LETTERS TO THE EDITOR

Comments on: Effects of Soil Moisture Stress on Seed Germination (2) (All references given after Reply.)

Equation [2] of Hadas (2) does not, except for times approaching germination of the seed, describe the amount of water imbibed by germinating seed. Equation [2] of Hadas is as follows:

\[ \frac{M}{M_{\infty}} = 1 - 6 \sum_{n=1}^{\infty} \frac{1}{n^2} \exp \left( -\pi^2 \frac{n^2}{\alpha^2} \right) \]

The equation, in order to be general, should read as equation [5] of Phillips (4) and is as follows:

\[ \frac{M(t)}{M(t_g)} = \frac{(\pi^2/6) \sum_{n=1}^{\infty} (1/n^2) \exp \left( -\pi^2 n^2 D t / \alpha^2 \right)}{M(t_g)} \]

Where \( M(t)/M(t_g) \) is the ratio of the amount of water imbibed at some time, \( t \), to the amount of water imbibed at the time of germination, \( t_g \). \( D \) is the diffusivity of the seed to water and is assumed to be constant or the average diffusivity, and \( \alpha \) is the average radius of the assumed, spherical seed. This equation assumes that the water content at the seed-medium (soil) interface remains constant and describes flow of water from the soil into the seed if the \( D \) value is that of the soil or describes flow within the seed itself if the \( D \) value is that of the seed itself; however, the validity of the equation is not better than the validity of the initial and boundary conditions as applied to the flow equation.

Equation [5] of Phillips reduces to equation [2] of Hadas if and only if the infinite series in the denominator of equation [5] of Phillips is small in comparison to the value of \( \pi^2/6 \). This is not true for most seeds of agronomic crops germinating in moist soil. The value of the left-hand side of equation [2] of Hadas does approach the value of the left-hand side of equation [5] of Phillips when the time, \( t \), of concern approaches the time required for germination, \( t_g \). One can see that the value of the left-hand side of equation [5] of Phillips approaches the value of unity when \( t \) approaches \( t_g \). The same is true of equation [2] of Hadas. The values of the left-hand sides of equation [2] of Hadas and of equation [5] of Phillips differ by as much as 100% and more for smaller times, \( t \), in which the seed has been imbibing water. This difference can be seen in Figure 1 of Phillips (1); the curves in the Figure is a plot of \( M(t)/M(t_g) \) versus \( D \alpha^2 n^2 \) for differing ratios of \( t_g/t \) calculated from equation [5] of Phillips. The curve labelled \( = \) represents the same plot calculated from equation [2] of Hadas. One can see from Figure 1 of Phillips that the estimate of the time required for a seed to imbibe a certain fraction of water required for germination will be significantly over-estimated if the curve labelled \( = \) (equation [2] of Hadas) is used rather than the correct one. The correct curve to use is determined by experimentally knowing the ratio \( M(t)/M(t_g) \) for a given time, \( t \), and the ratio \( t_g/t \).

The data presented by Phillips (4) for germination of soybean, corn, and cotton seed in aerated, distilled water and in moist soil indicate that seed germinating in moist soil initially has a poor soil water-seed water contact. The soil water-seed water contact evidently becomes progressively better as time of germination increases. For example, the diffusivity of soybean seed germinating in aerated, distilled water was found by Phillips to be approximately \( 32 \times 10^{-4} \text{ cm}^2 \text{ hr}^{-1} \) while the \( D \) value of soybean seed germinating in a silt loam soil at 20% water on an oven-dry weight basis, approximately field capacity increased with time after planting and was not found to exceed \( 11 \times 10^{-4} \text{ cm}^2 \text{ hr}^{-1} \). This conclusion is contrary to the conclusion of Hadas who concluded that "the imbibition state is little affected by the total contact area".

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Comments on article by A. Hadas (2)

Hadas (2) has presented procedures for calculation of the time required for seed to germinate, purporting to base them on the water transmission properties of soil and the seed. His procedures make use of well known equations used in analysis of diffusion systems, e.g., Crank (Crank, J. 1956. The mathematics of diffusion. Oxford Press). However, his calculated times for the seed to absorb sufficient water for germination to occur are much shorter than are normally recorded in the literature.

On examination, the discrepancy is seen to arise because the models chosen are inappropriate for the situations considered and in the case of the first model considered, the analysis equation is misused.

The first model described is of a spherical sink (seed) surrounded by a soil of a constant and known diffusion coefficient. The equation used however, is that for diffusion into a spherical sink whose surface is at constant moisture content and where the diffusion coefficient should be that of the seed and not the soil. To use a soil diffusion coefficient which is three orders too large, instead of that of seed, would give rise to the small times tabulated by Hadas.

Phillips (4) has presented a procedure for determining the "average" diffusion coefficient for a seed, based on submersion of the seed in free water and measurement of the rate of water absorption. The analytical model for this is the same as that used in Hadas' first model and we find it gives values of 0.5 to 2.0 \( \times 10^{-4} \text{ cm}^2 \text{ hr}^{-1} \) for two varieties of wheat which compare with 0.2 to 0.3 \( \times 10^{-4} \text{ cm}^2 \text{ hr}^{-1} \) obtained by Phillips for a number of different seed types.

In the second model, Hadas envisages a restricting coat to the seed and uses the mathematical model of a hollow sphere (Crank, op. cit., p. 92). The boundary conditions of this mathematical model are that the concentration at the outermost and innermost surfaces of this hollow sphere remain constant. Thus Hadas envisages the centre of his seed as a perfect sink. Additionally we believe it is inappropriate to use the "average" diffusion coefficient of seed in such a model.