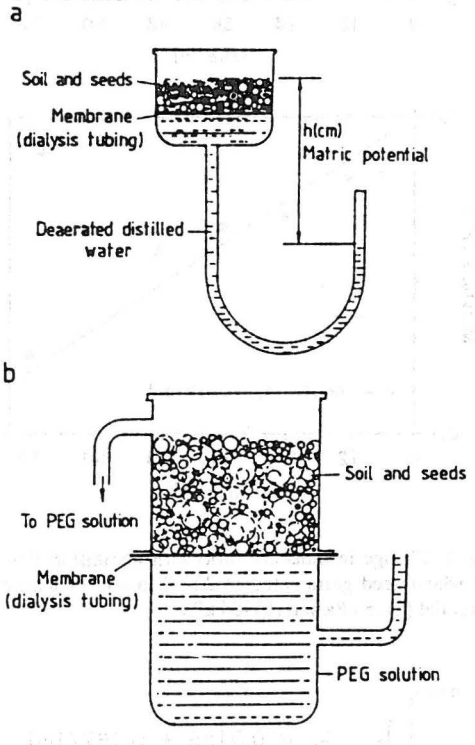

Fig. 1. Experimental setup for seed water uptake showing method of constant matric potential by means of (a) constant water head - up to 200 cm suction and (b) PEG solution for suction above 200 cm.

Determination of seed water uptake

Wheat seed (v. Riband) was used for the experiment. The seed lot was dried to 10 % dry basis (d.b.) in a layer 20 mm deep with air at 40 °C, 10 % relative humidity using a rig designed for drying particulate crops [20]. The germinative capacity of the seed was determined following the method recommended by the ISTA [10] viz. eight replicates of 50 seeds were germinated on a double layer of moistened filter paper (Whatman No. 9) in the dark at 20 °C and the number of germinated seeds counted after seven days. The criteria used for a germinated seed was appearance of at least 1 mm of radicle. The germinative capacity of the seed lot was 98 %.

Seeds (100 at 10 % moisture content d.b.) were sown at a depth of 5 cm. All experiments were carried out at 22 °C. The seeds were removed at intervals, cleaned of soil particles, and weighed. Seed moisture content was then determined using the oven method [3]. In each setup replicates corresponding to the number of sampling intervals were used until seed germination was observed. Once roots were seen the number of germinated seeds were counted and discarded and this process was repeated at intervals up until the sixth day after sowing. The procedure was repeated for soil samples of different matric potentials.

RESULTS AND DISCUSSION

Examples of water uptake curves, up to the last sampling time just prior to germination, for seeds sown in soil at the highest (-5 kPa) and lowest (-66 kPa) matric potential are shown in Fig. 2. The uptake curves can be compared to that predicted from experiments with seeds set germinate in free water [11]. It can be seen (Fig. 2) that the uptake rate is slower than that for free water resulting in a longer period from the start of imbibition to the start of germination. Germination was also distributed over a longer time period than that observed for seeds germinating on filter paper with free water. From the sigmoid distribution of seed germination it was observed that the average time from the start of germination for over 90 % of the seeds to germinate was 48 h as opposed to less than 12 h for a sample from the same seed population germinated on filter paper.

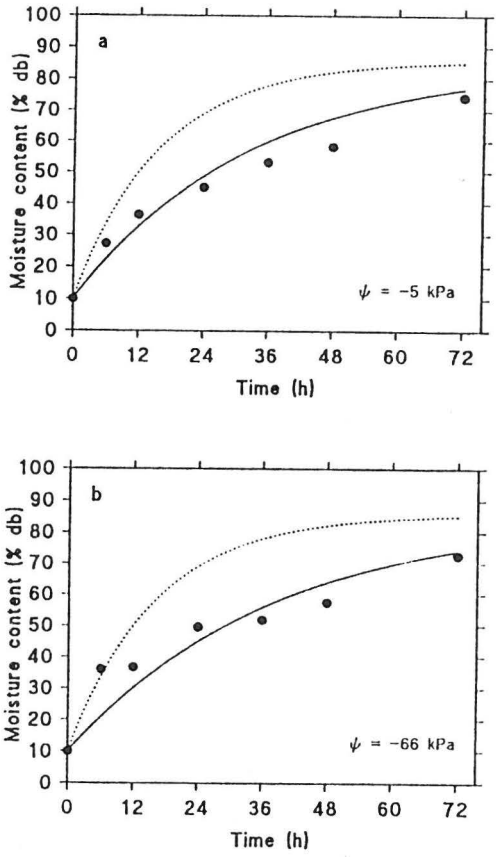

Fig. 2. Water uptake curves for wheat seed germinated in soil at 22 °C in soil of matric potential (a) -5 kPa and (b) -66 kPa. Solid curve calculated from water uptake model based on the soil germination data. Dotted line calculated from water uptake model for germination in free water [11].

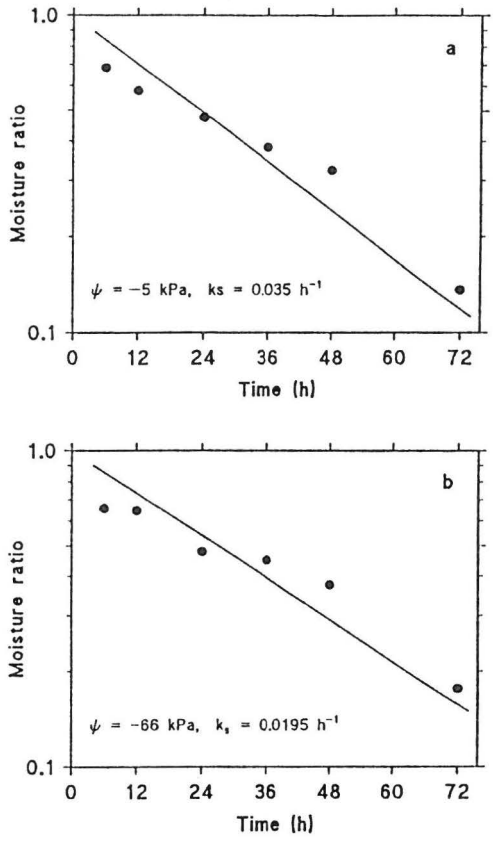

Fig. 3. Change in moisture ratio with imbibition time for wheat seed germinated at 22 °C in soil of matric potential (a) -5 kPa and (b) -66 kPa.

From previous experiment [11] the average moisture content of wheat seeds at the time of appearance of the radicle was found to be 86 % (d.b.). This moisture content was used to calculate the change in moisture ratio with time for each sample. Using Eq. (3) the wetting constants for seeds at each matric potential were determined as illustrated in Fig. 3. When plotted against soil matric potential (Fig. 4) it can be seen that a hyperbolic relationship exists between wetting constant, k_s and matric potential, (kPa), whereby:

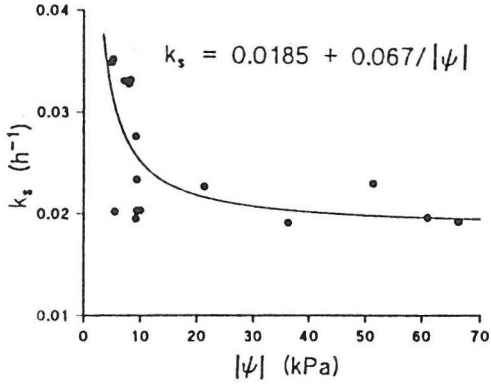

Fig. 4. Relationship between soil wetting constant (k_s) and soil matric potential (ψ) for wheat seed germinated at 22 °C.

$$k_s = 0.0185 + \frac{0.067}{\Psi} \ (h^{-1}) . \qquad (4)$$

While this particular empirical relationship is not in itself significant it is useful as a means of examining the effect on seed water uptake rates as matric potential changes. If the soil wetting constant and the free water wetting constant for wheat [11], at a germination temperature of 22 °C, are equated then the equivalent free water matric potential is found to be -1.5 kPa. This potential is in effect an indication of the degree of saturation of the seed surface in the free water test. Although very low, in absolute terms, when compared to the water potential of the whole seed during the period of imbibition before germination, typically < -100 kPa [16], it shows that, rather than zero potential, there is actually a small negative potential, probably due to capillary forces in the seed surface structure, hindering the uptake of water by seeds germinated in excess water on filter paper.

As the matric potential of the medium surrounding the seed decreases the rate of water uptake decreases rapidly. However, the spread of k_s values at potentials above -15 kPa is an indication of the effect of contact area between the seed and soil particle surfaces and also possibly air-filled pore spaces. Below about -15 kPa the wetting constant then decreases very little to -66 kPa which is the limit of matric potential examined here. This effect will be important when considering the optimum structure of a seed bed and shows that, for the soil moisture contents considered here, the seed water potential is sufficient to overcome the matric potential of the soil. Further work is required to determine the limits of the model as soil matric potential approaches that of the dry seed at sowing.

The property of the seed which governs water uptake is seed water potential [16] which is a function of seed diffusivity and moisture content. Since a seed can only take up water if its water potential is below that of the surrounding soil then, provided the seed parameters and the soil water potential are known, it is possible using the method outlined here to estimate the length of time from sowing to germination for seeds sown under different cultivation conditions. By correlating cultivation techniques with seed bed structure and subsequent soil potential it may be possible to quantify optimal approaches to seed bed preparation.

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